Introduction

Resistance training is acknowledged as the most effective training method to increase strength and muscle mass. Whereas it was once considered a training method of athletes, it is now recommended for a variety of populations including the elderly (29) as a means of combating the age-related decline in strength, muscle mass (i.e., sarcopenia), and overall physiological function. Different forms of resistance training are possible through manipulation of the acute program variables (10), which appear to cause differing long-term adaptations within the neuromuscular system (7,13), at least in young or athletic populations. For example, resistance training with high loads (i.e., 85–100% of 1 repetition maximum [1RM]), few repetitions per set (i.e., 1–5), and relatively long interset rest periods (i.e., 3–5 minutes) have been classified as “maximum strength” resistance training and primarily improves maximum force production with limited increases in muscle mass (5,7). Conversely, resistance training with medium loads (i.e., 60–85% of 1RM), large number of repetitions per set (i.e., 8–14), and short interset rest periods (i.e., 1–2 minutes) have been classified as “hypertrophic” resistance training, which primarily improves muscle mass and resistance to fatigue (7,8,32).

Earlier studies that have compared the responsiveness of older subjects (60–85 years) with young subjects (20–40 years) previously unaccustomed to resistance training observed similar increases (i.e., no statistical differences) in strength and muscle mass over a resistance training period of 3–6 months (14,23). These findings would suggest that older subjects respond similarly to the same training protocols as young subjects. In other words, recommendations for resistance training programs would be similar for young and older groups. This notion would, however, seem counterintuitive given the previously observed differences in muscle activation (e.g., Ref. 17), muscle fiber composition (e.g., Ref. 22), as well as hormonal (e.g., Ref. 15) and molecular (e.g., Ref. 9) responses to resistance training between young and older age groups.

In support of this hypothesis, other studies have been able to determine statistically significant differences in the

Similar Increases in Strength After Short-Term Resistance Training Due to Different Neuromuscular Adaptations in Young and Older Men

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Abstract

Walker, S and Häkkinen, K. Similar increases in strength after short-term resistance training due to different neuromuscular adaptations in young and older men. J Strength Cond Res 28(11): 3041–3048, 2014—This study investigated whether differences in neuromuscular performance and muscle hypertrophy occur between young and older men. Twenty-three young (29 ± 9 years) and 26 older men (64 ± 8 years) completed 10 weeks of high-volume, medium load “hypertrophic” resistance training with low frequency (twice per week) with 10 young (34 ± 11 years) and 11 older men (65 ± 3 years) acting as non-training control subjects. Training consisted of 2–5 sets of 8–14 repetitions (1- to 2-minute rest), Lower-limb dynamic (leg press) and isometric maximum leg extension force, as well as lower-limb lean mass and vastus lateralis cross-sectional area were assessed before and after the training period. Training led to significant increases in 1 repetition maximum (1RM) leg press performance in both training groups (young: 13 ± 7%, p < 0.001; older: 14 ± 9%, p < 0.001). Performance improvements were accompanied by increased muscle activation, assessed by voluntary activation level (29 ± 51%, p < 0.05) and electromyography amplitude (35 ± 51%, p < 0.01) in older men only. Conversely, only young men showed significantly increased lower-limb lean mass (2.4 ± 2.5%, p < 0.01). Furthermore, increases in 1RM performance and lower-limb lean mass were significantly related in young men only (r = 0.524, p = 0.01, n = 23). In conclusion, although high-volume, medium load “hypertrophic” resistance training may induce similar improvements in strength between young and older men, it appears that different mechanisms underpin these improvements.

Key Words: hypertrophy, muscle activation, leg press, voluntary activation, aging

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magnitude of hypertrophy between young and older subjects (20,24,34). Furthermore, a recent meta-analysis has shown that young subjects may increase muscle mass to a greater, statistically significant, extent than older subjects (28). Consequently, the aim of the present study was to examine the effects of a high-volume, medium load “hypertrophic” resistance training period using low frequency (twice per week) on maximum strength, muscle mass, and muscle activation of the lower limbs in healthy young and older men.

