Mixed-methods resistance training increases power and strength of young and older men

ROBERT U. NEWTON, KEIJU HÄKKINEN, ARJA HÄKKINEN, MATT MCCORMICK, JEFF VOLEK, and WILLIAM J. KRAEMER

The Human Performance Laboratory, Ball State University, Muncie, IN; Neuromuscular Research Center and Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, FINLAND; Department of Physical Medicine and Rehabilitation, Central Hospital, Jyväskylä, FINLAND; Center for Sports Medicine, Pennsylvania State University, University Park, PA; and Neag School of Education, University of Connecticut, Storrs, CT

ABSTRACT

NEWTON, R. U., K. HÄKKINEN, A. HÄKKINEN, M. MCCORMICK, J. VOLEK, and W. J. KRAEMER. Mixed-methods resistance training increases power and strength of young and older men. Med. Sci. Sports Exerc., Vol. 34, No. 8, pp. 1367–1375, 2002. Purpose: This study examined the effects of mixed-methods resistance training on young and older men to determine whether similar increases in muscle power were elicited. Methods: Effects of 10 wk of a periodized resistance-training program designed to increase muscle size, strength, and maximal power on isometric squat strength, time course of force development, muscle fiber characteristics, and muscle activation (iEMG), as well as force and power output during squat jumps, were compared in young (YM, 30 ± 5 yr, N = 8) and older men (OM, 61 ± 4 yr, N = 10). Results: Isometric squat strength was higher in the YM compared with OM at all testing occasions and increased over the training period by 23 ± 15% and 40 ± 42% for the YM and OM, respectively. The early phase of the force-time curve was shifted upward in both groups over the course of the training. During the squat jumps, the YM produced higher force and power output at all test occasions and at all loads tested compared with the OM. The YM increased power output by 15 ± 14%, 33 ± 16%, and 26 ± 12%, and the OM by 7 ± 5%, 36 ± 23%, and 25 ± 16% for the 17 kg, and 30% and 60% 1RM loads, respectively. Conclusion: Although the results of this study confirm age-related reductions in muscle strength and power, the older men did demonstrate similar capacity to young men for increases in these variables via an appropriate periodized resistance-training program that includes rapid, high-power exercises. Key Words: AGING, RATE OF FORCE DEVELOPMENT, ELECTROMYOGRAPHY

It has been reported that age-related decreases in maximal power production take place to a greater degree than that of maximal muscle strength (11,17). For example, Metter et al. (26) report that muscle power declines at a 10% faster rate than strength in aging men. Further, Skelton et al. (31) have shown that isometric strength declines 1–2% per annum but muscle power declines approximately 3.5% per annum in men over 65 yr old. With aging, muscle atrophy results from a gradual process of fiber denervation with loss of some fibers and atrophy of others (7,24). Fast fibers show more denervation and atrophy than slow fibers (7), and this atrophy, particularly of the fast-twitch fibers, is most likely due to a combination of the effects of aging and physical activity levels which have declined to a chronically low intensity (6). Faulkner et al. (8) have demonstrated that the peak power output of Type II fibers is four-fold that of Type I fibers. Therefore, it is expected that a selective reduction in the percentage and area of Type II fibers will result in a considerable loss of power output with aging. A loss of muscle power has been shown to have profound effects on functional activities, such as speed of walking up stairs, standing up from a chair, and gait speed (1). Given that recovering balance after a trip or slip requires the application of a large amount of force in a short period of time, muscle power should be a significant factor in the risk of falling (6). This hypothesis is supported by previous research that demonstrates a clear relationship between maximal muscle power and a static balance test (1,17).

It is clear that heavy-resistance training has profound effects on muscle size, and strength in older people (10,33) and that power can also be increased using traditional resistance training (19). However, several studies in younger adults have shown differential effects of explosive versus heavy-resistance training with regard to the development of muscle power and the ability to generate force rapidly (14,30). For example, in a study involving athletes, maximal power training involving ballistic movements was found to be more effective than traditional resistance training for increasing power performance (30). The question remains as to whether older people tolerate exercises involving high-power output and whether they exhibit similar training adaptations toward faster and more powerful performance (5). Furthermore, as increased strength and muscle size are also important goals of resistance-training programs designed for older people, can these three components be developed simultaneously, and how are these changes mediated in terms of neural and muscle fiber adaptations?

