The Effects of High- and Moderate-Resistance Training on Muscle Function in the Elderly

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The purpose of this study was to investigate the effects of a 12-week resistance-training program on muscle strength and mass in older adults. Thirty-three inactive participants (60–74 years old) were assigned to 1 of 3 groups: high-resistance training (HT), moderate-resistance training (MT), and control. After the training period, both HT and MT significantly increased 1-RM body strength, the peak torque of knee extensors and flexors, and the midthigh cross-sectional area of the total muscle. In addition, both HT and MT significantly decreased the abdominal circumference. HT was more effective in increasing 1-RM strength, muscle mass, and peak knee-flexor torque than was MT. These data suggest that muscle strength and mass can be improved in the elderly with both high- and moderate-intensity resistance training, but high-resistance training can lead to greater strength gains and hypertrophy than can moderate-resistance training.

Key Words: intensity, 1-RM, isokinetic peak torque, computed tomography scans

One of the most well-known effects of aging is reduction of muscle strength (Lindle et al., 1997). The decline in muscle strength of older adults is associated with decreased functional performance (Bassey et al., 1992) and increased number of falls (Wolfson, Judge, Whipple, & King, 1995). The major cause of decline in muscle strength is the decrease of muscle mass with aging (Frontera, Hughes, Lutz, & Evans, 1991). Regular participation in a supervised resistance-training program has proven an effective and safe intervention to increase muscle strength and mass in the elderly (Frontera, Meredith, O’Reilly, Knutgen, & Evans, 1988; Hurley et al., 1994; Taaffe, Pruitt, Pyka, Guido, & Marcus, 1996) and frail elderly (Binder et al., 2002; Sullivan, Wall, Bariola, Bopp, & Frost, 2001), as well as in the very old (Fiatarone et al., 1990; 1994). Research has indicated that there are various increments in muscle strength and mass after participation in resistance-training programs with various degrees of intensity (Frontera et al., 1988; Taaffe et al.; Vincent et al., 2002).

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Frontera et al. (1988) reported gains in muscle strength of 107% and 227% in knee extension and flexion, respectively, with an 11% increment in total muscle area of the thigh, after a high-intensity (80% of one-repetition maximum [1-RM]) resistance-training program of 12 weeks. With a similar resistance-exercise protocol, Welle, Totterman, and Thornton (1994) noted significant improvements in knee-extension and -flexion strength of 64% and 32% respectively, and a 6% improvement in muscle area of the knee extensors after a 12-week resistance-training program. Taaffe et al. (1996), using a low-intensity exercise protocol, reported increases in leg strength (leg press) of 41.5% after a 52-week period. In addition, Moritani and de Vries (1980) used intensity equal to 66% 1-RM and found a 23% gain in elbow-flexion strength during an 8-week resistance-training program.

The variation in gains in muscle strength and mass in previous studies might be attributed to the differing ages of participants (Fiatarone et al., 1990; Frontera et al., 1988), their different initial physical activity levels (Hurley et al., 1994; Treuth et al., 1995), the type of evaluation (Frontera et al., 1988; Hurley et al.; Roman et al., 1993), the duration of the programs (Harridge, Kryger, & Stensgaard, 1999; Menkes et al., 1993), the muscle group exercised (Brown et al., 1990; Judge, Underwood, & Gennosa, 1993), the number of set and repetitions of the resistance exercises (Brown, McCann, & Sale, 1990; Charette et al., 1991; Treuth et al.; Vincent et al., 2002), and, mainly, the intensity of the exercise (Taaffe et al., 1996). In the present study, an effort was made to isolate the intensity of the resistance training and to keep the other factors under control and evaluate the effects of different intensities on improvement of muscle strength and mass.

The present study was designed to determine the effects of resistance training at different intensities (high and moderate) on muscle strength and mass measured by 1-RM, isokinetic peak torque, computed tomography scans, and anthropometry and to identify the differences between the two training programs. We hypothesized that the two resistance-training programs would obtain similar strength and mass increases after 12 weeks of exercise.

