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Changes in Power with Resistance Training in Older and Younger Men and Women

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Background. Muscle power diminishes with increasing age and inactivity. The capacity for older adults to increase muscle power with resistance exercise has not been examined; therefore, we examined the influence of progressive resistance training (PRT) on muscle power output in 17 men and women aged 56–66 years, and compared their responses to 15 men and women aged 21–30 years.

Methods. All subjects performed 12 weeks of PRT at a workload equivalent to 80% of the one repetition maximum (1RM). All training and assessments of 1RM and power were made on Keiser pneumatic resistance machines. Subjects performed five exercises, three sets per exercise, twice weekly. Muscle power was measured (isotonically) at resistances equivalent to 40, 60, and 80% of the 1RM, on the knee extension and arm pull machines.

Results. All subjects increased arm pull power similarly at 40 and 60% of 1RM, independent of age or sex. There was not a significant increase in arm pull power at 80% of 1RM. Older and younger subjects also had similar absolute increases in leg extensor power at 40 and 60% of 1RM, but men responded with greater absolute gains than women at these percentages ($p < .05$). The increase in leg extensor power at 80% of 1RM was similar in all groups. Older and younger subjects increased strength similarly in all exercises except the left knee extension. Independent of age, men increased strength more than women in all exercises except the double leg press.

Conclusions. These data demonstrate that individuals in their sixth decade can still improve muscle power (and strength); however, men may realize greater absolute gains than women.

AGING is associated with losses in muscle mass, strength, and contractile velocity (1–3). The primary reason for the age-related decrease in muscular strength is a decrease in muscle cross-sectional area caused by fiber atrophy and loss of muscle fibers (4), a process that appears to be accelerated beyond the fifth to sixth decade. The decreased contractile velocity of aging muscle may be related to a reduction in the relative proportion of type II fibers in the muscle cross-sectional area (4,5) and a diminishing number of motor units (6,7) which alter innervation patterns and contractile protein expression.

The decrements in muscle mass and function incurred by older individuals can be attenuated or partially reversed by performing progressive resistance training (8–15). Therefore, it is likely that many of the age-associated changes in skeletal muscle are a result of an increasingly sedentary lifestyle adopted by many healthy aging individuals or imposed upon them by injury or disease.

Although research from the last decade clearly demonstrates that older people can realize training-induced gains in muscle strength that are similar to those in young adults, few investigations have focused on changes in muscle power with age (16,17). Bassey and colleagues (16) demonstrated that in very old adults, leg muscle power is more important than strength for performing daily activities such as stair-climbing, rising from a chair, and walking. Older adults who required the use of assistive aids to perform these tasks had 42–54% less leg extensor power than those who could complete these tasks without assistance. Because the power output of type II fibers is four times that of type I fibers (18), the selective atrophy of type II fibers in aging muscle may hasten decrements in power output with increasing years.

The necessity of muscle power for performing daily habitual activities in elderly populations underscores the importance of examining what capacity older adults have for improving muscle power. In order to investigate the potential for older adults to improve muscle power, as well as to determine if a protocol which has been shown to increase strength is also effective for improving power, we examined the influence of 12 weeks of high intensity, progressive resistance training on strength and power output among healthy older and younger men and women. Based on preliminary data from our laboratory, we hypothesized that gains in muscle power from resistance training may be attenuated in older individuals, We also hypothesized that resistance training would elicit similar increases in muscle strength in older and younger individuals.

METHODS

Subjects

All procedures used in this investigation were approved by the Pennsylvania State University Institutional Review Board for the Protection of Human Subjects. Seventeen healthy sedentary older individuals (9 men and 8 women, 60.3 ± 0.8 years, mean ± *SE*), and 17 healthy younger individuals (8 men and 9 women, 26.0 ± 0.8 years, mean ± *SE*) volunteered to participate in this study. The older women were at least 2 years postmenopausal and not on estrogen replacement therapy. None of the volunteers had performed resistance exercise in ≥1 year before beginning this study. Only one of the older subjects had previously resistance trained. Each subject underwent a thorough screening procedure which included a medical history, physician-administered physical examination, resting electrocardiogram, and routine clinical blood and urine analyses. People with diabetes, uncontrolled hypertension, or physical disabilities rendering them susceptible to injury during resistance training were excluded. Based on several published research studies from this laboratory indicating a lack of learning effect of muscle testing, we did not feel it necessary to once again include nonexercise groups in this investigation (2,10,19,20). Each of the volunteers gave their informed written consent to participate in this study after receiving a complete written and verbal explanation of the proposed measures and purpose of the investigation.