The purpose of this study was to examine the effects of a 10-wk periodized resistance-training program whose program variables were manipulated to simultaneously train for...
three dimensions of muscle characteristics: hypertrophy, maximal force production, and maximal power output. It was hypothesized that such a program would lead to increases in maximal strength and power production in both younger and older men.

METHODS
Experimental Design and Approach to the Problem

To determine whether a mixed-model periodized resistance-training program could improve strength and power over a short-term training period in young and older men, a two-group, pre-post design was used. In addition, training background and activity levels were approximately matched to allow for more equitable comparisons. The total duration of the study was 13 wk. The subjects were tested on five different occasions using identical protocols. The first 3 wk were used as a control period during which no strength training was carried out nor any other changes to the subjects’ normal patterns of work and recreational physical activities. Thereafter, the subjects began a supervised strength training intervention for a period of 10 wk. The measurements were taken during the control and experimental training period at weeks −3, 0, 3, 6, and 10.

Subjects

Eighteen healthy men, drawn from two age groups, young men (YM) (30 ± 5; N = 8) (mean age ± SD yr) and old men (OM) (61 ± 4; N = 10), volunteered as subjects for the study. This study was part of a larger training study of which a previously published manuscript (16) has already reported hypertrophy of the trained muscles. The subjects were carefully informed about the design of the study with specific information on possible risks and discomfort that might result. Thereafter, the subjects signed a written consent form before participation in the project. The study was approved by The Pennsylvania State University, Institutional Review Board for use of Human Subjects. Medical control and quantification of the physical activity (via a questionnaire) revealed that all subjects were healthy and habitually physically active. To keep fit, they had taken part in various recreational physical activities, such as walking, jogging, aerobics, or biking, but none of the subjects had any background in regular strength training or competitive sports of any kind. None of the subjects were taking medications that would have affected performance. No subjects were injured during either the testing or training protocols. Only those subjects with 100% compliance to the training program (i.e., all sessions completed) are included in this report. The physical characteristics of the two subject groups before and after the training period are presented in Table 1.

Testing Protocols

Anthropometry. All anthropometric measurements were obtained by the same investigator on the right side of the subjects’ body. Skin-fold thicknesses were obtained with a Harpenden skin-fold caliper (H. E. Morse Co., London, UK, 10 g·mm⁻¹ constant pressure) at the chest, mid-axillary, abdomen, suprailiac, subscapula, triceps, and thigh. Repeated trials were performed until two measures within 1 mm were obtained, with the mean of the two measures utilized. The Jackson and Pollock (17) seven-site equation was used to estimate body density, and percent body fat was subsequently calculated.

Isometric squat. Maximal isometric force and measures of the force-time characteristics were measured while the subject attempted to push upward against a fixed bar positioned across the shoulders. The bar of a Pyrometric Power System (PPS) (Norsearch, Lismore, Australia) described by Newton et al. (30) was used and positioned at a height such that the subject’s knee and hip angles were 90 and 110° degrees, respectively. The bar was positioned at the appropriate height using adjustable length chains secured at each end, and resistive force transducers (Entran, NJ) were placed in series with each chain to record the tensile force being generated. The subjects were instructed to push upward against the bar with their maximal force as fast as possible during a period of 2.5–5.0 s. Three to four maximal trials were completed for each subject until no further increases in peak force were produced. Maximal peak force was defined as the highest value of the force (N) recorded during the pushing movement. The force-time analysis included the calculation of the absolute force produced 0–100, 100–500, 500–1500, and 1500–2500 ms from the onset of force. The time to reach relative force levels of 30, 60, 90, and 100% were also calculated (11).

Squat jump. Squat-jump performance was assessed using the PPS under loads of bar weight (17 kg), and 30% and 60% of the subject’s previously determined 1RM. The 1RM data have been presented previously (22). Subjects were placed in a position of 90° knee flexion with the heels directly under the bar of the PPS. They were then instructed to push upward while attempting to jump for maximal height. Bar displacement and mass were recorded with subsequent calculation of bar velocity and acceleration, as well as the force and power applied to the bar. Performance in the squat jump was quantified by two variables, power and force. Power was calculated as the highest instantaneous power output during, and force was calculated as the highest force output during the jump. Previous research has shown

