High-resistance versus variable-resistance training in older adults

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ABSTRACT


Purpose: The purpose of this study was to compare the effects of high-resistance (HR) training, 3 times·wk⁻¹ at 80% maximum strength (1RM) with 3 times·wk⁻¹ variable-resistance (VR) training (once-weekly training at 80%, 65%, and 50% 1RM) in older adults.

Methods: The study was a 6-month resistance training intervention conducted in the Birmingham Alabama metropolitan area, and included healthy volunteer men and women over the age of 60. Twenty-eight subjects were assigned randomly to two training groups. Eight volunteers served as controls. Before and after 25 wk of training, body composition was measured by densitometry; strength by isometric tests; and difficulty in performing daily activity tasks (DAT) by measuring heart rate, oxygen uptake, electromyography, and perceived exertion. In addition, 1RM strength was measured every 25 d throughout the 6 months of training. Repeated measures ANOVA and paired t-tests with Bonferroni corrections for additive alpha were used to analyze the data.

Results: The control group did not significantly change in any study parameter. No significant change in body weight occurred for any group. However, the HR and VR groups increased fat free mass (FFM) similarly (1.8 kg and 1.9 kg, respectively). Both training groups increased strength significantly, without significant differences in change. No significant change in oxygen uptake occurred during DAT. However, there was a significant time effect for heart rate and perceived exertion. Greater decrease in normalized integrated electromyography during the carry task was found in the VR group over the HR and control groups.

Conclusion: Despite similar increases in strength and fat free mass, the VR group decreased difficulty of performing the carry task more than the HR group. These data suggest that larger improvements in DAT may be achieved if frequency of high-resistance training is less than 3 times·wk⁻¹. Key Words: STRENGTH, DAILY ACTIVITY TASKS, AGING, RESISTANCE TRAINING

A number of studies have shown that older adults increase strength and muscle size after resistance training (5,8,18,26,30). It is generally accepted that training at exercise intensities below 60% of maximal voluntary strength will be associated with relatively small increases in muscle strength, and the optimal rate of improvement is found when training resistance is between 80% and 90% of maximum (1). Most of these studies report relatively high training intensities of approximately 80% of the maximum weight that can be lifted one time (1RM) (5,7,8,22).

We have previously reported that strength increases were inversely related to percent of 1RM used in training by women 60–77 yr old (17). The resistance training program consisted of two sets of 12 repetitions for 10 exercises performed 3 times·wk⁻¹ for 16 wk. The exercise resistance for the individual subjects varied between 50% and 80% of 1RM. These inverse relationships between increased strength and exercise resistance were independent of initial strength and age, suggesting those women who were training at the higher resistance may have been adapting more slowly to training stress. Since older muscle may take longer to recover after strenuous exertion (19), we hypothesized that training 3 times each week at a high resistance would offer older adults insufficient time to recover adequately. Previous research has shown, at least in younger subjects, that training adaptations are enhanced for programs with frequencies greater than 2 times each week (11–14). It is possible that variations in exercise resistance on different days of the week may allow adequate recovery from high-resistance training while maintaining exercise continuity between exercise days. Therefore, it is hypothesized that training with varying resistance across 3 training days each week would result in larger increases in strength and muscle size in older adults than training at high resistance 3 times each week.

Another very important consideration in evaluating the efficacy of resistance training programs is how the training affects the ability to perform daily activity tasks. Resistance training has been shown to increase walking speed and decrease the difficulty of climbing stairs, standing from a chair, and carrying a simulated box of groceries (16,24,25,28). To our knowledge, no one has evaluated the effects of varying exercise resistance on changes in strength,
muscle mass, and difficulty during daily activity tasks in older adults.

It is hypothesized that variations in exercise resistance on different training days during the week would allow for more improvement in strength in older adults than training at a high resistance 3 times each week (i.e., 80% 1RM 3 days each week). Therefore, the purpose of this study was to compare the effects of 3 d-wk⁻¹ training at 80% 1RM (high-resistance (HR) group) with a training model in which subjects trained each exercise at a different exercise resistance, 50%, 65%, and 80% 1RM each of the 3 weekly training days (variable-resistance (VR) group).

