Age and gender responses to strength training and detraining

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ABSTRACT

LEMMER, J. T., D. E. HURLBUT, G. F. MARTEL, B. L. TRACY, F. M. IVEY, E. J. METTER, J. L. FOZARD, J. L. FLEG, and B. F. HURLEY. Age and gender responses to strength training and detraining. *Med. Sci. Sports Exerc.*, Vol. 32, No. 8, pp. 1505–1512, 2000. **Purpose:** The purpose of this study was to examine the effects of age and gender on the strength response to strength training (ST) and detraining. **Methods:** Eighteen young (20–30 yr) and 23 older (65–75 yr) men and women had their one-repetition maximum (1 RM) and isokinetic strength measured before and after 9 wk of unilateral knee extension ST (3 d·wk^{-1}) and 31 wk of detraining. **Results:** The young subjects demonstrated a significantly greater ($P < 0.05$) increase in 1 RM strength (34 ± 3%; 73 ± 5 vs 97 ± 6 kg; $P < 0.01$) than the older subjects (28 ± 3%; 60 ± 4 vs 76 ± 5 kg, $P < 0.01$). There were no significant differences in strength gains between men and women in either age group with 9 wk of ST or in strength losses with 31 wk of detraining. Young men and women experienced an 8 ± 2% decline in 1 RM strength after 31 wk of detraining (97 ± 6 vs 89 ± 6 kg, $P < 0.05$). This decline was significantly less than the 14 ± 2% decline in the older men and women (76 ± 5 vs 65 ± 4 kg, $P < 0.05$). This strength loss occurred primarily between 12 and 31 wk of detraining with a 6 ± 2% and 13 ± 2% decrease in the young and older subjects, respectively, during this period. **Discussion:** These results demonstrate that changes in 1 RM strength in response to both ST and detraining are affected by age. However, ST-induced increases in muscular strength appear to be maintained equally well in young and older men and women during 12 wk of detraining and are maintained above baseline levels even after 31 wk of detraining in young men, young women, and older men. **Key Words:** RESISTANCE TRAINING, WEIGHT TRAINING, DISUSE, AGING, MEN, WOMEN

Aging is associated with a reduction in muscle mass (10,18,33,34), which in turn has been implicated as a primary, causative factor in the reduction of muscular strength with age (19). This muscular weakness is associated with an increased risk for falls (3,22), as well as impaired functional abilities in elderly populations (2,14). The consequence of this impairment appears to be more severe in women than men (15). Strength training (ST) has been shown to be a safe (13,25) and effective intervention for increasing strength (9,11,13,24,32) and improving functional ability (1,28) in the elderly. However, direct comparisons of age and gender for strength responses to ST and detraining have not been reported.

Although losses in muscular strength with age and increases with ST are well documented, the contribution of a decline in muscular exertions to the age-associated losses in strength is still unknown. By comparing the response of young and older individuals to a standardized program of ST and subsequent detraining, new information can be obtained on the role of muscular activity on the age-related changes in strength. This information should help to develop a better understanding of the relative contributions of aging versus those of a decline in muscular exertions in explaining the loss of strength that accompanies the aging process.

Previous investigations reported that strength can be maintained from 4 to 32 wk after training has ended in young subjects (6,8,12,23,30,35,37) and from 5 to 27 wk in elderly subjects (20,29,31). These studies were very specific in their design and utilized only young women (30,35), young men (6,8,37) or elderly men and women (20,29,31), but none made direct age and gender comparisons. Furthermore, no studies have compared age and gender responses to ST in the untrained contralateral limb. This could provide new information on differences in cross-education effects.

Therefore, the purpose of this study was to compare the effects of 9 wk of unilateral knee extension ST and 31 wk of detraining on muscular strength levels in young and older men and women. The results within each group were compared with the untrained leg as a reference control.

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METHODS

Subjects. Fifty-one healthy untrained young (age 25 ± 1 yr, mean ± SE, range 20–30 yr) and older (age 69 ± 1 yr, range 65–75 yr) men and women volunteered to participate in this study. Data were missing on three young men and one young woman, while one older man and five young women withdrew from the study for reasons unrelated to the study. The remaining 41 subjects, who completed all aspects of the study, included 10 young and 12 older men and 8 young and 11 older women.