<p>| Table 1. The physical characteristics of the two subject groups before and after the training period. |</p>
<table>
<thead>
<tr>
<th>Age</th>
<th>Young Mean</th>
<th>Young SD</th>
<th>Old Mean</th>
<th>Old SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>29.75</td>
<td>5.34</td>
<td>61.00*</td>
<td>4.40</td>
</tr>
<tr>
<td>Height</td>
<td>177.17</td>
<td>5.21</td>
<td>177.09</td>
<td>7.18</td>
</tr>
<tr>
<td>Pre weight (kg)</td>
<td>88.38</td>
<td>12.34</td>
<td>86.99</td>
<td>13.45</td>
</tr>
<tr>
<td>Post weight (kg)</td>
<td>90.48</td>
<td>13.86</td>
<td>87.32</td>
<td>14.16</td>
</tr>
<tr>
<td>Pre body fat (%)</td>
<td>17.04</td>
<td>6.79</td>
<td>20.41</td>
<td>4.62</td>
</tr>
<tr>
<td>Post body fat (%)</td>
<td>17.73</td>
<td>5.33</td>
<td>21.21</td>
<td>3.89</td>
</tr>
<tr>
<td>Pre lean body mass (kg)</td>
<td>72.73</td>
<td>6.80</td>
<td>69.20</td>
<td>11.12</td>
</tr>
<tr>
<td>Post lean body mass (kg)</td>
<td>73.88</td>
<td>7.67</td>
<td>68.76</td>
<td>11.31</td>
</tr>
</tbody>
</table>

* Significant difference between young and old groups; no other significant differences between groups or pre to post training.
these two variables to be highly indicative of performance in a ballistic activity, such as jumping (30).

**Electromyography.** Electromyographic (EMG) activity during the isometric squat test was recorded from the vastus lateralis (VL) and vastus medialis (VM) of the right and left legs. Two active silver/silver chloride, pregelled, disposable surface EMG electrodes (3 M) separated by 2 cm were attached to the belly of each muscle on the approximate position of the motor point area determined using anatomical landmarks, and a third ground electrode was attached to the lateral malleolus. The active electrodes were aligned parallel to the direction of pull of the muscle under investigation determined as a straight line between origin and insertion. Before electrode application, each site was shaved, cleansed with alcohol, and gently abraded. An ink pen was used to mark the positions of the electrodes. These marks were checked at every subsequent training or testing session, and, if necessary, ink was reapplied to ensure they remained visible throughout the entire 13-wk experimental period. These marks were to ensure the same electrode positioning at each test. The EMG signals were amplified using a Noraxon EMG amplifier (Noraxon, Phoenix, AZ), and the amplified myoelectric signals and force transducer output were collected at 500 Hz per channel using a 80486DX computer running Windows 3.11 and a DT21-EZ analog to digital card (Data Translation, Marlboro, MA). The digitized EMG data were stored together with the force on computer disk for later analysis. The average EMG was calculated by full-wave rectification followed by integration (iEMG) over the peak force phase (500–1500 ms) of the maximal isometric action (to calculate maximum iEMG) for each muscle separately and then averaged for further analyses.

**Muscle fiber analysis.** Muscle fiber data were obtained from our previously published manuscript (16), and we have included these data to provide new insights on the relationships to strength and power in this report. Muscle biopsies were obtained before the start of training and about 72 h after the last training session. The samples were obtained from the superficial portion of the vastus lateralis muscle of the dominant leg. Muscle fiber types were divided into four groups (Types I, IIa, IIab, and IIb), and fiber type percentages were calculated from the number of fibers as well as fiber areas in the muscle tissue sections. Greater detail on these methods can be found in our previous report (16).