METHODS

Subjects

Fifteen women and 15 men, 61–77 yr old, participated in a 25-wk resistance training program. Although all the subjects completed the study, data from one woman (HR group) and one man (VR group) are not reported because injury from unrelated activities caused the subjects to miss over 20% of the training sessions. Subjects had a normal body mass index (BMI) and were free of any metabolic disorders and medications that may affect energy expenditure. All subjects were nonsmokers and weight-stable (defined as within 1% body weight during the previous 4 wk). None of the subjects had ever participated in resistance training before and all subjects except one were sedentary (defined as exercising less than once per week for the past year). One male subject was a runner and ran between 6 and 7 miles-wk⁻¹ in three to four exercise sessions. He continued running at the same level throughout the course of the study. All the women were postmenopausal. Institutional Review Board approved written informed consent was obtained before participation in the study in compliance with the Department of Health and Human Services Regulations for Protection of Human Research Subjects and the policy statement of Medicine and Science in Sports and Exercise regarding the use of human subjects. Subjects were randomly assigned to either the HR (eight men and six women) or the VR (six women and eight men) group. Subjects were evaluated before and after 25 wk of resistance training. An additional four women and four men volunteered to serve as controls and were evaluated on body composition, isometric strength tests, and daily activity tasks two times, 6 months apart. Control subjects were not evaluated on the 1RM tests.

Strength Testing

1RM test. For the first three exercise sessions, the subjects trained with a resistance that allowed them to become familiar with both the equipment and the exercises. On the fourth session, the subjects performed a 1RM test on the leg press, chest press, elbow flexion, and seated press using methods previously described (15,20,32). 1RM testing was repeated every 25 d throughout the remaining 25 wk of training.

Isometric strength tests. Maximal elbow flexion and knee extension strength were measured using previously described methods (16). During the elbow flexion test, the subject stood with arms fixed to the side wearing a harness designed to limit shoulder movement during the task. Force was measured on the right forearm at the level of the styloid process. Subjects were asked to attempt to flex the elbow as hard as possible with the elbow fixed at a position of 110° elbow flexion. Integrated electromyography (IEMG) of the biceps was measured during the isometric elbow flexion test. Isometric knee extension strength was obtained at 110° extension while subjects were seated and the legs and upper torso were strapped to the chair to prevent hip movement. Force was measured at the ankle. Subjects were instructed to attempt to straighten the leg as hard as possible. Force was measured with a universal shear beam load cell (LCC 500, Omega Engineering, Stamford, CT). A digital transducer (DP2000, Omega Engineering) gave instantaneous force measurement feedback to the subjects. After three practice trials, three maximal isometric contractions were recorded. Sixty seconds of rest was allowed between trials. The average of the two highest maximal forces generated was used for statistical purposes.

EMG Analysis

Bipolar EMG electrodes were placed over the biceps brachii muscle. The ground wire was applied to the ear lobe. The landmarks for placement of the EMG electrodes were identified according to standard procedures (4). Bipolar silver-silver chloride (AG-AG/CL) SensorMedics (Yorba Linda, CA) EMG surface electrodes were used, with the center of each electrode separated by 2.5 cm in a longitudinal line along the muscle. All leads had an impedance of less than 10 kΩ. The raw EMG signal was processed through a Grass Polygraph DC Amplifier (Grass Instruments Company, Quincy, MA) and integrated with a time constant of 100 ms and sampled at a rate of 100 Hz. The IEMG was stored in a Gateway (North Sioux City, SD) 2000 DX-66 Computer System LabVIEW program (National Instruments, Austin, TX) for Windows 3.1 (Microsoft, Redmond, WA).