All subjects were screened for musculoskeletal disorders and any obvious signs of cardiovascular disease, using comprehensive medical history and physical activity questionnaires and a graded exercise test. The older subjects also underwent a physical examination by a physician. Subjects were excluded if they were current smokers, were taking any antihypertensive, cardiovascular, or metabolic medications, or if they had participated in any form of regular exercise in the 6 months before initiation of the study.

After an explanation of the purpose, risks, and procedures of the study, subjects signed a written informed consent before their participation in the study. The procedures in this study were approved by the human subjects institutional review boards of the College Park and Baltimore campuses of the University of Maryland.

Aerobic power ($\dot{V}O_{2max}$). To better characterize the subjects and to confirm that they were not aerobically trained, and therefore exercising regularly, $\dot{V}O_{2max}$ was assessed on a treadmill using an incremental incline and a constant speed protocol. $\dot{V}O_{2max}$ was determined from the fractional concentrations of O_2 and CO_2 measured from expired air using either a SensorMedics V_{max} 229 metabolic cart (SensorMedics Corp., Yorba Linda, CA) or the Douglas Bag technique using a Perkin Elmer 1100 Mass Spectrometer (Perkin Elmer Corp., Pomona, CA). Subjects walked for 5–10 min on the treadmill before the $\dot{V}O_{2max}$ test in order to find the appropriate speed and grade that elicited 70% of their age-predicted maximal heart rate (HR_{max}). After the appropriate speed and grade were obtained, subjects were allowed to rest for 5–10 min. The test was started at the previously determined speed and grade, and every 3 min the grade was increased 3.5% while speed was held constant. The test was terminated when the subjects could no longer continue or demonstrated ECG abnormalities. To be classified as achieving a true $\dot{V}O_{2max}$, subjects had to meet two of the three following criteria: 1) plateau in $\dot{V}O_2$, 2) RER > 1.1, or 3) HR within 10 beats of their age-predicted HR_{max}.

Body composition assessment. Total body non-osseous fat free mass (FFM) and fat mass were estimated by the use of a Lunar DPXL dual-energy x-ray absorptiometer, as previously described (32). Subjects were instructed to not eat or drink after midnight before their morning scan. A calibration standard was scanned daily, and measurement accuracy was ensured by scanning a water/oil phantom of known proportions (41% fat) monthly. The coefficient of variation of repeated measurements was $< 1.0\%$.

One repetition maximum (1 RM) strength test. Before assessment of the 1 RM strength test, subjects underwent three low-resistance ST sessions in order to familiarize themselves with the leg extension machine and to practice proper lifting technique. This was also done to help control for large early gains in strength due to motor learning, as well as to reduce the risk of injury.

After the familiarization sessions, 1 RM of the leg extensors was assessed unilaterally for both the trained and untrained leg. The trained leg was the dominant leg as determined by kicking preference. The subjects were positioned on a Keiser K-300 leg extension machine (Fresno, CA) so that the rotational axis of the machine was aligned with the lateral femoral epicondyle. Subjects were then secured to the machine using a Velcro strap around the pelvis. After a 5-repetition warm-up, a resistance was chosen that was estimated to be slightly below the subject's 1 RM value. The subject was instructed to lift that resistance one time. If the subject was able to complete the repetition, the resistance was increased and another trial performed after a 60-s rest. This routine was repeated until the subject could not successfully move the resistance one time. The last resistance that was successfully completed was recorded as the 1 RM. Approximately the same number of trials and time between trials was used before and after the training for the 1 RM test. The seat back and body position was also duplicated at all time points. In order to determine the initial resistance for the ST program, a 5 RM test was also conducted on the leg that was involved in the training.