**Training Program**

The subjects participated in a nonlinear, resistance-training program consisting of three sessions each week for a period of 10 wk. Each training session included the squat, knee extension, and knee flexion exercises on machines; trunk extension and trunk flexion exercises using free weights; and/or bench press or calf raise exercises on machines. During each week, the day’s training protocols (mixed model) were broken into a “hypertrophy day,” a “strength day,” and a “power day.” For the hypertrophy session of the week, the subjects performed sets of 8–10 RM with 1-min rest periods. This format of resistance training has been demonstrated to elicit a large response by the endocrine system and is hypothesized to provide a greater stimulus to increasing muscle size (23). The strength session concentrated on high-intensity resistance training using sets of 3–5 RM. Performing sets of low numbers of repetitions and using a resistance close to the subject’s 1 RM has been shown to produce gains in maximal strength (13). The third training session of the week was designed to specifically increase maximal power output. For this session, the subjects performed the squat and the knee extension exercises with lower loads, but for these exercises the subjects were instructed to complete the concentric phase of the movement “as fast and powerful as possible” for 6–8 reps per set. All the exercises were performed using concentric muscle actions followed by eccentric actions performed in a controlled manner during the “lowering” phase of the movement. Each session the subjects performed 3–6 sets of each exercise. The volume of the training progressively increased throughout the 10-wk of training, a nonlinear, periodized program (9). During the 10-wk training period, the subjects continued taking part in physical activities, such as walking, jogging, or biking, one to two times per week in a similar manner to what they were accustomed to before this experiment.

**Statistical Analysis**

Standard statistical methods were used for the calculation of means, standard deviations (SD), and Pearson product-moment correlation coefficients. The data were then analyzed utilizing analysis of variance (ANOVA) with repeated measures. Univariate ANOVA tests were used for follow-up comparisons, when required, to further examine main effects or interactions. An alpha level of $P \leq 0.05$ was used as the criterion for establishing statistical significance.

**RESULTS**

**Anthropometry.** Body mass and the percentage of body fat remained statistically unaltered during the experimental period in both subject groups (Table 1). A reduction in lean body mass by 0.44 kg was measured for the OM; however, it should be pointed out that this is well within the error of estimation of body composition by the skin-fold technique and does not necessarily represent an actual loss of lean tissue.

**Isometric squat.** Peak force during the isometric squat recorded at week −3 was significantly higher for the YM compared with the OM (Fig. 1). Peak force remained unchanged during the 3-wk control period for both YM and OM (Fig. 1); however, over the 10 wk of resistance training, there was a significant increase in both YM (by 23%) and OM (by 40%) groups (Table 2). No significant differences were found between the YM and OM in the percentage change pre to post.
The OM at all loads tested at both the pre and post training produced significantly higher force output compared with (week 0) to post (week 10) are shown in Table 3. The YM however, over the 10 wk of resistance training, there were significant increases (Fig. 3), and percentage change pre to post training for any of the loads tested (Table 3). There were no significant differences between the YM and OM in the percentage change pre to post for any of the loads tested (Table 3).

**Correlation analysis.** A number of significant correlation coefficients were observed between the subjects’ age, maximal strength, maximal power, and muscle fiber characteristics. Muscle fiber data were obtained from our previously published manuscript (16), and we have included these data to provide new insights on the relationships to strength and power in this report. Peak isometric force and age were significantly correlated at both the pre ($r = -0.747, P \leq 0.01$) and post ($r = -0.748, P \leq 0.01$) training tests; however, there was no relationship between age and change in isometric force with training. Peak isometric force pretraining was negatively correlated ($r = -0.599, P \leq 0.05$) with the percentage change in peak isometric force resulting from the training.

For the squat jump tests, force and power output at all three loads were significantly correlated ($r = -0.741$ to $-0.866$, $P \leq 0.01$) with age. There were no significant relationships between age and the percentage change pre to post training of any of the force or power measures. Peak force measured during the isometric squat was positively correlated ($r = 0.711$ to $0.854$, $P \leq 0.01$) with all of the squat jump performance measures. The percentage change over the training period in power produced during squat jumps with the 60% 1RM load was negatively correlated with the pretraining power output for the 30% 1RM ($r = -0.524, P \leq 0.05$) and 60% 1RM ($r = -0.566, P \leq 0.05$) loads.

Fiber type distribution was related to age and a number of the performance measures. The percentage of Type Iib fibers was inversely related to age both pre ($r = -0.539, P \leq 0.05$) and post ($r = -0.574, P \leq 0.05$) training. No other fiber type percentages were related to the age of the subjects. After the training period, Type I percentage was negatively correlated with the posttraining power measured at loads of 17 kg ($r = -0.574, P \leq 0.05$), 30% 1RM ($r = -0.607, P \leq 0.05$), and 60% 1RM ($r = -0.603, P \leq 0.05$).