Selected Daily Tasks

Selected daily tasks were walking, climbing stairs, and a weight-loaded walking test. The weight-loaded walking test involved walking for 4 min on a treadmill (Quinton Instruments, Seattle, WA) at a constant speed of 2.0 mph and 0% grade while carrying a load that weighed 30% of the subject’s maximum isometric elbow strength. The weighted load was held by the right arm with the elbow at a fixed position of 110° flexion. A shoulder harness was used to keep the humerus fixed in a position parallel with and touching the side of the trunk. Regular feedback from electromiometer readings was used to maintain the 110° elbow position throughout the test. EMG activity of the biceps brachii muscle was measured 20 s, 120 s, and 230 s after the test began. IEMG during the weight-loaded walking test was normalized (nIEMG) by dividing the IEMG during weight-
loaded oxygen consumption from the maximal elbow flexion test.

Submaximal oxygen uptake (VO₂), heart rate (Polar Beat heart rate monitor, Polar Electra Inc., Woodbury NY), and perceived exertion (PE) were obtained in the steady state, during the third and fourth minutes. Oxygen consumption and carbon dioxide production were measured continuously via open circuit spirometry and analyzed using a Sensor-Medics metabolic cart (Model #2900). Before each test, the gas analyzers were calibrated with certified gases of known standard concentrations. Average VO₂ for the third and fourth minutes was considered metabolic economy. Submaximal VO₂, heart rate, and PE were also measured during the third and fourth minutes of steady-state walking at 3 mph and climbing stairs (60 steps-min⁻¹ with 7-in stairs).

**Body Density**

Body density was evaluated with the BOD POD version 1.69 (Body Composition System, Life Measurement Instruments, Concord, CA) as we have previously described (6). Calibration of chamber pressure amplitudes occurred prior to all tests using a 50-L calibration cylinder. While wearing a tight-fitting swimsuit, the subject’s raw body volume was determined in the chamber. In a separate step, thoracic gas volume measurement was measured. Thoracic gas volume measurement required the subject to sit quietly in the BOD POD and breathe through a disposable tube and filter that was connected to the reference chamber in the rear of the BOD POD. After four or five normal breaths, the airway was occluded during midexhalation and the subject was instructed to make two quick light pants. The Db from the BOD POD was calculated as follows: 
\[ Db = \frac{\text{subject mass} + \text{0.40 thoracic gas volume (VTG)} - \text{surface area artifact (SAA)} \times 0.40 \text{VTG}}{\text{subject mass}} \]

**Resistance Training**

Resistance training took place at a local fitness center where the subjects exercised for 25 wk, 3 times-wk⁻¹ for approximately 45 min-session⁻¹. Each session was supervised by investigators trained in the procedures, and average adherence rate of the subjects was over 90% and was not significantly different between exercise groups. Each exercise session began with a 5-min warm-up on either a bicycle ergometer or treadmill at a low work level followed by 10 static stretches. The resistance exercises were elbow flexion, elbow extension, seated row, seated overhead press, back extension on Cybex Systems equipment (Rokonkoma, NY); leg extension, leg curl, and bench press on Keiser K-300 pneumatic variable resistance machines (Fresno, CA); and bent leg sit-ups (15–25 repetitions). Twenty-five bent leg sit-ups were also done. In addition, seven of the subjects in both the HR and VR groups did squats and seven did leg presses. Subjects were instructed to complete two sets of 10 repetitions (or until failure, whichever came first) in all exercises with a 2-min rest between each set. Three initial training sessions were to allow subjects to become familiar with the equipment and exercises, after which subjects followed either the HR or VR training protocols. The HR group trained at 80% of 1RM each training day and the VR group trained at 50%, 65%, and 80% 1RM across the 3 weekly training days. Resistance of training for the VR group varied across the 10 exercises so that no more than three exercises were performed at any percentage any day. Progression was incorporated into the program with daily training log evaluations (resistance was increased the next training session if two sets of 10 repetitions were completed for any exercise performed at 80% 1RM) and 1RM testing every 25 d.