Methods

Experimental Approach to the Problem
Young and older men performed 10 weeks of whole-body resistance training twice per week with the emphasis on lower-limb exercises. The training program consisted of high-volume, medium intensity exercise with short rest intervals, typically performed by bodybuilders (i.e., 2–5 sets of 8–14 repetitions, 1- to 2-minute rest). Lower-limb exercises, leg press, knee extension, and knee flexion, were performed before upper-body exercises. At least 48-hour rest was required between training sessions. Maximum dynamic and isometric neuromuscular performance, as well as lean leg and muscle mass, were examined before and after the training period. Body composition assessment took place 3–4 days and neuromuscular measurements were performed 7 days after the last training session. The subjects were physically active but unaccustomed to resistance training for the previous 6 months. Training and testing took place throughout the day (9 AM–7 PM), but young and older subjects were pair matched to avoid any time-of-day effects on neuromuscular performance measurements. All subjects were given nutritional advice in an attempt to maximize muscle hypertrophy; however, no nutritional intervention was performed in the present study.

Subjects

Young (20–35 years; 28 ± 5 years, 179 ± 6 cm, 77 ± 12 kg, 21 ± 8% fat) and older (60–72 years; 65 ± 4 years, 177 ± 6 cm, 80 ± 10 kg, 23 ± 6% fat) men responded to an advertisement in a local newspaper and signed consent to participate in the study after thorough verbal and written information regarding the study methods. The study was accepted by the University Ethics Committee and was conducted in accordance with the Declaration of Helsinki.

The experimental groups consisted of 23 young and 26 older men (training groups), and the nontraining control groups consisted of 10 young and 11 older men. Subjects were habitually active 2–3 times per week taking part in endurance-type exercises, including jogging, cycling, and cross-country skiing. Baseline characteristics of all groups are presented in Table 1. All subjects were healthy, did not take medication that may interfere with the neuromuscular or endocrine systems, and were cleared to participate in strenuous resistance testing and training after an electrocardiogram and physician’s examination.

Neuromuscular Performance Measurements

Subjects reported to the laboratory at specified intervals throughout the day, which was maintained for all subsequent testing visits to control for time-of-day effects on performance. A prior familiarization session, where all devices were set according to the individual subject anthropometry and practice trials were performed, took place 7 days before testing. Subjects were required to perform these trials with perfect technique before the cessation of the session. Five to 10 warm-up contractions were performed before maximal trials. Maximum bilateral isometric force production of the leg extensors (hip, knee, and ankle) was measured using an electromechanical dynamometer. The subjects were in a seated leg press position with knee and hip angles of 107 and 110°, respectively. The subjects were instructed to push “as fast and as hard as possible” and maintain their maximum force for approximately 3 seconds. A minimum of 3 trials were performed with the trial yielding the highest force used in further analysis. If the subjects improved by more than 5% between trials, then another trial was performed. The force signal was sampled at 2000 Hz and low-pass filtered (10 Hz) using Signal software (version 4.04; Cambridge Electronic Design, Cambridge, United Kingdom).

Maximum unilateral isometric knee extension torque was measured using a modified David 200 knee extension device (David Health Solutions Ltd., Helsinki, Finland) fitted with

<p>| Table 1. Baseline characteristics and neuromuscular performance.† |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Fat percentage (%)</th>
<th>Leg press 1RM (kg)</th>
<th>Maximum isometric force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young training</td>
<td>29 ± 9***</td>
<td>178 ± 6</td>
<td>75 ± 10*</td>
<td>21 ± 8</td>
<td>158 ± 29*</td>
</tr>
<tr>
<td>Young control</td>
<td>30 ± 11***</td>
<td>180 ± 7</td>
<td>86 ± 16</td>
<td>20 ± 9</td>
<td>177 ± 22*</td>
</tr>
<tr>
<td>Older training</td>
<td>63 ± 8</td>
<td>177 ± 5</td>
<td>81 ± 8</td>
<td>24 ± 6</td>
<td>137 ± 24</td>
</tr>
<tr>
<td>Older control</td>
<td>65 ± 3</td>
<td>177 ± 7</td>
<td>75 ± 10</td>
<td>22 ± 7</td>
<td>138 ± 28</td>
</tr>
</tbody>
</table>

†p ≤ 0.05; ***p < 0.01 vs. older men. 1RM = 1 repetition maximum.
a locking system and strain gauge. Again, the subjects were seated with knee and hip angles firmly secured at 107 and 110°, respectively, with 3 trials of 3-second duration performed. Once the torque had plateaued, a supramaximal superimposed single-twitch electric pulse was given onto the quadriceps muscles to assess voluntary activation level of the quadriceps.