**Methods**

**PARTICIPANTS**

Thirty-three men and women age 60–74 years participated in the present study. All participants signed a written informed-consent form after being informed of all risks, discomforts, and benefits associated with the procedures to be followed in the study. The research design and procedures of the study were approved by the investigational review committee of the Department of Physical Education and Sport Sciences at the Democritus University of Thrace. The participants were physically inactive before the study, and the scores obtained on the Modified Baecke Questionnaire for Older Adults (below 9.4) were indicators of physical inactivity (Voorrips, Ravelli, Dongelmans, Deurenberg, & Van Staveren, 1991). According to the medical questionnaire completed in interviews of participants with a physician, they did not suffer from cardiovascular, orthopedic, or neuromuscular diseases or other chronic conditions. They were nonsmokers and using no medications that would interfere with the safety and conduct of the training programs. Finally, the participants performed a progressive diagnostic treadmill
test to exhaustion according to Bruce’s protocol, with a resting 12-lead electrocardiogram to determine their heart rate, blood pressure, and electrocardiogram responses to submaximal and maximal exercise. Participants were included in the study if they exhibited no signs of cardiovascular and respiratory problems during the exercise test (American College of Sports Medicine [ACSM], 1995).

ANTHROPOMETRY

Body weight was measured to the nearest 0.1 kg using a medical beam scale (Seca 707, Hamburg, Germany), with the participants wearing only underclothes (Lohman, Roche, & Martorell, 1988). Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca; Lohman et al.). Skinfold measurements at the triceps, subscapular, abdominal, thigh, and suprailiac sites were taken with a Lange caliper (Country Technology, Gay Mills, WI) using specific anatomic landmarks (ACSM, 1995). These measurements were repeated until there was no more than a 1-mm difference between duplicated measurements and then averaged. Body circumferences at the waist, abdomen, hip, and thigh were assessed to the nearest 0.1 cm with a Gulick flexible tape (Country Technology; ACSM). These measurements were repeated until there was no more than a 0.5-cm difference between duplicated measurements. The mean values were used for the statistical analysis.

MUSCLE STRENGTH

Maximal concentric strength of the upper and lower body was assessed before and after the training period using 1-RM with Universal machines (Irvine, CA; Heyward, 1998). Test–retest reliability in our laboratory of 1-RM strength is high \((r = .95)\). In addition to measurements of dynamic concentric strength, peak muscle torque of the knee extensors and flexors was measured using an isokinetic dynamometer (Cybex 6000, Lumex Corporation, New York, NY) before and after the training period. The participants were evaluated at angular velocities of 60°/s and 180°/s in both legs. The length of the dynamometer arm was recorded during the pretest for each participant, and the arm reset to the same length for the posttesting session. The test protocol included one set of three maximal repetitions at each speed, separated by 120-s rests between leg intervals. The highest peak torque at each speed was used for statistical analysis. Peak-torque evaluation at 60°/s and 180°/s was used to represent slow and fast dynamic isokinetic strength (Frontera et al., 1988). Before the test, participants performed a warm-up of 10 min of cycling (Monarch) followed by three submaximal trials on the isokinetic dynamometer. Five participants (1 from HT, 2 from MT, and 2 from the control group) could not familiarize themselves with the isokinetic dynamometer, and they did not participate in the isokinetic measurement. In order to verify test–retest reliability, strength tests were repeated 48 hr apart during pre- and posttesting sessions. The intraclass correlation coefficient ranged from .90 to .93 \((p < .05)\).

COMPUTED TOMOGRAPHY SCANS

The cross-sectional areas (CSAs) of muscle and subcutaneous fat at the nondominant midthigh were measured before and after the training period by computed
tomography scan (Frontera et al., 1988; Hurley et al., 1994). To ensure that midthigh images were obtained from the exact same anatomic position before and after the training period, the halfway point between iliac crest and lower pole of the patella was marked while the participants were supine and their thighs relaxed. The scanner used in this study was a General Electric CT Max 640, with a scanning time of 4.8 s, slice width of 10 mm, and mA/s of 55, operating at 120 kV. Images were viewed at a window width of 500 Hounsfield units (H) and a level setting between –10 and +40 H to achieve the best contrast among muscle, fat, and bone tissue. The number of matrixes on each image was 640 × 640. The areas of the quadriceps, hamstrings, subcutaneous fat, and total muscle were identified and measured by manual planimetry (Model 1224, Lafayette Instruments, IN) to the nearest 0.01 cm² (Hurley et al.). In the control group, only 10 participants had computed scans because of the high cost of the procedure. The computed tomography scans were analyzed without knowledge of participants’ names, testing conditions (before or after the training period), or group of training intensity. Each image was measured repeatedly until a variation of 1% was obtained between trials (Hurley et al.). Two trials were needed to obtain a variation of less than 1%, with the mean of the two measurements reported. In addition, the coefficient of variation of total muscle CSA between measurements of the same 20 scans, after a week, was 0.9%.