**Statistical Analysis**

Two (pre vs post) × 3 (control vs HR vs VR) ANOVA with repeated measures on the first factor was run to determine differences on the body composition, the isometric strength measures, and the results of the selected daily tasks. Two (HR vs VR) × 7 (delta 1RM, pre-1RM subtracted from each of the seven 1RM measures every 25 d) ANOVA with repeated measures on the first factor was run to determine differences for 1RM across the 25 wk of training. Paired t-tests were conducted to examine specific post hoc contrasts using Bonferroni adjustments. Alpha was set at 0.05 for all tests.

**RESULTS**

The main purpose of this study was to compare the effects of the HR training model with VR training model in older adults. A 2 (training group) × 2 (gender) × 2 (pre-post) ANOVA with repeated measures on the pre-post variable showed no three-way interaction for any variable, indicating men and women responded to the two training models similarly. Therefore, the data for men and women are pooled to optimize statistical power. Body composition and isometric strength results are contained in Table 1. Subjects did not change weight, but significant ANOVA interactions and post hoc tests indicate the VR and HR groups decreased percent fat and FM, and increased FFM, maximal elbow flexion force, and maximal knee extension force significantly. Post hoc results also indicated that gain scores were not significantly different between the VR and HR groups for any variable. Post hoc tests indicate the control group did not significantly change on any variable.

A significant training effect was observed for all four delta 1RM tests (press, 26.6%; bench press, 28.5%; arm curl, 63.7%; and leg press, 37.1%). However, no significant
resistance or training by resistance interaction was found for any of the four delta 1RM tests (Fig. 1).

Table 2 shows the results of the selected daily tasks. The control group did not significantly change on any variable. Oxygen uptake and ventilation during the tasks did not change significantly for either training group after the training. However, heart rate and perceived exertion during the tasks decreased significantly after the training. A significant interaction at 20 s and 230 s with significance approached at 120 s (P < 0.13) occurred for the carry task. Post hoc tests indicate the VR group decreased nIEMG significantly but the control and HR groups did not change significantly after training.

**DISCUSSION**

The results of this study support in older adults the use of variable-resistance training for reducing muscle activation needed to carry a box. The primary purpose of this study was to compare the efficacy of two different training models, HR (80% 1RM 3 times-wk⁻¹) versus VR (80%, 65%, and 50% 1RM training each week) for strength and body composition in older adults. Although both groups increased FFM and strength and decreased heart rate and perceived exertion during the tasks of daily living, contrary to our original hypothesis no significant difference was observed between the groups for increases in any strength measure. However, the VR group decreased relative muscle activation and tended to decrease perceived exertion more during the selected daily tasks than the HR group. Despite similar increases in FFM and strength, these data suggest that VR may be better than HR training for decreasing muscle activation needed to carry objects in older adults.

Almost identical increases in FFM of about 2 kg occurred in the two exercise groups. Since little change in weight occurred for the two exercise groups, the increases in FFM were accompanied by decreases in percent fat of over 2%. These changes in FFM were similar to those reported previously (2,31) and are consistent with the increases in muscle cross-sectional area previously reported (5,8,22,31).

The majority of studies comparing frequency of training in young adults have found that more frequent training generally produces greater increases in strength than less frequent training (11–14). In one exception, Carroll et al. (3) reported no statistically significant difference in strength gain between 2 and 3 times-wk⁻¹ resistance training. However, the sample size was small (five in one group and six

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**TABLE 1. Pre-post resistance training, body composition, and isometric strength variables.**