Type Iia fiber percentage pretraining was negatively correlated with the percentage change in Type Iia pre to post training ($r = -0.574, P \leq 0.05$). Type Iib fiber percentage pretraining was positively correlated with peak isometric force both pre ($r = 0.607, P \leq 0.05$) and post ($r = 0.553, P \leq 0.05$) training, as well as power measured post training at all three loads ($r = 0.528$ to $0.618, P \leq 0.05$). Type Iib fiber percentage posttraining was positively correlated with peak isometric force both pre ($r = 0.568, P \leq 0.05$) and post ($r = 0.677, P \leq 0.01$) training and with power produced at loads of 30% ($r = 0.535, P \leq 0.05$) and 60% ($r = 0.529, P \leq 0.05$) 1RM at the posttraining test.

Fiber area was also related to age and a number of the performance measures. The mean area of Type Iia fibers was inversely related ($r = -0.539, P \leq 0.05$) to age at the pretraining test. Pretraining Type I fiber area was inversely related ($r = -0.669, P \leq 0.01$) to the change pre- to posttraining of Type I fiber area and directly related ($r = 0.556, P \leq 0.05$) to the change pre- to posttraining of Type Iia fiber area. Before the training, Type Iia fiber area was significantly higher for the YM compared with the OM at all three loads tested (Fig. 3). Power remained unchanged during the 3-wk control period for both YM and OM; however, over the 10 wk of resistance training, there were no significant increases (Fig. 3), and percentage change pre (week 0) to post (week 10) are shown in Table 3. The YM produced significantly higher power output compared with the OM at all loads tested at both the pre and post training testing occasions (Table 3).

In terms of the development of force over the early phase of the isometric squat, there were no differences pre-training between the YM and OM, however, post training the YM could produce greater force at all time points. Further, both YM and OM increased their absolute force capacity 100–500, 500–1500, and 1500–2500 ms into the isometric squat test over the course of training, but the percentage changes were not significantly different between the two groups (Fig. 2). There were no significant main effects or interactions for the time to reach 30, 60, 90, or 100% of peak force.

When the two groups were pooled together there was a significant increase in iEMG of the quadriceps over the 10-wk training period. The YM increased iEMG by 40%, which was borderline significant ($P = 0.063$), and the OM increased by 43%, but this was not significant ($P = 0.107$) (Table 2).
positively correlated with power measured during the squat jump at loads of 30% (r = 0.632, P = 0.05) and 60% (r = 0.616, P = 0.05) 1RM. After the training period, Type IIa fiber area was not related to any of the performance variables. Pretraining Type IIb fiber area was negatively correlated (r = -0.768, P = 0.01) with the percentage change over the training period in Type IIb area. In addition, Type IIb fiber area was positively correlated with the percent change in power at the 30% (r = 0.600, P = 0.05) 1RM load pre- to posttraining.

DISCUSSION

The periodized resistance-training program used in this study was composed of a mixture of exercises for the development of muscle hypertrophy, maximal force or strength, and maximal power output. This type of training protocol has been referred to previously as the mixed methods model (29). There were significant increases in maximal isometric force in both young and older men, as well as increased force during the early phase of the isometric squat. The gains in maximal isometric strength were accompanied by significant increases in the voluntary neural activation of the quadriceps muscles.

A principal aim of this aspect of the study was to examine maximal muscle power development in young and old men. Force and power output during the squat jump were significantly higher in the young men at all the loads tested, and this remained so after the training period. Both young and old men adapted to the training intervention with significant and relatively large increases in force and power output. However, the percent changes were not significantly different between the young and old groups.

It is well known that muscular strength and power decrease with increasing age (4,17,32). This is supported by the current study in which the older men produced only 64% as much force in the isometric squat as that of the young men before the resistance training (Table 2). The difference between young and old was not altered by the training as the OM could only produce 62% of the isometric force of the YM at the posttraining testing (Table 2). Both groups

![FIGURE 2](image-url)

**FIGURE 2**—Force development during isometric squat for young men (pre ◆, post ○) and old men (pre ■, post □). There were no significant differences between the groups at any time point pre training. * Significant difference between young and old groups post training; ** significant change pre to post training for young men; *** significant change pre to post training for old men.

![FIGURE 3](image-url)

**FIGURE 3**—Power output of squat jumps performed with loads of A) 17 kg, B) 30% 1RM, and C) 60% 1RM during a 3-wk control period and 10 wk of resistance training by young (○) and old (□) men. * Significant difference between young and old groups; ** significant change pre to post training for young men; *** significant change pre to post training for old men.