Isokinetic peak torque (PT). To estimate neurological contributions to strength gains in response to the ST program, isokinetic knee extension PT was measured before and after training as a nontraining-specific strength test (27). Differences in 1 RM and PT responses to ST indicate involvement of factors other than muscle mass and are likely to reflect neurological contributions. PT was assessed twice bilaterally before training on separate days and once within 24–48 h after an exercise session at the end of 9 wk of ST, and once each at 12 and 31 wk after training using a Kin-Com 125E isokinetic dynamometer (Chattecx Corp., Chattanooga, TN). The load cell was calibrated before every test by positioning and stabilizing the lever arm horizontally to the floor and hanging a known weight on the load cell. The resulting force reported by the Kin-Com was compared with that of the actual weight and was adjusted accordingly.

Before testing, a 3-min, light warm-up was performed on a cycle ergometer followed by stretching of the quadriceps and hamstrings. After the stretching was completed, subjects were seated on the KinCom and stabilized using pelvis, chest, and thigh straps. The rotational axis of the dynamometer was then aligned with the lateral femoral epicondyle and the resistance pad positioned just proximal to the lateral malleolus of the ankle joint. After a goniometer-measured reference angle was recorded, limb weight was measured at 2.62 rad for gravity correction. An angle of 2.62 rad was used to avoid any effects of passive hamstring tension on the gravity correction value. A joint range of motion was then established from 1.75 to 2.88 rad. Acceleration and decel-

TABLE 1. Physical characteristics.

	Young Men		Young Women		Older Men		Older Women	
	Before Training	After Training	Before Training	After Training	Before Training	After Training	Before Training	After Training
Age	25 ± 1	—	26 ± 1	—	69 ± 1	—	68 ± 1	—
Height (cm)	177 ± 2	—	169 ± 2	—	173 ± 2	—	161 ± 2	—
$\dot{V}o_{2\,max}$ (mL·kg^{-1}·min^{-1})	43 ± 1	—	33 ± 3	—	25 ± 2	—	20 ± 1	—
Body mass (kg)	83 ± 5	83 ± 5	63 ± 4	63 ± 4	80 ± 3	81 ± 3	68 ± 3	68 ± 3
Percent body fat	25 ± 2	24 ± 2	30 ± 2	31 ± 1	29 ± 2	29 ± 1	39 ± 2	38 ± 2
Fat free mass (kg)	62 ± 3	62 ± 3	43 ± 2	43 ± 2	56 ± 1	57 ± 1	41 ± 1	42 ± 1

All values are mean ± SE.
None of the within group differences were significantly different.

eration were set for medium speed for concentric testing (Con). The test initiation force was set at 50 N for the quadriceps muscle group and 75 N for the hamstrings muscle groups. PT was then measured at 0.52 rad·s^{-1}, using three warm-ups and three maximal efforts. During the maximal effort trials, subjects were motivated with loud and consistent vocal encouragement. Each test was followed with a minimum of 30-s rest. The highest value obtained during the three maximal efforts was used as the PT value. Only values for the quadriceps are reported, since that was the muscle group involved in the ST.

Training program. The ST program consisted of five sets of unilateral knee extension exercise of the dominant leg on a Keiser K-300 leg extension machine. Subjects trained 3 d·wk^{-1} for 9 wk. Each training session started with a light, 3-min warm-up on a cycle ergometer followed by supervised stretching of the quadriceps and hamstring muscle groups.

The training program consisted of a warm-up set comprising 5 repetitions at approximately 50% of the 1 RM value for the trained leg, followed by 4 training sets. The warm up set was followed by a 30-s rest period. The second set consisted of 5 RM, which was adjusted as needed to maintain a 5 RM throughout training. This set was followed by a 1.5-min rest interval. The third set consisted of 10 repetitions with the initial resistance set at the 5 RM value. During this set, subjects were instructed to perform as many repetitions as possible at the 5 RM resistance and then to decrease the resistance just enough to accomplish 1 or 2 more repetitions. This process of lowering the resistance was continued until a total of 10 repetitions were accomplished. This set was followed by a 2-min rest period. The 4th and 5th sets also started with a 5 RM resistance and were similar to the 3rd set, except the subjects completed 15 and 20 repetitions, respectively. The 4th set was followed by a 3-min rest period before the last set. During each set subjects were instructed to perform the concentric phase in ~1 s, and the eccentric phase in ~ 2 s. The purpose of this protocol was to provide an individualized training program that produced both a heavy relative resistance and high volume for each subject. Compliance to the training protocol was confirmed during every training session by direct observation of every repetition from at least one of the investigators at all times. The untrained leg was maintained in a neutral position throughout the training program.