<table>
<thead>
<tr>
<th></th>
<th>Pre (N = 8)</th>
<th>Post (N = 8)</th>
<th>Pre (N = 14)</th>
<th>Post (N = 14)</th>
<th>Pre (N = 14)</th>
<th>Post (N = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>65.9 ± 4.0</td>
<td>67.3 ± 4.7</td>
<td>65.9 ± 4.3</td>
<td>69.2 ± 12.3</td>
<td>68.8 ± 12.2</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.3 ± 24.1</td>
<td>75.0 ± 11.4</td>
<td>75.4 ± 12.3</td>
<td>75.4 ± 12.3</td>
<td>74.6 ± 3.2</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>25.1 ± 5.7</td>
<td>24.7 ± 3.2</td>
<td>24.7 ± 3.3</td>
<td>24.6 ± 3.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td>32.2 ± 7.7</td>
<td>28.9 ± 11.0</td>
<td>26.7 ± 11.3</td>
<td>35.1 ± 9.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>49.3 ± 15.3</td>
<td>53.2 ± 10.8</td>
<td>55.1 ± 11.6</td>
<td>44.8 ± 10.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FM (kg)</td>
<td>23.5 ± 11.1</td>
<td>21.7 ± 9.8</td>
<td>20.3 ± 10.0</td>
<td>24.3 ± 8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KN Max Force (N)</td>
<td>419 ± 142</td>
<td>502 ± 160</td>
<td>620 ± 216*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EF Max Force (N)</td>
<td>213 ± 89</td>
<td>255 ± 77</td>
<td>288 ± 95*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BMI, body mass index; FFM, fat free mass; FM, fat mass; KN Max Force, knee extension maximal isometric force; EF Max Force, Elbow flexion maximal isometric force; ψ, Significant time by group interaction (P < 0.05).

* Significant pre-post post hoc change with training (P < 0.05).

A significant group difference was found at the P < 0.05 level only for elbow flexion maximal isometric force.

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**FIGURE 1—Percent change in 1RM strength across the 25 wk of training. Significant time effect was found for all four tests but no group × time interaction effect was found for any test. Significance was set at P < 0.05. The solid line represents the VR group and the dotted line represents the HR group.**
TABLE 2. Pre-post changes for select daily tasks.

<table>
<thead>
<tr>
<th></th>
<th>Control (N = 8)</th>
<th>HI (N = 14)</th>
<th>VI (N = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>VO₂ (mL O₂·kg⁻¹·min⁻¹)</td>
<td>13.5 ± 1.5</td>
<td>13.7 ± 1.4</td>
<td>13.4 ± 2.4</td>
</tr>
<tr>
<td>Heart rate (beats·min⁻¹)</td>
<td>115 ± 16</td>
<td>112 ± 15</td>
<td>112 ± 16</td>
</tr>
<tr>
<td>V₅ (L·min⁻¹)</td>
<td>33.7 ± 15.7</td>
<td>31.6 ± 12.3</td>
<td>33.2 ± 9.5</td>
</tr>
<tr>
<td>PE</td>
<td>11.6 ± 2.7</td>
<td>10.9 ± 2.5</td>
<td>13.3 ± 2.0</td>
</tr>
<tr>
<td>% Max nIEMG₁</td>
<td>46 ± 9</td>
<td>51 ± 22</td>
<td>49 ± 12.2</td>
</tr>
<tr>
<td>% Max nIEMG₂</td>
<td>45 ± 12</td>
<td>47 ± 16</td>
<td>58.2 ± 18.4</td>
</tr>
<tr>
<td>% Max nIEMG₃</td>
<td>45 ± 17</td>
<td>49 ± 23</td>
<td>57.9 ± 17.4</td>
</tr>
</tbody>
</table>

VO₂, V₅, and PE, average oxygen uptake, ventilation, and perceived exertion during climbing stairs, walking at 3 mph, and carrying a simulated box of groceries; nIEMG₁, nIEMG measured 20 s after the carry task began; nIEMG 2, nIEMG measured 120 s after the carry task began; nIEMG 3, nIEMG measured 230 s after the carry task began; ψ, significant time by group interaction (P < 0.05).