Experimental Protocol

All training and assessments of strength and power were completed on Keiser pneumatic resistance machines (Keiser Sports Health Equipment, Fresno, CA). The resistance training program included two upper body and three lower body exercises: seated chest press (pectoralis major and minor, deltoids and triceps brachii), seated arm pull (latissimus dorsi, trapezius, teres major and minor, rhomboids, deltoids, biceps brachii and brachialis, triceps brachii, pectoralis major and minor, and serratus anterior), seated unilateral knee extension (quadriceps femoris), seated bilateral leg curl (biceps femoris, semimembranosus and gluteus maximus), and seated bilateral leg press (gluteus maximus, adductor magnus, hamstrings, and quadriceps).

Maximal strength was assessed using one repetition maximum (1RM) for each exercise both before and after 12 weeks of training. This protocol has been previously described (21,22). Strength was measured in Newton-meters for knee extension and leg curl, and in Newtons for chest press, arm pull, and double leg press. Upper body and dominant knee extensor power were also measured on the arm pull and leg extension machines, respectively, before and after 12 weeks of resistance training at three relative intensities (40, 60, and 80% of 1RM). Posttraining power was assessed relative to the posttraining 1RM, not the 1RM determined at baseline. The Keiser pneumatic resistance equipment used for this study was computer interfaced. The velocity of movement was calculated via ultrasonic transducers attached to the air cylinders. The use of Keiser pneumatic resistance machines for measuring muscle power has been previously described (23). With Keiser equipment, strength and power output are measured during isotonic contractions. Isotonic contractions closely mimic normal muscular contraction in which the muscle is maximally loaded at only one point during the range of motion. In order to determine the coefficient of variation of power measurements using the Keiser equipment in our laboratory, we measured power output in 11 subjects in the morning and the afternoon of the same day, the following day, and the following week, on both the knee extension and arm pull machines. These data are shown in Table 1.

Subjects trained two times per week for 12 weeks. During each session, subjects performed three sets each of two upper body and three lower body exercises at an intensity equivalent to 80% of 1RM. Subjects performed eight repetitions during sets 1 and 2, and performed repetitions to volitional muscular fatigue in the third set. If subjects were able to perform 12 or more repetitions during the third set, the workload was increased by 5–10% for the next exercise session. Each subject had an individual trainer for every resistance training session. The resistance was pushed or pulled through the full range of motion in a controlled manner, with the concentric and eccentric phases lasting approximately 3 seconds each. Subjects rested 2 minutes between each set, and 5 minutes between each exercise. Every training session started and ended with 10 minutes of low intensity (heart rate ≤ 100 beats per minute), stationary cycling exercise and 5 minutes of stretching for the major muscle groups used during the resistance exercise session.

Body Composition

Bioelectrical impedance (Xitron Technologies, San Diego, CA) was used to estimate fat free mass (FFM) before and after 12 weeks of resistance training using age-specific equations (23–25). Impedance measurements were made in a thermoneutral room the morning following an overnight fast, with the subjects in the supine position and their arms angled (~30°) away from the body and legs apart such that the thighs were not touching. Measurements were made 5 minutes after assumption of the supine position. Tetrapolar surface electrode arrangement was used with a single frequency of 50 kHz. Body weight was also recorded before every exercise session with the subject in similar clothing each time.

Statistical Analyses

Gender specific age-related differences in baseline body weight, FFM, strength, and power were assessed using *t* tests. A three-way analysis of variance (ANOVA) (Age × Sex × Time design), with repeated measures on time was performed on all strength and power data, as well as body weight and FFM. All calculations were performed using PROC GLM (General Linear Models Procedure) of SAS (Statistical Analysis System) version 6.07 (SAS Institute Inc., Cary, NC). Significance was established at $p < .05$ (two-tailed). Unless otherwise noted, all values are reported as mean ± standard error.