### TABLE 2. Peak force and iEMG produced by young and old men during the isometric squat test performed pre and post 10 wk of resistance training.

<table>
<thead>
<tr>
<th></th>
<th>Young Men (N = 8)</th>
<th>Old Men (N = 10)</th>
<th>%change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>%change</td>
</tr>
<tr>
<td>Peak force (N)</td>
<td>1040 ± 171</td>
<td>1318 ± 247</td>
<td>23 ± 15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>iEMG (mV/s)</td>
<td>222 ± 64</td>
<td>308 ± 124</td>
<td>40 ± 47&lt;sup&gt;c,d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Significance difference in peak force between young and old men at pre or post test.

<sup>b</sup>Significant change pre to post training.

<sup>c</sup>Borderline significant change pre to post training (P = 0.063 and P = 0.107 for YM and OM, respectively).

<sup>d</sup>Significant change pre to post training for the pooled group.
produced relatively large increases in isometric strength over the 10 wk of resistance training, and this is consistent with previous research involving both young (14) and old (12,15,33) subjects. However, there was no significant difference in the percentage change exhibited by the YM versus OM. The mean percentage change by the OM was 40% (Table 2), which is larger than the 23% (Table 2) change by the YM, but there was considerable variability for the OM with the standard deviation of percentage change being 42% (Table 2), with a resulting coefficient of variance of 105%. This suggests that older subjects exhibit greater variability in their strength adaptation to a resistance-training program, perhaps a factor of the degree of age-related muscle atrophy or Type II fiber loss specific to each subject. It is interesting, however, that this variability in adaptation was not evident in any of the power measures and may be more a reflection of the older subjects having difficulty performing the isometric squat test and/or that there is greater contribution of neural factors to power performance than for the isometric squat test. What is clear is that the resistance-training program used in this study resulted in meaningful increases in isometric strength of the hip and knee extensors both in young and old men.

There was a significant increase in iEMG pre to post training when both old and young subjects were pooled (Table 2). This is consistent with other studies reported in the literature (12,15,28). When examining the changes in neural activation over the course of the training for the YM and OM groups, there were considerable increases of 40% and 43%, respectively; however, the changes were only of borderline significance (Table 2). Increases in maximal strength observed during strength training in both young and older subjects can be attributed largely to the increased motor unit activation of the trained agonist muscles. Although the actual nature of adaptations in the nervous system is difficult to determine, progressive strength training can lead to not only increased activation of the agonists but training-induced learning effects in terms of reduced co-activation of the antagonists that may also play a contributing role in both young and older subjects (3,12). The variability in the iEMG measurements was considerable (Table 2), and each group had a low N size, resulting in low statistical power (0.42 YM; 0.39 OM) to detect a statistically significant change. We had previously reported significant increases in the size of both the Type I and IIA muscle fibers in both the YM and OM, and this would have accounted for a proportion of the increase in isometric strength (16).

In terms of absolute force produced during the early phase of the isometric squat, the YM were significantly higher than the OM, and this suggests that YM have better ability to rapidly increase force. Both groups also increased force 100–500, 500–1500, and 1500–2500 ms into the isometric squat as a result of the training but not for the earliest phase (0–100 ms). The fact that there were no differences between the OM and YM with the standard deviation of percentage change being 42% (Table 2), with a resulting coefficient of variance of 105%. This suggests that older subjects exhibit greater variability in their strength adaptation to a resistance-training program, perhaps a factor of the degree of age-related muscle atrophy or Type II fiber loss specific to each subject. It is interesting, however, that this variability in adaptation was not evident in any of the power measures and may be more a reflection of the older subjects having difficulty performing the isometric squat test and/or that there is greater contribution of neural factors to power performance than for the isometric squat test. What is clear is that the resistance-training program used in this study resulted in meaningful increases in isometric strength of the hip and knee extensors both in young and old men.

FIGURE 4—Force output during squat jumps performed with loads of A) 17 kg, B) 30% 1RM, and C) 60% 1RM during a 3-wk control period and 10 wk of resistance training by young (○) and old (□) men.

Unpublished conduct of the American College of Sports Medicine

TABLE 3. Pre to post changes and relative differences between young and old men in power and force produced during squat jumps performed with 17 kg, and 30% and 60% of 1RM.