TRAINING PROCEDURE

The participants in the study were randomly assigned to one of three groups: high-resistance training (HT, n = 11), moderate-resistance training (MT, n = 12), or a control group (n = 10). The resistance-training groups exercised 3 days per week, on nonconsecutive days, for 12 weeks. At the beginning of each training session, the participants of the training groups performed a 5-min warm-up of cycling (Monarch, Varberg, Sweden) at 50% of maximum heart rate, with 5 min of stretching for the upper and lower body. The groups exercised on six Universal machines involving the major muscles of upper and lower body: leg extension, chest press, leg curl, latissimus pull-down, arm curl, and triceps extension. After the resistance exercises the participants performed abdominal crunches (sit-ups) and low-back exercises (three sets of 12 repetitions for Weeks 1–6 and three sets of 20 repetitions for Weeks 7–12). The 1-RM on each resistance exercise was measured at the beginning of every week until the training period was completed. By the beginning of the first week, the HT participants performed three sets of eight repetitions at 80% 1-RM and remained at this level until the end of the training period. The MT participants performed three sets of 15 repetitions at 60% 1-RM and continued at that intensity until the end of the training period. Before the start of the training period the participants performed three resistance sessions with no or little resistance to become familiar with the equipment and proper exercise techniques (Hurley et al., 1994). In addition, this helps control the large increases in strength measurements during the initial phases of training (Hurley et al.).

The participants were instructed to perform each repetition in 6 s—to raise the weight in 2 s, pause briefly for 2 s, and slowly lower the weight in 2 s (Frontera et al., 1988). They paused for 2–3 s between repetitions and 2 min between sets (Frontera et al., 1988). At the end of each training session, the training groups performed a 5-min cool-down of cycling at 40% of maximum heart rate. Heart rate
and blood pressure were measured before exercise began, every 5 min during the exercise, and after the end of exercise until they both stabilized at preexercise levels. The control group did not exercise but participated in the measurement procedures.

**STATISTICAL ANALYSIS**

Data were analyzed using the SPSS PC program for Windows®. Means ± SDs were calculated. One-way analysis of variance (ANOVA) was used initially to examine possible differences among the three groups in the initial measurement values for each dependent variable. A repeated-measures MANOVA (2 × 3, time by group) was performed for differences in main effects and time-by-group interactions on each variable. When the F ratio for time-by-group interaction was significant, post hoc comparisons of means were analyzed using Scheffé’s multiple-comparison tests. In order to compare the three group’s effectiveness in changing each dependent variable at the end of the training period, a one-way ANOVA (with group as the independent factor) was conducted to examine the relative differences between pre- to posttraining measurements. When F ratios were significant, post hoc comparisons of means were performed with Scheffé’s multiple-comparison tests. Pearson’s coefficient correlation was used to express the relationship between measurements of interest. Statistical significance was accepted at p < .05.

**Results**

The attendance rate of the 33 participants who completed the 12-week program was 98.5%. No significant differences were found for the physical characteristics of the participants (Table 1) and all pretraining data on anthropometric characteristics (body weight, body-mass index, waist:hip ratio, skinfolds, and circumferences), muscle strength (1-RM and peak torque), subcutaneous fat, and muscle mass (midthigh CSAs) for any participants.

<table>
<thead>
<tr>
<th>Group</th>
<th>Gender</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>Height (m)</th>
<th>Baecke score</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT, n = 11</td>
<td>7 women, 4 men</td>
<td>64.6 ± 5.1</td>
<td>78.6 ± 17.4</td>
<td>1.63 ± 0.07</td>
<td>9.09 ± 1.39</td>
</tr>
<tr>
<td>MT, n = 12</td>
<td>8 women, 4 men</td>
<td>65.7 ± 4.2</td>
<td>78.7 ± 10.6</td>
<td>1.59 ± 0.07</td>
<td>9.21 ± 1.27</td>
</tr>
<tr>
<td>C, n = 10</td>
<td>6 women, 4 men</td>
<td>64.4 ± 3.4</td>
<td>75 ± 11.6</td>
<td>1.59 ± 0.08</td>
<td>9.10 ± 1.24</td>
</tr>
</tbody>
</table>

*Note. HT = high-resistance-training group; MT = moderate-resistance training group; C = control group.*
Body weight, body-mass index, and waist:hip ratio did not change significantly in the three groups after the training period. By Week 12, abdominal circumference decreased significantly by an average 1.8 cm in both training groups (\(p < .001\)), as shown in Table 2. The HT and MT groups showed significantly higher decrements in abdominal circumference than those of the control group (\(p < .001\)).