Statistical analyses. Changes in 1 RM strength and PT were assessed by ANOVA with repeated measures. To assess whether absolute changes in 1 RM strength with ST and detraining differed between age and gender groups, absolute changes in 1 RM strength during ST and detraining were analyzed in an age × gender × time (2 × 2 × 4) ANOVA.

To determine whether there were differences between the two isokinetic strength tests performed before training to establish baseline testing, PT was analyzed using a 4 × 2 (group × time) repeated measures. An age × gender × time (2 × 2 × 4) analysis was performed to assess age and gender effects on PT in response to ST and detraining. Planned comparisons were performed to assess within group differences using Tukey's HSD and paired *t*-tests. Because they were planned before data collection, these analyses were performed independent of significant *F*-ratios in the overall ANOVA. All data are presented as means ± SE.

Pearson product correlations were used to assess whether the increases in strength during ST were related to decreases in strength during detraining for all subjects pooled together, as well as when subjects were divided into age and gender groups. Using a Fischer transform and a *z*-test, the correlations between the young and older subjects and between the men and women were tested to examine whether the correlations for each pairing were significantly different from each other. The level of significance was set at the 0.05 level for all comparisons.

RESULTS

Subjects. Table 1 shows the physical characteristics of all four groups. Before training, there were no significant differences in height between the young women and both groups of men, or between the older women and young women, but the older women were significantly shorter than both groups of men ($P < 0.05$). The body mass of the young men was similar to the older men, but significantly greater than both groups of women (both $P < 0.05$). Percent body fat was similar between the young and older men, whereas the older women had significantly greater percent body fat compared with the other three groups. $\dot{V}O_{2max}$ values for all four groups were consistent with their aerobically untrained status. Young subjects displayed $\dot{V}O_{2max}$ values that were significantly greater than the older subjects. In addition, the young men had $\dot{V}O_{2max}$ values that were significantly greater than those of the young women (all $P < 0.05$).

1 RM strength tests. Figure 1 shows the within group changes for the trained leg in response to training and

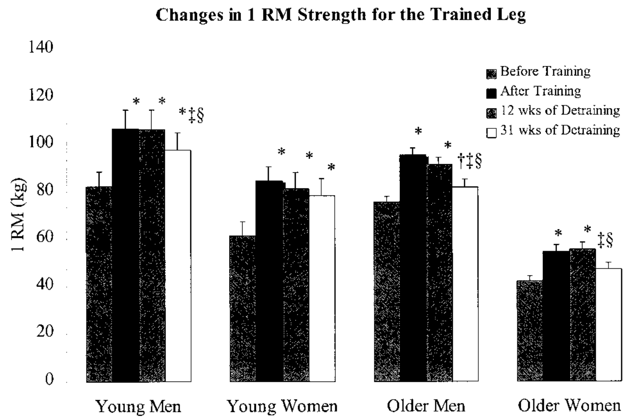

Figure 1—1 RM strength values in the trained leg before and after training and at 12 wk and 31 wk of detraining. * Significantly different from before training, $P < 0.01$. † Significantly different from before training, $P < 0.05$. ‡ Significantly different from after training, $P < 0.01$. § Significantly different from 12 wk of detraining, $P < 0.01$.