Results

Two young men did not complete the study as they experienced some knee joint discomfort. All other subjects completed 100% of the training sessions. Descriptive characteristics of the

Table 1. Average Coefficient of Variation for Right Knee Extension and Arm Pull Power Measurements at 20, 40, 60, and 80% of the 1RM

N = 11	Right Knee Extension	Arm Pull
20% 1RM	4.0 ± 0.8%	3.3 ± 0.9%*
40% 1RM	4.3 ± 0.4%	3.4 ± 0.6%
60% 1RM	4.6 ± 0.4%	4.0 ± 0.6%
80% 1RM	7.9 ± 1.1%	5.9 ± 0.9%

Values are means ± *SE*. *$N = 5$ for arm pull at 20% 1RM, as resistance could not be lowered enough to accommodate the other six subjects at this intensity. The coefficient of variation is the average of the four trials.

subjects who completed the study are shown in Table 2. Both older men and women were heavier than their younger counterparts. Fat free mass was similar between older and younger women, but slightly different between older and younger men ($p < .05$). Body weight and fat free mass were unchanged after 12 weeks of resistance training.

Power

Power was assessed on the same Keiser pneumatic resistance equipment that was used for resistance training. Initial and final arm and leg power results for all relative training intensities are shown in Table 3. Arm pull power assessed prior to the resistance training program was not different between older and younger men at any of the three intensities. However, older men had less leg extensor power than younger men at all three intensities at baseline ($p < .05$). Across all intensity levels, baseline arm pull and leg extensor power were greater in younger versus older women ($p < .05$). Men had greater absolute arm pull power than women at any time point, independent of age ($p < .05$).

We were interested foremost in the influence of both age and gender on changes in muscular power with resistance exercise. However, there was not a significant relationship among age, gender, and changes in power over time for any of the power (or strength) variables measured in this investigation. The next relationship of interest was the influence of age alone or gender alone on changes in power over time (Age × Time or Gender × Time interaction). These interactions were not signficant for arm pull power (Table 3), demonstrating that older and younger individuals increased arm pull power similarly subsequent to resistance exercise training, irrespective of gender; and men and women increased arm pull power similarly in response to resistance training, irrespective of age. Because older and younger men and women increased arm power similarly, these data can be combined, resulting in a mean increase in arm pull power of 15 ± 3.4% and 9.5 ± 2.3% at 40 and 60% of 1RM ($p < .05$), respectively, over time. No significant training-induced increases were observed for arm pull power at 80% of 1RM. Figure 1 shows the change in arm pull power after 12 weeks of resistance training at 40, 60, and 80% of 1RM.

Changes in leg extensor power after 12 weeks of resistance training are shown in Figure 2. Once again, the relationship between both age and gender on leg power responses over time was not significant. Further, an examination of the influence of age alone (Age × Time interaction) on changes in leg power

Table 2. Subject Characteristics at Baseline

Group	*N*	Age, years	Height, cm	Weight, kg	FFM, kg
Older Men	9	60.2 ± 1.1	173.5 ± 1.8	90.2 ± 2.9*	53.4 ± 1.4*
Young Men	6	26.1 ± 0.9	177.0 ± 1.6	75.6 ± 5.4	59.3 ± 2.5
Older Women	8	60.4 ± 1.3	164.1 ± 1.8	79.8 ± 3.0*	43.1 ± 1.7
Young Women	9	25.9 ± 1.2	164.3 ± 1.5	57.3 ± 1.7	43.1 ± 1.0

Values are means ± *SE*. *$p < .05$ versus younger counterpart of same sex.