<table>
<thead>
<tr>
<th>Load</th>
<th>Young Men (N = 8)</th>
<th>Old Men (N = 10)</th>
<th>Old vs Young (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Change Pre to Post</td>
<td>% Change Pre to Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Power (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 kg</td>
<td>15 ± 14a</td>
<td>7 ± 5b</td>
<td>72a</td>
</tr>
<tr>
<td>30%</td>
<td>33 ± 16a</td>
<td>36 ± 23b</td>
<td>55a</td>
</tr>
<tr>
<td>60%</td>
<td>26 ± 12b</td>
<td>25 ± 16b</td>
<td>86a</td>
</tr>
<tr>
<td>Force (N)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 kg</td>
<td>5 ± 6b</td>
<td>4 ± 4b</td>
<td>88a</td>
</tr>
<tr>
<td>30%</td>
<td>29 ± 13b</td>
<td>29 ± 14b</td>
<td>69a</td>
</tr>
<tr>
<td>60%</td>
<td>29 ± 8a</td>
<td>24 ± 3a</td>
<td>78a</td>
</tr>
</tbody>
</table>

*Significance difference between young and old groups.

Significant change pre to post training.
the groups in the time to reach 30, 60, 90, or 100% peak isometric force indicates that ability to attain relative force levels was not different between the age groups and the training program used in this study did not alter this ability. This was somewhat unexpected given the results of previous research, which has demonstrated increased rate of force development (14) after explosive resistance training. However, in the current study, it appears that increase in force capability was more predominant than rate of onset of that force. It may be that only one session of explosive-type exercise per week was insufficient to produce increases in explosive strength or that the hypertrophy and maximum strength sessions interfered with the development of explosive strength.

The isometric squat test was intended to indicate differences in isometric strength and the time course of force development; however, the squat jump is a more specific test of maximal power output and even more specific to functional daily activities. In terms of maximal power output, the old men were capable of around 55–77% of the performance of the young men in the squat jump (Table 3), and the difference between YM and OM was still observable after the training. Power and force output increased as a result of the training in both the YM and OM and at all the loads tested, but the percentage changes pre to post were the same regardless of age group. Therefore, the periodized program designed to increase muscle size, strength, and maximal power was effective at increasing performance in the squat jump, resulting in considerable increases in power output in both young and old men. This finding is consistent with reports increased in squat-jump performance of middle-aged and older men and women after combined heavy- and explosive-resistance training (12). Such a result is important because muscle strength and power have been shown to be related to functional performance of daily living activities, such as walking, climbing stairs, and rising from a chair (1). Therefore, the resistance-training program used in the current study may be effective for improving and/or maintaining the functional capacity of older people. Further, Evans and Campbell (6) have suggested that muscle strength and power may be related to risk of falling. It could be hypothesized that implementation of a resistance-training program similar to that used in the present study might be effective in the prevention of falls by the elderly; however, this requires investigation in future clinical research. Clearly, resistance-training programs should be designed to increase not only muscle strength but also power, because this factor has the greatest impact on performance of activities of daily living, as well as avoiding falls (5,15,19).

It can be concluded from the results of this study that old men have a similar capacity to increase performance in maximal power activities to young men if a resistance-training program of appropriate intensity and duration is completed and explosive exercises are included. Although similar changes were observed between YM and OM, there were differential changes across the loads tested. Although the heavier 30% and 60% 1RM loads produced similar percentage increases of 19–36%, both force and power output increases were only 4–15% for the lightest load of bar weight only (17 kg). This is most probably a reflection of the loads used in training, which were 60% 1RM or higher, and thus a load-specific training adaptation was observed, with only small but significant increases in performance with the lower load resulting from training. This result is in agreement with previous research reporting loads (21,25) and velocity- (20,27) specific adaptations to resistance training.

The work of Bobbert and Van Soest (2) has particular relevance to the findings of the current study. By using computer modeling, it was determined that increasing muscle strength alone does not increase vertical jump performance without modification to the neural control of the movement (2). Presumably, such modification would occur in the human as a result of practicing the skill of jumping. The training program used in the current study combined exercises designed to increase muscle strength and maximal power. The result was that both strength, as indicated by the isometric squat test, as well as power output, as measured in the squat jump, improved considerably in both age groups. Thus, it may be important that resistance-training programs for aged people include rapid, high-power exercises to enable transfer of the strength gains from traditional resistance training into more functional strength and power. Future research should address the relative efficiency of training solely for strength and then altering the program to train solely for maximal power versus the simultaneous strength and power training used in the current study.