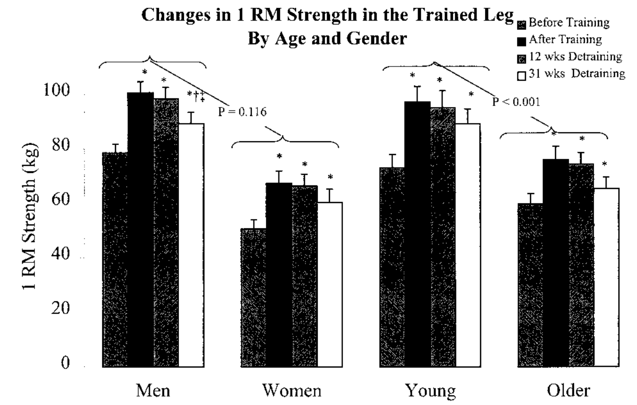

Figure 2—1 RM strength values in the trained leg before and after training and at 12 wk and 31 wk of detraining grouped by age and gender. * Significantly different from before training, $P < 0.05$; † Significantly different from after training, $P < 0.05$. ‡ Significantly different from 12 wk of detraining, $P < 0.05$. There was no significant age × time × gender ($P = 0.370$) or gender × time interaction ($P = 0.116$), but there was a significant age × time interaction ($P < 0.001$).

detraining in each of the age and gender groups. All four groups showed significant increases in 1 RM strength with ST and significant reductions with 31 wk of detraining (all $P < 0.05$, Fig. 1). There was a 31 ± 5% increase in young men (82 ± 6 vs 107 ± 8 kg, $P < 0.01$), a 39 ± 4% increase in young women (61 ± 6 vs 84 ± 6 kg, $P < 0.01$), a 27 ± 3% increase in older men (76 ± 2 vs 96 ± 3 kg, $P < 0.01$), and a 29 ± 4% increase in older women (42 ± 2 vs 55 ± 3 kg, $P < 0.01$). At 12 wk of detraining, none of the groups had strength values that were significantly different from their values after the ST program. By the end of 31 wk of detraining, the young and older men showed 1 RM values that were still significantly higher than before training ($P < 0.01$ and $P < 0.05$, respectively) but were significantly lower than values observed immediately after training and after 12 wk of detraining ($P < 0.01$). The strength value for the older women at 31 wk of detraining was not significantly different from their before training value and was significantly lower than their immediately after training and 12 wk detraining values ($P < 0.01$). In contrast, the strength value at 31 wk of detraining for the young women was still significantly higher than before training ($P < 0.01$) and was not significantly different from that obtained either immediately after training or at 12 wk of detraining.

There were significantly greater increases in 1 RM strength in the young compared with older subjects with ST (34 ± 3% vs 28 ± 3%, $P < 0.05$) and significantly greater losses in 1 RM strength with 31 wk of detraining in the older compared with the young subjects (14 ± 2% vs 8 ± 2%, $P < 0.05$) in the trained leg (see Fig. 2). There was no significant difference between age or gender groups for absolute changes in 1 RM strength during the first 12 wk of detraining, but age did affect strength changes between 12 and 31 wk of detraining, with the young subjects decreasing strength less than the older subjects (6 kg vs 9 kg, $P < 0.05$). When men were pooled across age, strength levels were significantly lower at 12 and 31 wk of detraining compared with right after training, whereas, strength levels in women at 12 and 31 wk were not significantly different than after training. However, there was no significant gender × time interaction with training or detraining ($P = 0.116$). In addition, strength levels of both men and women remained above baseline values at the end of the detraining period. Moreover, relative strength changes between after training and 31 wk of detraining were similar between men and women (11% vs 10%, respectively).

Within-group changes for the untrained leg are shown in Figure 3. The older men showed increases in 1 RM strength in the untrained leg after training ($P < 0.01$) that were maintained through 12 wk of detraining. By the end of the 31 wk of detraining, the older men showed 1 RM strength in the untrained leg that was significantly lower than after training ($P < 0.01$) and after 12 wk of detraining ($P < 0.01$) and was no longer higher than the before training value. Older women did not show any significant increases in 1 RM strength with training or any changes during detraining in the untrained leg. The young women significantly increased their 1 RM strength with training ($P < 0.01$) and maintained this increase throughout the detraining period