* Significant pre-post post hoc change with training (P < 0.05).

in another) with the percentage increase of 32% for 3 times-wk⁻¹ versus 22% for 2 times-wk⁻¹. Therefore, it may be advantageous to keep training frequency at 3 times-wk⁻¹. However, we had previously reported an inverse relationship between training resistance and increase in 1RM in older women who resistance-trained for 16 wk, suggesting less than optimal training adaptations for the older women training at high resistance 3 times-wk⁻¹ (17). In addition, when older adults trained 3 times-wk⁻¹, rate of strength gain was not different when training at a high resistance versus moderate resistance (21,27). Taken together, these results suggest that older adults may not respond to high-resistance training 3 times-wk⁻¹ as well as younger adults (21,27), perhaps because of a slower recovery in muscle after strenuous exertion (19). Varying the resistance across 3 training days was one way to maintain the continuity of training frequency while adjusting resistance to improve recovery.

It is difficult to explain why VR training would be associated with reduced nIEMG while carrying a box but not greater increases in strength than the HR group. The decrease was substantial, 23% to 28% during a 4-min carry task, and similar to what was shown previously, an average of 36% (16), and suggests that the difficulty for performing this task was substantially decreased. We had originally hypothesized the VR group would improve more in both strength and the selected daily tasks because of an inability of the older subjects to adapt to the combination of relatively high training volume and high resistance used in the HR group. However, all subjects improved strength substantially, and no difference in strength increase was found between the groups. We observed an attenuated improvement in nIEMG during the carry task in the HR group compared with the VR group. Other high-resistance strength training studies designed to induce an overtraining response have found an attenuation of performance in activities requiring motor control without an attenuation of strength (9,10). It can be argued that relative muscle activation on standard tasks, such as the carry task in this study, would be related to ability to maximally perform these tasks (23).

Strength increases after any training program are the consequence of motor learning as well as physiologic changes in muscle. One possibility is that the physiologic potential for developing force was impaired in the HR group during the last weeks of training. Motor learning of the specific strength task may have compensated for any physiologic decrease in maximal strength potential. Fry et al. (9) have demonstrated that this is definitely possible. In a study of overtraining during high-resistance strength training, control subjects increased voluntary isometric strength but did not change electrically stimulated strength over 2 wk, suggesting the control subjects increased motor learning for the specific task but did not change physiologic potential for strength. The overtrained subjects decreased electrically stimulated strength but did not change in voluntary strength, suggesting a decrease in strength potential (electrically stimulated strength) was compensated for by an increase in motor learning of the strength task. In the current study, subjects were 1RM tested on the same movements used in training. Since the HR group trained at a high resistance more frequently than the VR group, it is possible that a decrease in maximal strength potential in the HR group may have been compensated for by greater motor learning. Whatever the reason, in older adults strength adaptations were not compromised when subjects trained at high resistance 3 times-wk⁻¹; however, improvements in the percent of maximal muscle electrical activity needed to perform the carry task were reduced compared with subjects training with variable resistance.

Strength was evaluated every 25 d during the study, with strength continuing to increase even during the last measurement period (Fig. 1), suggesting the subjects may still have been capable of further increases. Although several studies have shown increases in strength after 12 or more months of training (21,22,27), most have not evaluated strength frequently enough during the study to determine if older adults can continue to increase strength after 6 months of training. Pruitt evaluated strength frequently but only reported pre- and posttraining values. However, one group that has evaluated strength frequently in a long-term study indicated strength adaptations can continue for well over 6 months (22). It is possible that increases in ability to perform daily activity tasks would be further improved with an extension of training time. It is also possible that if the attenuated improvement in performing daily activity tasks found in the HR group was because of an inability of the older adults to adapt to the high-resistance training, more pronounced differences between the two training groups may have been found as training duration increased.
CONCLUSION

This study adds to the list of studies demonstrating resistance training in older adults can be used to increase muscle mass and strength and make performance of daily tasks easier. It also suggests that older adults who train at variable resistance on different days of the week may reduce difficulty in carrying more than older adults who train at a high resistance 3 times wk\(^{-1}\).

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