A David 210 horizontal leg press dynamometer (David Health Solutions Ltd.) was used to measure maximum bilateral concentric force production of the leg extensors. The subjects were seated so that the starting knee angle was 60° (±2°). Upon verbal command, the subject fully extended the legs (knee = 180° and hip = 110°). After each repetition, the load was increased until the subject was no longer able to extend the legs to full extension. The last acceptable trial with the highest load was determined as the 1RM. Each subject performed 3–5 trials with a rest period of 2 minutes between trials.

Surface Electromyography and Muscle Stimulation Procedures
Bipolar Ag/AgCl electrodes (5 mm diameter, 20 mm interelectrode distance, common mode rejection ratio >100 dB, input impedance >100 MΩ, baseline noise <1 μV/2 ms) were positioned, following shaving and skin abrasion, on the vastus lateralis (VL), vastus medialis (VM), and biceps femoris (BF) of the right leg according to SENIAM guidelines. During the neuromuscular performance tests, surface electromyogram (EMG) was sampled at a frequency of 2000 Hz and amplified at a gain of 500 (sampling bandwidth, 10–500 Hz). Raw signals were passed from a transportable pack to the receiving box (Telemyo 2400R; Noraxon, Scottsdale, AZ, USA), were relayed to an AD converter (Micro1401; Cambridge Electronic Design) and recorded by Signal 4.04 software (Cambridge Electronic Design). After testing, EMG signals were band-pass filtered (20–350 Hz) and maximum integrated EMG was determined from a time window of 500–1500 milliseconds during isometric leg extension and 65–170° knee angle during concentric leg extension trials using customized scripts. Values for the VL and VM muscles were averaged [(VL + VM)/2]. Biceps femoris values are not reported as there were no changes in coactivation ratio.

Muscle stimulation was performed by placing 4 paired self-adhesive electrodes (6.98 cm V-trodes; Mettler Electronics Corp., Anaheim, CA, USA) on the proximal regions of the quadriceps muscle belly. Single 1 millisecond rectangular pulses (400 V) were delivered by a constant current stimulator (Model DSTAH; Digitimer Ltd., Letchworth Garden City, United Kingdom) onto the muscle during a resting state with increasing current until a torque plateau was observed. An additional 25% stimulation current was added to that identified to produce maximum torque. During the unilateral maximum isometric knee extension trials, this supramaximal single-pulse stimulation was delivered during the plateau of peak torque and then one more pulse 2 seconds after contraction cessation to assess voluntary activation level. The level of voluntary activation was assessed using the formula of Bellemare and Bigland-Ritchie (4); voluntary activation % = [1 − (superimposed twitch torque/passive twitch torque)] × 100. Biceps femoris EMG showed that our methods did not stimulate this antagonist muscle.

Body Composition Measurements
The subjects fasted overnight (12 hours) and were instructed to drink 0.5 L of water 60 minutes before measurements. After determination of height using a fixed wall-scale and weighing in underwear without shoes, dual-energy x-ray absorptiometry (DXA) was used to assess whole-body composition (LUNAR Prodigy Advance with enCORE software version 9.3; GE Medical Systems, Madison, WI, USA). The legs were secured together by nonelastic straps about the knees and ankles to prevent movement during scanning. The lean mass of the upper and lower limbs were isolated from the trunk and assessed by software-generated regions.

Cross-sectional area (CSA) of the VL was assessed by B-mode axial plane ultrasound (model SSD-a10; Aloka Co., Ltd., Tokyo, Japan) using a 10 MHz linear array probe (60 mm width) with the extended-field-of-view mode. The validity (3) and reliability (26) of this method has been reported. Oriented in the axial plane, the probe was moved manually with a slow and continuous movement from the lateral to medial along a marked line on the skin. Great care was taken to diminish compression of the muscle tissue. Images were obtained throughout the movement. As the orientation of each image relative to adjacent images is known, the software builds a composite image. Three panoramic CSA images were taken at 50% femur length, from the lateral aspect of the distal diaphysis to the greater trochanter, and 3 images were taken 2 cm distally from this point. Cross-sectional area was determined by manually tracing along the border of the VL muscle using ImageJ software (version 1.37; National Institute of Health, Bethesda, MD, USA). The mean of the 2 closest values were taken as the CSA result for each sites (50% femur length and 2 cm distally) and then the mean of the 2 sites was used in further analysis.