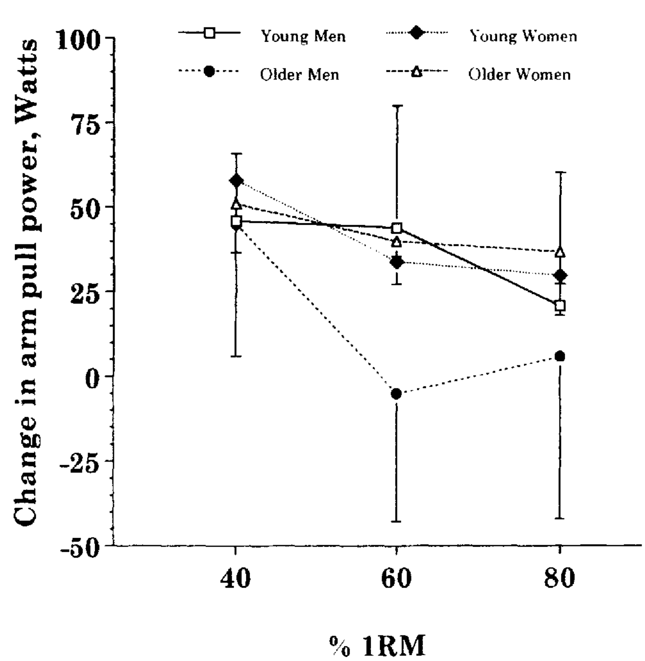

Figure 1. The change in arm pull power at 40, 60, and 80% of the 1RM after 12 weeks of resistance training. No significant interactions. The main effect of time was significant ($p < .05$) at 40 and 60% of 1RM only, and the main effect of sex was significant at 40, 60, and 80%.

Table 3. Arm Pull and Leg Extensor Power Before and After 12 Weeks of Resistance Training

		Older Men	Young Men	Older Women	Young Women
AP40, Watts	Week 0	535 ± 49.9	556 ± 45.4	209 ± 6.9	248 ± 13.6
(§, ‖)	Week 12	580 ± 52.4	602 ± 29.1	248 ± 14.9	282 ± 11.3
AP60, Watts	Week 0	638 ± 55.9	650 ± 56.0	235 ± 17.3	292 ± 13.2
(§, ‖)	Week 12	633 ± 56.9	694 ± 30.3	275 ± 20.6	326 ± 12.4
AP80, Watts	Week 0	582 ± 48.5	629 ± 59.4	236 ± 19.6	289 ± 14.1
(§)	Week 12	589 ± 70.1	650 ± 53.9	273 ± 21.7	319 ± 16.1
KE40, Watts	Week 0	265 ± 25.2	426 ± 36.3	129 ± 8.9	204 ± 11.7
(†)	Week 12	335 ± 18.3	478 ± 43.3	155 ± 12.1	238 ± 9.8
KE60, Watts	Week 0	308 ± 32.6	483 ± 57.6	141 ± 10.4	228 ± 10.3
(*,†)	Week 12	385 ± 27.1	574 ± 48.9	181 ± 15.4	281 ± 14.6
KE80, Watts	Week 0	304 ± 32.3	476 ± 61.5	130 ± 8.6	220 ± 15.1
(‡, §, ‖)	Week 12	348 ± 14.6	523 ± 74.1	184 ± 19.4	269 ± 13.5

Values are means ± *SE*. AP40, AP60, AP80 = arm pull power at 40, 60, and 80% of 1RM, respectively. KE40, KE60, KE80 = knee extensor power at 40, 60, and 80% of 1RM, respectively. *$p < .05$ Time × Age; †$p < .05$ Time × Gender; ‡$p < .05$ age main effect; §$p < .05$ gender main effect; ‖$p < .05$ time main effect.

over time revealed that older and younger individuals increased leg extensor power similarly at all three relative intensities of 1RM. The absolute values for leg extensor power before and after resistance training are shown in Table 3. Although there were no age differences in the ability to increase leg extensor power over time, men had greater absolute increases than women, independent of age ($p < .05$) at the lower intensities, 40 and 60% of 1RM (Figure 2). This gender interaction was still significant when the data were adjusted for FFM. Younger and older men and women responded with similar increases in leg extensor power over time at 80% of 1RM.