### 1-RM MEASURES

The 1-RM strength tests revealed substantial increases in strength after the training period in both training groups (Table 3). The HT group had significantly higher improvements for the 1-RM of all variables (knee extension and flexion, total of lower limbs, elbow flexion, elbow extension, upper limbs, chest press, and latissimus pull-down) than did the MT group (\(p < .001\)) or the control group (\(p < .001\)), and the MT group showed significantly higher improvements than those of the control group (\(p < .001\)).

### ISOKINETIC STRENGTH

Significant increments in peak muscle torque, at both 60/\(s\) and 180/\(s\), were observed in the HT and MT groups after 12 weeks of training (Table 4). The HT group showed significantly higher improvements for all variables than those of the

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**Table 2  Circumference Measurements (cm) in the Three Groups (\(M \pm SD\))**

<table>
<thead>
<tr>
<th>Site</th>
<th>HT ((n = 11))</th>
<th>MT ((n = 12))</th>
<th>C ((n = 10))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen pre</td>
<td>100.34 ± 13.20</td>
<td>103.33 ± 6.85</td>
<td>100.08 ± 13.38</td>
</tr>
<tr>
<td>Abdomen post</td>
<td>98.73 ± 12.86(^a)(^b)</td>
<td>101.52 ± 6.10(^c)</td>
<td>100.38 ± 13.10</td>
</tr>
<tr>
<td>Waist pre</td>
<td>91.29 ± 15.13</td>
<td>92.66 ± 9.16</td>
<td>92.25 ± 10.44</td>
</tr>
<tr>
<td>Waist post</td>
<td>91.80 ± 15.55</td>
<td>92.95 ± 9.46</td>
<td>92.45 ± 10.21</td>
</tr>
<tr>
<td>Hip pre</td>
<td>106.13 ± 9.53</td>
<td>109.08 ± 7.90</td>
<td>104.05 ± 7.65</td>
</tr>
<tr>
<td>Hip post</td>
<td>106.55 ± 9.87</td>
<td>109.50 ± 8.20</td>
<td>104.10 ± 7.48</td>
</tr>
<tr>
<td>Arm pre</td>
<td>30.38 ± 4.39</td>
<td>31.12 ± 3.37</td>
<td>30.33 ± 3.15</td>
</tr>
<tr>
<td>Arm post</td>
<td>30.95 ± 4.90</td>
<td>31.54 ± 4.04</td>
<td>30.81 ± 3.08</td>
</tr>
<tr>
<td>Thigh pre</td>
<td>54.96 ± 4.95</td>
<td>55.95 ± 5.25</td>
<td>52.85 ± 3.18</td>
</tr>
<tr>
<td>Thigh post</td>
<td>55.49 ± 5.07</td>
<td>56.12 ± 5.00</td>
<td>52.79 ± 3.12</td>
</tr>
<tr>
<td>Waist:hip ratio pre</td>
<td>0.8560 ± 0.0867</td>
<td>0.8500 ± 0.0784</td>
<td>0.886 ± 0.0816</td>
</tr>
<tr>
<td>Waist:hip ratio post</td>
<td>0.8570 ± 0.0894</td>
<td>0.8500 ± 0.0772</td>
<td>0.886 ± 0.080</td>
</tr>
</tbody>
</table>

*Note.* HT = high-resistance-training group; MT = moderate-resistance-training group; C = control group.

\(^a\)\(^p\) < .001; significant differences between pre- and posttraining. \(^b\)\(^p\) < .001; significant differences between HT and C. \(^c\)\(^p\) < .001; significant differences between MT and C.

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**ANTHROPOMETRY**

Body weight, body-mass index, and waist:hip ratio did not change significantly in the three groups after the training period. By Week 12, abdominal circumference decreased significantly by an average 1.8 cm in both training groups (\(p < .001\)), as shown in Table 2. The HT and MT groups showed significantly higher decrements in abdominal circumference than those of the control group (\(p < .001\)).
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control group (p < .01) and significantly higher improvement in right knee extension and flexion at 60°/s and flexion at 180°/s than the MT participants (p < .05). The MT participants showed significantly more improved left and right knee extension and flexion at 60°/s and right knee extension and flexion at 180°/s than did the control participants (p < .01).