Resistance Training Program
Training was performed by both young and older men twice per week for a total of 10 weeks with at least 2 days between sessions, and all major muscle groups were performed in 1 training session (Table 2). Briefly, leg exercises (bilateral leg press, knee extension, and knee flexion) were performed before upper-body and torso exercises; bench press, pull-down, shoulder press, seated row, triceps pushdown, biceps curl, abdominal crunches, and back raises. The subjects performed medium intensity, high-volume training consisting of 2–3 sets and 12–14 repetitions (reps) (60–70% 1RM) per exercise (weeks 1–4), then 2–3 sets and 10–12 reps (70–80% 1RM) per exercise (weeks 5–7), and 3–4 sets per exercise and 8–10 reps (75–85% 1RM) per exercise (weeks 8–10).
One-minute rest was given between sets during weeks 1–4, and then 2-minute rest was given between sets during the remaining weeks 5–10. One set was performed to failure during each training session.

Subjects were given nutritional counseling during the study, for example, to consume ~20 g of protein within 1 hour of training and in total ~1.5–1.8 g of protein per kg body mass per day, to optimize the muscle hypertrophy response. However, no dietary intervention was performed or diet diary recorded. The control group subjects were instructed to maintain their normal physical activity levels and refrain from resistance training throughout the intervention. None of the subjects suffered harm during training or testing.

Statistical Analyses
All data are reported as mean and SD, and all within-group statistical analyses reported as mean difference to pretraining values with 95% confidence intervals (CI). Normal distribution was determined through the Shapiro-Wilk test. Baseline characteristics were assessed by 1-way analysis of variance. Analysis of covariance was used to assess the pre- to postraining effects between groups, using baseline values as the covariate. Bonferroni adjustments were used as post hoc tests when a significant main effect for group was identified. Within-group (time effects) analyses were performed by paired T-test. SPSS version 18 (IBM Corp., Armonk, NY, USA) was used for statistical analyses. Reliability values for the data presented were as follows: 1RM load: 0.969 and 2.1%; bilateral isometric leg extension force: 0.921 and 4.2%; unilateral isometric knee extension torque: 0.889 and 3.4%; lean leg mass: 0.987 and 1.1%; total body fat mass: 0.998 and 2.2%; VL CSA: 0.952 and 4.7%; EMG amplitude: 0.906 and 7.2%; and voluntary activation level: 0.797 and 8.7% for intraclass correlation coefficients and coefficient of variation %, respectively. The alpha level was set at 0.05.

RESULTS
Baseline Subject Characteristics
Baseline anthropometric and body composition data, as well as neuromuscular performance data are presented in Table 1. In addition to age (p < 0.01) at baseline, significant differences were observed between young and older training groups in body mass (p ≤ 0.05) and leg press 1RM (p ≤ 0.05), and between young and older control groups in leg press 1RM (p ≤ 0.05; Table 1).

Neuromuscular Performance
Significant main effects for time and group were observed in maximum force production of the leg extensors assessed by leg press 1RM (time: F = 10.43, p = 0.002, effect size = 0.14; group: F = 10.82, p < 0.001, effect size = 0.33) and for group in bilateral isometric leg extension force (F = 42, p = 0.009, effect size = 0.17). Bonferroni post hoc tests revealed differences between the young training and older nontraining control groups (mean difference = 9.1 kg, 95% CI = 4.3–13.9,
$p < 0.001$), as well as between the older training and older control groups (mean difference = 8.2 kg, 95% CI = 3.6–12.8, $p < 0.001$) for leg press 1RM. For isometric leg extension, a significant difference was observed between the young training and control groups (mean difference = 220 N, 95% CI = 3.1–438, $p = 0.045$). Over time, both training groups made statistically significant improvements in leg press 1RM (young: 13 ± 7%, $p < 0.001$; older: 14 ± 9%, $p < 0.001$; Figure 1) and isometric leg extension force (young: 17 ± 22% $p < 0.01$; older: 12 ± 26% $p < 0.001$; Figure 1) during the 10-week period. The young nontraining control group increased maximum leg press 1RM performance (6 ± 6%, $p = 0.05$; Figure 1) but not in any other test of neuromuscular performance, and no differences were observed in the older control group in any test.