Strength

Table 4 contains the means of the strength measurements (1RM) for each of the four groups, on each of the five exercises, before and after 12 weeks of resistance training. At baseline, older men were significantly weaker than their younger counterparts in right and left knee extension strength. Although baseline chest press, arm pull and leg press strength tended to be lower in older versus younger men, these differences did not reach statistical significance (Table 4). At baseline, older women had less right and left knee extension and chest press strength than younger women, but similar arm pull ($p = .11$) and double leg press ($p = .6$) strength. Improvement in strength was similar for all exercises among older and younger subjects after 12 weeks of resistance training. On every exercise, men were stronger than women, even when the data were adjusted for FFM.

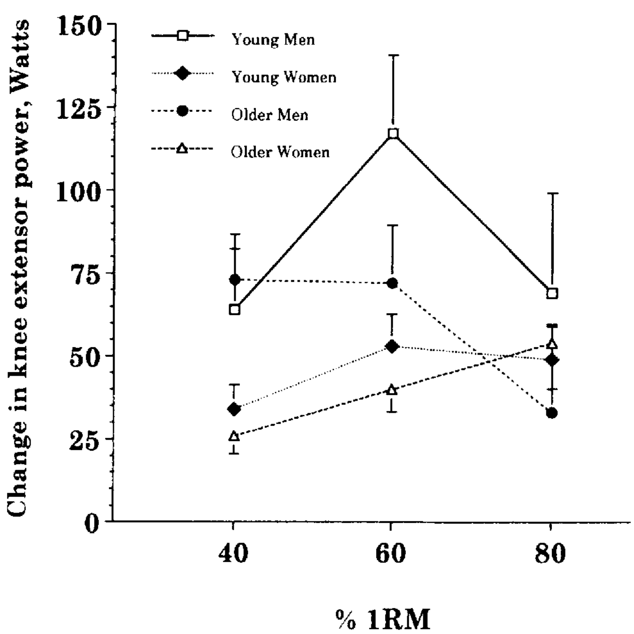

Figure 2. The change in knee extensor power at 40, 60, and 80% of 1RM after 12 weeks of resistance training. The Time × Age interaction was significant at 60%; the Time × Sex interaction was significant at 40 and 60%; and the main effects of time, sex, and age were significant at all three percentages.

Strength increases were similar between older and younger individuals for all exercises except left knee extensor strength. When the influence of gender alone on strength responses over time was examined, it was apparent that men increased strength more than women over time, independent of age, in all exercises except the double leg press. Figure 3 demonstrates this gender-specific response, the top panel showing the change in strength in all exercises in the younger group and the lower panel showing the older group. When these data were adjusted for FFM, men still had greater increases in right and left knee extensor strength, but there were no longer gender differences in upper body strength (arm pull and chest press) responses.

Discussion

In contrast to our hypothesis, both older and younger adults had similar improvements in arm pull and leg extensor power. Although a number of investigations have demonstrated that similar increases in strength can occur in both older and younger adults, few studies have examined the effects of progressive resistance exercise on power in older adults (11,17), and none have compared the adaptations of young and older subjects with the same training intervention. Skelton and colleagues (17) examined the effects of 12 weeks of resistance exercise on strength and power development in 20 older men and women between 76 and 93 years of age. Subjects performed three sets of four to eight repetitions three times per week. One session was supervised while the other two were unsupervised. Exercise consisted of using 1 to 1.5 kg rice bags or elastic tubing for resistance. Although not statistically significant ($p =$

Table 4. Maximal Strength (1RM) Before and After 12 Weeks of Resistance Training

Exercise		Older Men	Young Men	Older Women	Young Women
RKE, Nm	Week 0	140 ± 10.7	206 ± 14.8	80 ± 9.3	113 ± 4.7
(†)	Week 12	189 ± 11.9	252 ± 14.3	98 ± 7.7	144 ± 6.4
LKE, Nm	Week 0	137 ± 8.3	204 ± 13.3	75 ± 9.8	114 ± 4.6
(*, †)	Week 12	185 ± 6.1	258 ± 11.8	97 ± 10.0	146 ± 8.0
CP, N	Week 0	551 ± 30.4	641 ± 61.3	287 ± 16.6	399 ± 18.1
(†)	Week 12	627 ± 30.7	734 ± 69.0	324 ± 18.7	430 ± 21.9
AP, N	Week 0	596 ± 21.2	647 ± 34.8	314 ± 23.1	358 ± 12.9
(†)	Week 12	713 ± 34.4	753 ± 51.0	367 ± 26.1	416 ± 11.2
LP, N	Week 0	1446 ± 60.2	1622 ± 156.0	1010 ± 63.6	1065 ± 76.8
(§, ‖)	Week 12	1694 ± 95.8	1973 ± 212.0	1220 ± 79.1	1250 ± 53.6