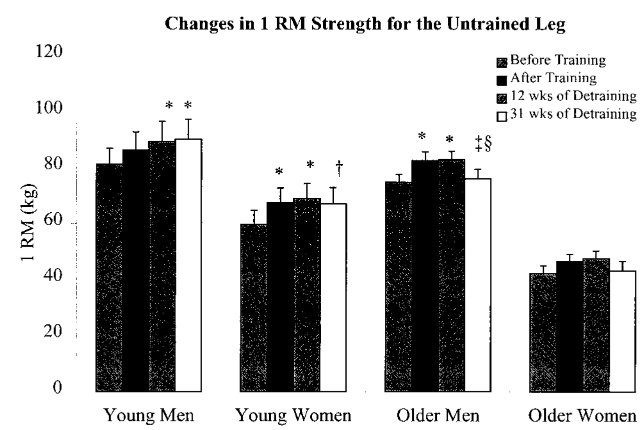

Figure 3—1 RM strength values in the untrained leg before and after training and at 12 wk and 31 wk of detraining. * Significantly different from before training, $P < 0.01$. † Significantly different from before training, $P < 0.05$. ‡ Significantly different from after training, $P < 0.01$. § Significantly different from 12 wk of detraining, $P < 0.01$.

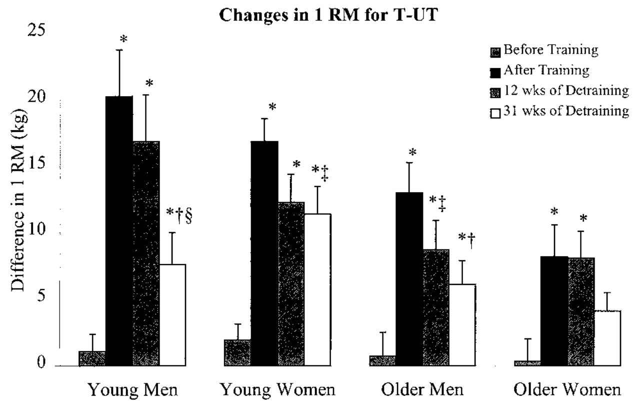

Figure 4—1 RM strength values for the difference between the trained leg and untrained leg (T-UT) before and after training and at 12 wk and 31 wk of detraining. * Significantly different from before training, $P < 0.01$. † Significantly different from after training, $P < 0.01$. ‡ Significantly different from after training, $P < 0.05$. § Significantly different from 12 wk of detraining, $P < 0.01$.

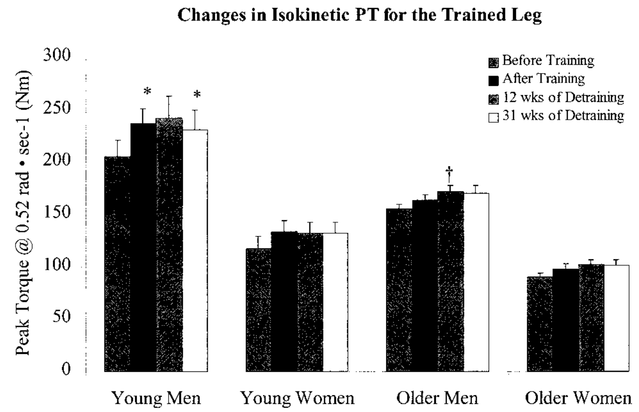

Figure 5—Isokinetic strength values at 0.52 rad·s^{-1} in the trained leg before and after training and at 12 wk and 31 wk of detraining. * Significantly different from before training, $P < 0.01$. † Significantly different from before training, $P < 0.05$.

($P < 0.05$), whereas the young men actually had increases during detraining ($P < 0.01$) but not immediately after training.

In the untrained leg, there was no significant interaction between age and gender or a difference in gender responses in 1 RM strength levels with training or detraining. However, the young subjects lost less strength compared with the older subjects during 31 wk of detraining ($P < 0.05$) and between 12 and 31 wk of detraining ($P < 0.05$) in the untrained leg. Changes in 1 RM strength with training and 12 wk of detraining showed no significant difference between or within age groups in the untrained leg.