Maximum isometric knee extension also demonstrated a significant main effect for time ($F = 10.85$, $p = 0.002$, effect

![Figure 1.](image1.png)

**Figure 1.** Maximum neuromuscular performance in the leg press (left) and isometric leg extension (right) before and after the training period in young and older men. *$p ≤ 0.05$; **$p < 0.01$; ***$p < 0.001$ compared with before training. C = $p ≤ 0.05$ compared with control group.

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![Figure 2.](image2.png)

**Figure 2.** Lower-limb lean mass (upper left), vastus lateralis cross-sectional area (lower left), and voluntary activation level (lower right) before and after training in young and older men, as well as relationship between changes in 1RM performance and lower-limb lean mass during training in young men (upper right). **$p < 0.01$ compared with before training. C = $p ≤ 0.05$ compared with control group; YT = $p ≤ 0.05$ compared with young training group.
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size = 0.17) and a trend for group (F = 2.82, p = 0.069, effect size = 0.11). Post hoc tests revealed a significant difference between young training and older control groups (mean difference = 2.4 N·m⁻¹, 95% CI = 0.26–4.53, p = 0.023). Additionally, over time, both training groups significantly increased maximum isometric knee extension torque (young: 9 ± 11%, p < 0.01; older: 10 ± 16%, p < 0.01).

Body Composition
A significant main effect for group was observed for lean leg mass as assessed by DXA (F = 3.47, p = 0.021, effect size = 0.14). Post hoc tests revealed a significant difference between the young and older training groups (mean difference = 7.15 g, 95% CI = 3.3–13.98, p = 0.035). Over time, total fat mass decreased in both the older training (−11.3 ± 9.3%, p < 0.01) and older nontraining control (−5.3 ± 7.2%, p < 0.05) groups over the study period, whereas no significant changes occurred in the young men.

Significant main effects for time and group were observed for VL CSA as assessed by ultrasound (time: F = 7.94, p = 0.006, effect size = 0.11; group: F = 7.5, p < 0.001, effect size = 0.27). Post hoc tests revealed significant differences between the young training and young control (mean difference = 1.5 cm², 95% CI = 0.32–2.7, p = 0.006) and between young training and older control (mean difference = 1.7 cm², 95% CI = 0.51–2.82, p = 0.001). Over time, both young and older training groups increased VL CSA (young: 18.1 ± 13.4%, p < 0.01; older: 14.7 ± 11.5%, p < 0.01; Figure 2) during the 10-week period.

Muscle Activation
Significant main effects for time and group were observed in voluntary activation level (time: F = 33.6, p < 0.001, effect size = 0.39; group: F = 5.64, p = 0.006, effect size = 0.18), and for time in isometric leg extension EMG amplitude (F = 8.29, p = 0.006, effect size = 0.14). In voluntary activation level, post hoc tests revealed a significant difference between the young and older training groups (mean difference = 2.4%, 95% CI = 0.3–4.5, p = 0.023). Furthermore, voluntary activation level increased in the older training men only (from 90.9 ± 6.4% to 93.1 ± 5.7%, p ≤ 0.05; Figure 2). Over time, only the older training men increased EMG amplitude during the 10-week period, which was observed in both 1RM leg press (29 ± 51%, p ≤ 0.05) and in maximum isometric leg extension (35 ± 51%, p < 0.01).

**DISCUSSION**

The results of the present study suggest that large increases in strength occur during 10 weeks of resistance training in both young and older men previously unaccustomed to resistance training. However, the dominant mechanisms that may have led to these increases appear to be different between the 2 groups. Whereas younger men demonstrated large increases in muscle mass that were related to increased neuromuscular performance, older men demonstrated improved muscle activation with a lower magnitude of muscle hypertrophy during the initial 10 weeks of training.