Values are means ± *SE*. RKE, LKE = right and left knee extension; CP = chest press; AP = arm pull; LP = double leg press. *$p < .05$ Time × Age; †$p < .05$ Time × Gender; §$p < .05$ gender main effect; ‖$p < .05$ time main effect.

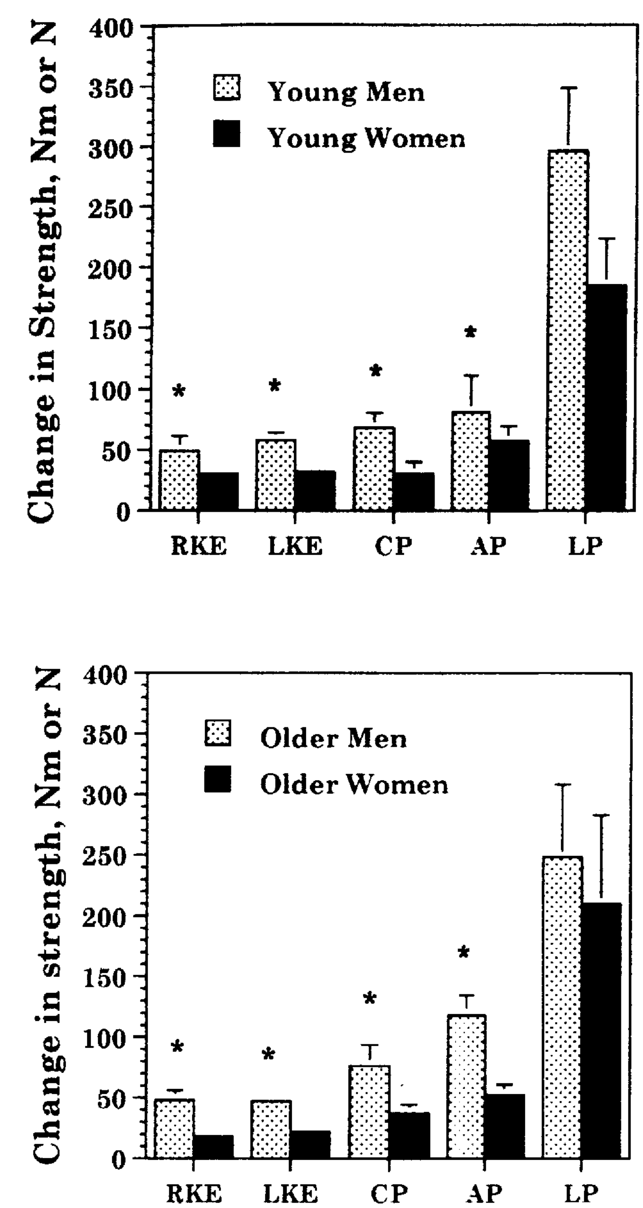

Figure 3. The change in maximal strength following 12 weeks of resistance training in younger men and women. Values are means ± *SE*. RKE, LKE = right and left knee extension; CP = chest press; AP = arm pull; LP = double leg press. $^*p < .05$ versus women. Note that there was no age difference in the response over time.