With increasing age, there was a decrease in all measured performance variables. However, there were no significant relationships between age and the percentage change in these variables pre to post training. Therefore, it can be concluded that within the training parameters of intensity, frequency, and duration used in the current study the OM adapt at a similar rate to that of the YM. Whether this finding would hold true, particularly over longer training periods, remains to be determined. Rather than age being the determining factor in training response, initial level of strength was found to be the main determinant of the size of training adaptation both in isometric strength and power output. This was a negative relationship, however, indicating that those subjects with lower initial strength levels produce the greatest increases in strength and power. Clearly the principle of diminishing returns applies such that people with higher initial levels of strength and power have a reduced window for adaptation to training (29,30).

Before discussing the results of the correlation analysis it should be noted that there are some limitations due to the small N size, as well as the bimodal age distribution. However, there are some pertinent points to be found in the correlation results, but caution should be exercised in interpreting the strength of the relationships. There were significant relationships between age and the percentage of Type IIb fibers as well as the area of Type IIa. These were negative correlations indicating that with increasing age there was a lower proportion and area of these respective subtypes of fast twitch fiber. This result supports
the findings of Lexell et al. (24) that aging results in a decrease in muscle fiber size, particularly Type II and possibly a loss of Type II fiber number. Whether this phenomenon is due exclusively to the aging process is not known, but it is most probable that the decline in physical activity levels, particularly in intensity, contributes substantially to this decline. The results of the current study, although not conclusive, suggest that this effect, which is commonly ascribed to “aging,” can be reduced with appropriate resistance training. It should be noted that all of the subjects in the current study were healthy and habitually physically active, and yet demonstrated some degree of muscle atrophy. It appears that low intensity physical activities are not sufficient stimulus, particularly to the Type II muscle fibers, to maintain muscle mass as we age.

In terms of relationships between fiber type and strength and power measures, a number of interesting patterns were observed. The higher the percentage of Type I fibers measured pre training, the lower the subject’s power production at the post training test. This suggests that subjects with a high proportion of slow-twitch fibers have a reduced ability to increase maximal power output. In addition, subjects with larger Type I fibers exhibited smaller changes in Type IIa fibers as a result of the training. Although the relatively small numbers of subjects reduce the power of correlation analysis, the results suggest that a high proportion and size of Type I fibers translates to reduced increases in Type II fibers and improvements in maximal power production as a result of resistance training. Type IIb proportion was positively correlated with both strength and power measures and the area of Type IIb was positively related to the change in power with training. Therefore, higher Type IIb characteristics appear to favor development of strength and power. Interestingly, in a previous study we reported that increases in maximal power output. In addition, subjects with a high proportion of slow-twitch fibers have a reduced ability to increase maximal power output. In summary, it can be observed from the results of this study that a periodized resistance-training program composed of a combination of exercises for increasing muscle size, maximal force, and maximal power produced significant increases in maximal isometric strength, early phase of isometric force production, and iEMG in both young and old men. Maximal power output was increased considerably in the squat jump at all loads tested, and this improvement did not appear to be affected by the age of the subjects. Finally, higher post training strength and power and greater improvements in muscle strength and power were observed in those subjects with higher proportions of Type II fibers and lower proportions of Type I fibers, suggesting that pretraining fiber profiles may influence force and power development training potential. The main finding was that older men have a similar ability to young men to increase, at least within the present training period of 10 wk, muscle power in a functional activity like the jump squat in response to a periodized resistance-training program that includes explosive exercises.

Address for correspondence: Robert U. Newton, Human Performance Laboratory, Ball State University, Muncie IN, 47306; E-mail rnewton@bsu.edu.

REFERENCES


16. Hakkinen, K., R. U. Newton, S. E. Gordon, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in skeletal muscle cross-sectional area during strength training was less in those subjects who possessed a lower proportion of Type II fibers in their muscles (16). It could be speculated that decreases in the ratio of Type II to Type I fibers both in area and number compromises the capacity to increase strength and power through resistance training. Resistance training throughout the lifespan would appear important to avoid the age-related decreases in Type II fiber ratio because it is possible that once lost, recovery of strength, power, and function will be more difficult.