REGIONAL BODY COMPOSITION

There was no significant change in the midthigh CSA of subcutaneous fat after the training period by any of the groups (Table 5). The HT and MT groups had significant increases in the midthigh CSAs of the quadriceps, hamstrings, and total muscle area at the end of the training period (Table 5). The HT group was more effective in increasing the midthigh CSA of the quadriceps, hamstrings, and total muscle area than were the MT and control groups, and the MT group showed significantly higher improvements than those of the control group (Table 5).
Discussion

It is generally agreed that strength and muscle mass decline with aging (Lindle et al., 1997; Young, Stokes, & Crowe, 1984, 1985). There is limited information available, however, regarding the effect of the intensity of resistance training on muscle strength and mass in the elderly. The results of this study confirm that both high- and moderate-intensity resistance-training programs can produce significant increases in muscle strength and mass in older adults. In comparison, high-resistance training can cause larger increments in 1-RM and muscle mass than moderate-resistance training does.

Table 4  Pre- and Posttraining Values for Isokinetic Peak Torque (N · m) of Both Knees in the Three Groups (M ± SD)

<table>
<thead>
<tr>
<th>Isokinetic measure</th>
<th>HT (n = 10)</th>
<th>MT (n = 10)</th>
<th>C (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left extensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°/s pre</td>
<td>99.30 ± 24.78</td>
<td>103.90 ± 36.41</td>
<td>90.88 ± 19.94</td>
</tr>
<tr>
<td>post</td>
<td>111.20 ± 30.21 &amp; c</td>
<td>112.70 ± 38.53 &amp; b</td>
<td>91.80 ± 20.00</td>
</tr>
<tr>
<td>180°/s pre</td>
<td>64.30 ± 19.96</td>
<td>60.60 ± 18.95</td>
<td>66.37 ± 12.55</td>
</tr>
<tr>
<td>post</td>
<td>74.40 ± 22.78 &amp; d</td>
<td>67.20 ± 23.21 &amp; a</td>
<td>66.30 ± 11.24</td>
</tr>
<tr>
<td>Left flexors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°/s pre</td>
<td>47.90 ± 16.23</td>
<td>55.40 ± 22.04</td>
<td>63.25 ± 20.35</td>
</tr>
<tr>
<td>post</td>
<td>58.70 ± 19.41 &amp; c</td>
<td>61.30 ± 22.25 &amp; a</td>
<td>63.20 ± 20.11</td>
</tr>
<tr>
<td>180°/s pre</td>
<td>36.40 ± 15.90</td>
<td>35.90 ± 17.51</td>
<td>40.50 ± 12.70</td>
</tr>
<tr>
<td>post</td>
<td>43.70 ± 17.77 &amp; d</td>
<td>40.70 ± 20.46 &amp; e</td>
<td>40.60 ± 13.12</td>
</tr>
<tr>
<td>Right extensors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°/s pre</td>
<td>101.10 ± 25.15</td>
<td>95.70 ± 32.71</td>
<td>93.00 ± 37.18</td>
</tr>
<tr>
<td>post</td>
<td>112.00 ± 30.28 &amp; a,d</td>
<td>102.50 ± 35.60 &amp; c</td>
<td>93.12 ± 38.45</td>
</tr>
<tr>
<td>180°/s pre</td>
<td>61.80 ± 17.80</td>
<td>64.90 ± 21.06</td>
<td>62.75 ± 16.32</td>
</tr>
<tr>
<td>post</td>
<td>70.00 ± 19.41 &amp; a,d</td>
<td>69.00 ± 20.55 &amp; a,c</td>
<td>63.12 ± 17.07</td>
</tr>
<tr>
<td>Right flexors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°/s pre</td>
<td>51.90 ± 20.35</td>
<td>53.30 ± 17.78</td>
<td>60.87 ± 22.86</td>
</tr>
<tr>
<td>post</td>
<td>62.10 ± 22.58 &amp; a,d,f</td>
<td>58.20 ± 18.96 &amp; e,f</td>
<td>61.00 ± 22.24</td>
</tr>
<tr>
<td>180°/s pre</td>
<td>37.90 ± 13.69</td>
<td>38.50 ± 17.17</td>
<td>35.56 ± 17.00</td>
</tr>
<tr>
<td>post</td>
<td>44.40 ± 15.97 &amp; a,d,g</td>
<td>41.90 ± 17.62 &amp; a,e,g</td>
<td>35.50 ± 16.60</td>
</tr>
</tbody>
</table>

Note. HT = high-resistance-training group; MT = moderate-resistance training group; C = control group.