It may be that older, previously untrained subjects respond to high-volume, medium load “hypertrophic” resistance training with low training frequency according to the classic model of adaptation proposed by Moritani and de Vries (25). Specifically, neural adaptations dominate the early improvements with a lower emphasis on muscle hypertrophy contributing to strength gain over a 10-week period. At least, these neural adaptations were clearly observable in the older men using the methods of the present study. It may be speculated that the neural adaptations in the present study were increases in agonist activation as both voluntary activation level and EMG amplitude increased. Both measures are influenced by motor unit recruitment and firing frequency, and improvements to either/both of these elements of muscle activation could have led to increased force production (2,19,33). Furthermore, no changes in coactivation of the BF muscle was observed, which has been shown to improve in some older individuals (12).

Young men, however, seem to increase strength primarily from muscle hypertrophy during 10 weeks of hypertrophic resistance training with no clear evidence of muscle activation improvements. It may be that the young men in the present study, despite a lack of previous resistance training experience, may have required greater loads (i.e., 85–100% 1RM) and lower number of repetitions per set to induce marked changes in agonist activation, as used in previous studies (12,18). The methods of the present study cannot rule out improved coordination between different agonist muscles and possibly also improved synergist activation contributing to strength increases (30). However, ultimately, the significant difference observed in voluntary activation level between the young and older training groups suggests divergent responses in the neural system to this type of resistance training.

The DXA results of the present study seem to suggest that older men did not increase muscle mass to the same extent as the young men, which supports the findings of the meta-analysis of Peterson et al. (28) from DXA data. There are several possible mechanisms that may have led to differences in the hypertrophic responsiveness of young and older men. For example (a) older individuals have been shown to have a higher proportion of type I fibers compared with young individuals (16), which have a lower potential for growth vs.
type II fibers (1,11); (b) studies have shown that resting hormone concentrations (20) and acute hormone responses to hypertrophic resistance exercise (6,15,20) are lower in older individuals, which form an important part of postexercise anabolism (21); and (c) some studies have shown lower responses in intramuscular protein signaling in older individuals to hypertrophic resistance exercise (9), which may or may not act independently of hormonal influences (31).

The results of the present study, demonstrating differing magnitudes of hypertrophy between age groups, conflicts with the studies of Hakkinen et al. (14) and Mayhew et al. (23). One possibility for the discrepancies between the studies may be a result of measurement specificity, that is, measuring quadriceps CSA by magnetic resonance imaging or ultrasound vs. lower-limb lean mass by DXA. However, CSA measures in other studies (12,20,24) were able to determine statistical differences between young and older subjects, suggesting that other factors are responsible for the collective data in the literature. It must be acknowledged that the present study assessed hypertrophy over a 10-week training period and it is possible that older men may have required a longer training period to match the hypertrophy of the young men.

One limitation of the study was that no dietary monitoring or intervention was included. This makes it difficult to assert that differences in lower-limb lean mass adaptations were because of the resistance training program in young and older men, especially as the older men demonstrated reduced fat mass over the 10-week period. A recent finding that older individuals consume a lower protein intake (24) combined with the reduction in fat mass suggests caloric deficit and a nonoptimal environment for muscle hypertrophy (27). It is recommended that future studies control nutritional factors when assessing the hypertrophic responsiveness of young and older men to resistance training.

In conclusion, high-volume, medium load resistance training twice per week led to large increases in the maximum strength of physically active nonresistance trained young and older men over a 10-week period. The main adaptations that accompanied this improved neuromuscular performance were quadriceps muscle hypertrophy in the young men and increased agonist activation in the older men.

**Practical Applications**

Both young and older men who are previously unaccustomed to resistance training can greatly improve strength from high-volume, medium load resistance training. Our results suggest that younger men may be more responsive, in terms of muscle hypertrophy, to this form of resistance training than older men, at least during short-term training. It also appears that young men may require higher intensity resistance training to induce a marked improvement in muscle activation (i.e., neural adaptation), whereas the training stimulus of the present study was sufficient to induce neural adaptation in older men. The strength improvement in the young men was largely accounted for by increased muscle mass and this should be the main goal of the training program when using high-volume, medium intensity resistance training in this age group. It is unclear whether another resistance training program (other than high volume, medium load, low frequency) would have elicited a greater hypertrophy response in the older men. Consequently, the results of the present study may help to assign goal-specific training programs as young men demonstrated marked hypertrophy but no obvious improvement in muscle activation, whereas older men demonstrated improved muscle activation but limited muscle hypertrophy.

**References**


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