.11), an 18% increase in leg extensor power was observed (mean ± *SD*, pre = 61.7 ± 23.0; post = 79.3 ± 18.7 Watts). Frontera and colleagues (11) examined the effects of isotonic high intensity resistance exercise on isokinetic muscle power measured on a Cybex isokinetic dynamometer, but did not see a significant change in power. However, they also demonstrated that although isotonic strength (1RM) showed a substantial improvement (>100%), isokinetic strength either was unchanged (at a rapid speed of contraction) or showed only modest improvements at a slow speed. This study demonstrated that training isotonically will likely produce significant effects, but these effects are seen only when muscle function is measured isotonically. Thus, our primary interest in the current investigation was to determine if an older population could improve isotonic muscle power and if they could realize similar improvements as young adults in response to the same protocol. In the current experimental protocol, both the resistance exercise training was performed isotonically, as were the assessments of strength and power, on the same Keiser pneumatic resistance equipment.

The difference in muscle power observed with age is likely a result of many factors. This includes decreased activity level, a selective atrophy of type II muscle fibers (4,5), and a decrease in the number of motor units, particularly those innervating high-threshold, fast twitch fibers (6,7). The morphological and functional characteristics of skeletal muscle appear to be relatively unchanged through the fifth decade of life (3,4), and changes in motor unit number and function have not been observed until after the sixth decade (6,7). Although we do not have histochemical data from the subjects in this investigation, it is likely that baseline differences in strength and power between the older and younger group were related in part to decreases in type II fiber area and corresponding increases in slow contractile protein content per cross-sectional area of muscle. Despite any such age-related changes in muscle morphology that may occur in this age group, similar improvements in strength and power were observed in both older and younger adults. These data demonstrate that healthy older individuals into their seventh decade can improve muscle power in response to resistance exercise. These improvements are on the same magnitude as those realized by younger adults performing the same exercise.

In addition to the finding that older individuals can improve muscle power similar to young adults in response to 12 weeks of resistance training, our data support the existing literature which demonstrates that older people can increase upper and lower body strength similar to younger people. Although several investigations have shown that the capacity to improve muscle strength is not impaired with increasing age (8–15), few investigations have made this direct comparison of the magnitude of the responses of older and younger individuals to the same training program (15,26). Welle and colleagues compared the hypertrophic responses and changes in specific tension (the ratio of three repetition maximum to cross-sectional area) to 3 months of progressive resistance training in younger (22–31 years) and older (62–72 years) men and women (15). They found that the increase in specific tension was similar in young and old groups for the elbow flexion (~20%) and knee extensors (~35%), but was more than double in the older group versus the younger group for the knee flexors (15). These data support our finding of similar increases in strength (+15% and +25% for upper and lower body, respectively) in older and younger subjects. Even after adjusting for fat free mass, the men in the current investigation had greater absolute increases in leg muscle strength than women, regardless of age, with strength training at the same relative intensity. Unfortunately, we did not have a true measure of muscle mass, only fat free mass, on all of the subjects in the investigation. Thus, we could not adjust the data for muscle mass per se. This observation of greater absolute increases in strength in men versus women has been demonstrated previously in younger adults (27).

In summary, contrary to our hypothesis, older and younger men and women increased muscle power output similarly in response to the same resistance training program. However, the data from this investigation suggest that men may experience greater absolute gains than women. Similar results were obtained for strength responses to resistance exercise in older and younger adults. Because the reduction in the number of motor units is greatest after the seventh decade, future research should focus on strategies to improve muscle power in the oldest old. Interestingly, the 18% increase in leg extensor power observed by Skelton and colleagues (17) was in 76–93-year-old men and women. Although not statistically significant, the observation is encouraging, as perhaps with more supervised, structured, and progressive resistance exercise, significant improvements may be observed. Further, although we did not attempt to determine the optimal training intensity for improving power in this investigation, future investigations should be designed with this goal in mind. It is clear that training at 80% of the 1RM is very effective for increasing muscle size and strength in older people (21). However, this training intensity may not be optimal for improving muscle power. In a cross-sectional investigation of muscle power using Keiser equipment (23), it was shown that power output was highest at 68% of 1RM. Perhaps greater improvements in muscle power than those observed in this investigation may be obtained if training is completed at the intensity that allows for peak power generation for a given individual. Although the older participants in this investigation were not frail elderly persons, these results demonstrate that it may be possible to maintain a critical level of muscle strength and power by resistance training, thereby attenuating or preventing the onset of frailty with increasing years.

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