& p < .001; significant differences between pre- and posttraining. & b p < .05; significant differences between pre- and posttraining. & p < .05; significant differences between HT and C. & p < .001; significant differences between HT and C. & p < .05; significant differences between MT and C. & p < .01; significant differences between HT and MT. & p < .05; significant differences between HT and MT.
In the present study, there were no significant changes in body weight or waist:hip ratio in either training group, which is in agreement with results of other studies (Cononie et al., 1991; Miller et al., 1994; Treuth et al., 1995, 1994). In addition, no changes were observed in skinfold measures or circumferences after the training period, except for abdominal circumference. Perhaps the decrease in abdomen circumference resulted from the preferential reduction of intra-abdominal adipose tissue. Treuth et al. (1994) found a significant 8% decrease in trunk fat in older men using dual X-ray absorptiometry. The same research group (Treuth et al., 1995) reported a significant 9.7% decrease in intra-abdominal subcutaneous adipose tissue, whereas there was no change in the skinfold and circumference measures in older women after a 16-week high-resistance-training program. They concluded that there is a preferential loss of abdominal fat around the central fat stores of the trunk. Although a decrease was detected in subcutaneous fat area of the thigh in both training groups, this decrement is not a significant finding, which is in agreement with the study of Fiatarone et al. (1990). Other studies, by Treuth et al. (1995, 1994), reported decrements in midhigh subcutaneous fat with no change in thigh circumference in older men and women after 16 weeks of high-resistance training.

The response of the older adults to resistance training was ideal, if we take into account the fact that the participants were over 60 years old and had low levels of physical activity according to the criteria of participant selection. The HT group

Table 5  Pre- and Posttraining Midthigh Cross-Sectional Areas (cm²) in the Three Groups (M ± SD)

<table>
<thead>
<tr>
<th>Muscle group</th>
<th>HT (n = 11)</th>
<th>MT (n = 12)</th>
<th>C (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
<td>pre</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>49.27 ± 13.37</td>
<td>53.79 ± 13.90</td>
<td>50.49 ± 17.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48.85 ± 10.81</td>
<td>52.83 ± 13.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47.83 ± 12.15b</td>
<td>47.59 ± 10.81</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>56.19 ± 18.89</td>
<td>57.01 ± 14.16</td>
<td>51.07 ± 12.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46.99 ± 10.90</td>
<td>47.83 ± 10.81</td>
</tr>
<tr>
<td>Total muscle</td>
<td>125.41 ± 35.29</td>
<td>125.06 ± 24.06</td>
<td>125.55 ± 24.41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>125.55 ± 24.41</td>
<td>125.55 ± 24.41</td>
</tr>
<tr>
<td>Subcutaneous fat</td>
<td>130.37 ± 49.62</td>
<td>127.52 ± 50.15</td>
<td>119.00 ± 55.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>119.67 ± 55.31</td>
<td>119.67 ± 55.31</td>
</tr>
</tbody>
</table>

Note. HT = high-resistance-training group; MT = moderate-resistance-training group; C = control group.

*p < .001; significant differences between pre- and posttraining. *p < .05; significant differences between pre- and posttraining. *p < .001; significant differences between HT and C. *p < .001; significant differences between MT and C. *p < .001; significant differences between HT and MT. *p < .001; significant differences between HT and MT. *p < .001; significant differences between HT and MT.
increased 1-RM strength in the upper and lower body by 66% and 78%, respectively, and CSA of the midthigh total muscle increased by 10.1%. Previous studies of high-resistance-training programs in older adults have produced larger or smaller relative changes in muscle strength and mass. Frontera et al. (1988) found a much larger increase in 1-RM strength in knee extension (107%) and flexion (227%), and they reported a similar increase in CSA of the total muscle of midthigh (11.4%) after a 12-week resistance-training program at 80% 1-RM. Welle et al. (1994), using a similar training protocol, reported smaller increments in 1-RM knee extension (32%) and a smaller increase in CSA of the quadriceps (6%).

The MT group showed significant improvements in upper and lower body muscle strength and mass in the midthigh. Moritani and deVries (1980) trained older men at 66% 1-RM for 8 weeks and reported gains of 23% in elbow-flexor 1-RM strength. They concluded that neural factors alone might be responsible for the increases in strength seen in older adults, but they used anthropometry to evaluate the changes in muscle size, not direct depiction of the muscle. In another recent study, Taaffe et al. (1996), using a low-intensity resistance-training program reported a 41.5% gain in 1-RM leg press after a 52-week training period. In the present study, a moderate-intensity resistance-training program at 60% 1-RM was carried out and produced a 7.1% significant increase in midthigh CSA total muscle area. There are few studies in the literature that have focused on determining whether moderate-intensity resistance training causes positive adaptations in muscle function and structure in the elderly. This study shows the actual effects of a moderate training program on muscle mass, using computed tomography scans for the direct evaluation of the hypertrophy. In addition, the results confirm that an aging muscle reacts with hypertrophy after a 12-week moderate-intensity resistance-training program in inactive older adults. Moreover, other studies used complex resistance-training programs (with high intensity and high number of repetition) and found various increases in muscle strength and mass (Hurley et al., 1994; Treuth et al., 1995, 1994).

Both training groups increased peak torque in knee extensors and flexors at 60°/s and 180°/s, respectively. This is similar to results of previous studies in which the increments in peak torque were lower than those in 1-RM strength (Brown et al., 1990; Frontera et al., 1988). When a combination of resistance machines and isokinetic exercises was used, however, the increments in peak torque were larger (Roman et al., 1993). According to Frontera et al. (1988), the greater improvements in 1-RM strength relative to peak torque are a result of evaluation of 1-RM, which shows the same technique and kinetic patterns with the resistance exercises the participants were doing. Furthermore, in the present study there was no correlation between 1-RM strength and peak torque because of neural adaptations that were created because of the specialized type of strength training and that are particularly intense in the evaluation of strength using the 1-RM method. The neural factors improve their activity through increased engagement of motor units and continuous use of more and more motor units, which result from the increase in muscle activation (Moritani & deVries, 1980).

In the present study, we attempted to control the large gains in strength at the beginning of training resulting from coordination and motor learning by having the participants perform three training sessions with little resistance before we initially evaluated their 1-RM strength. Although with this familiarization period the
decrease in strength gain was expected, this period helped indicate the actual
effects of resistance training. In addition, it might explain the correlation between
changes in knee-flexor 1-RM strength and hamstring CSA from HT and MT,
respectively.

The comparison of training groups showed that the high-resistance-training
program caused larger improvements in 1-RM strength of the upper and lower body,
in peak muscle torque of the right knee flexors at 60°/s and 180°/s, and in midthigh
CSA of total muscle area than those of the moderate-resistance training program.
A recent study in adults age 60–83 years by Vincent et al. (2002) reported
improvements in 1-RM body strength of 17.2% and 17.8% after a 24-week period
of low- (50% 1-RM) and high- (80% 1-RM) resistance training, respectively. This
limited improvement might result from the fact that participants in that study
performed only one set per exercise, so it is possible that the number of sets was not
sufficient to cause larger gains in muscle strength in high- than in low-resistance
training. In addition, note that in the present study the resistance-training program
was short in duration (12 weeks), and it is not known what differences in muscle
strength and mass would appear over a longer period of time between high- (80%
1-RM) and moderate- (60% 1-RM) resistance training. HT was more beneficial to
muscle strength and muscle mass than was MT, but MT also improved muscle
strength and mass, and over the long run this might improve compliance of and
acceptability to older adults.

From the present study, it is obvious that the intensity of resistance training
is a significant factor in improving muscle function in the elderly (Porter, Vandervoort,
& Lexell, 1995). Neuromuscular-system loading using submaximal or maximal
muscle contractions causes larger adaptations in muscle structure and function than
using moderate contractions against a resistance (Blimkie, 1992). The physiologi-
cal demands of the neuromuscular system are larger after a high-intensity training
program (Blimkie).

With aging, muscle mass diminishes, and this atrophy is accompanied by a
reduction in muscle strength (Kallman, Plato, & Tobin, 1990). The consequences
of this atrophy are functional limitations, increased risk of falls, and decreased
mobility (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995). The present
study demonstrates that high- and moderate-resistance-training programs increase
strength and mass in the elderly, with high-intensity resistance training causing
greater improvements than moderate-intensity training.

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References
prescription (5th ed.). Baltimore: Williams & Wilkins.