Because strength increased with training in both the trained and untrained legs, we examined the question of whether the gains in the trained leg were still significant after the changes in the untrained leg were subtracted. The within group changes for the difference between the trained and untrained legs (T-UT) at each time point are shown in Figure 4. Changes in T-UT with training demonstrated greater increases in the young subjects compared with the older subjects ($P < 0.01$) and in men compared with women ($P < 0.05$). The T-UT for all groups was significantly and substantially greater than before training at all time points ($P < 0.01$), except at 31 wk of detraining when the older women had a T-UT value that was similar to their baseline value. At 12 wk of detraining, the older men had a T-UT that was significantly lower than their after training value ($P < 0.05$), whereas the other three groups had T-UT values that were not significantly different from their after training values. By 31 wk of detraining, the older men, the young men, and young women had T-UT values that were significantly lower than their after training values ($P < 0.01$). The young men were the only group whose 31 wk T-UT detraining value was significantly lower than their value at 12 wk of detraining ($P < 0.01$).

Pearson product correlations were performed to assess whether changes in 1 RM strength in response to ST were related to losses in 1 RM strength with detraining. The relationships between changes in 1 RM strength during ST and detraining were similar between groups when subjects were divided into men and women or young and older subjects, except when using the period between 12 and 31 wk of detraining. Therefore, except for the relationship between these two detraining time points, subjects were pooled together when assessing the relationships between changes in strength with ST and detraining. Significant, but weak, relationships were shown between increases in strength with ST and declines in strength after 12 (r $= -0.364$, $P < 0.05$) and 31 (r $= -0.333$, $P < 0.05$) wk of detraining. In contrast, there was no significant relationship between gains in strength with ST and losses in strength between 12 and 31 wk of training when all subjects were combined. There was, however, a significant relationship for the older (r $= -0.434$, $P < 0.05$) but not for the young subjects (r $= -0.170$, $P =$ NS) during this same time period. A strong relationship was observed between changes in 1 RM strength during 12 wk of detraining and declines in strength over the full 31 wk of detraining in the older (r $=$ 0.728, $P < 0.01$) but not young subjects (r $= 0.115$, $P =$ NS). Furthermore, there was no significant relationship between declines in 1 RM strength during 12 wk of detraining and declines in strength between 12 and 31 wk of detraining for all groups combined. Nevertheless, there was a strong significant relationship between losses in strength during the full 31 wk of detraining and losses between 12 and 31 wk of detraining (r $= 0.851$, $P < -0.01$) for all groups combined. There were no significant relationships for changes in strength with ST and detraining in the untrained leg.

Isokinetic peak torque (PT). The within-group changes for isokinetic PT in the trained leg are shown in Figure 5. Because there was no significant difference between the two baseline isokinetic tests, the average of the two baseline tests was calculated and used as the before training value. The trained leg showed no age, gender, or time interactions for PT in response to ST and detraining, but a significant change in PT was shown with ST and detraining. *Post hoc* analysis revealed that neither young nor older women showed any significant changes in isokinetic PT in the trained leg with ST or detraining. The older men showed a significant increase in PT at 12 wk of detraining from baseline in the trained leg ($P < 0.05$), whereas young men showed a significant increase in PT after training and at 12 and 31 wk of detraining ($P < 0.01$).

The young men were significantly stronger for PT at all time points in both the trained and untrained leg compared with the other three groups ($P < 0.05$), except at 12 wk of detraining when the older men and young men had similar values. The young women had isokinetic PT values similar to older men and women in both the trained and untrained leg at all time points, except before training when the older men had greater PT in the trained leg than the young women ($P < 0.05$). The young women demonstrated significantly lower PT than the young men at all time points in both the trained and untrained leg ($P < 0.05$). At all time points, in both the trained and untrained leg, the older men were significantly stronger than the older women and were significantly weaker than the young men ($P < 0.05$), except at 12 wk of detraining when the PT of the untrained leg was similar between the older and young men. The isokinetic strength of the older men was similar to the young women, except at 12 wk of detraining when the PT of the older men was significantly greater than the young women in the trained leg ($P < 0.05$). At all time points the older women had PT values that were significantly lower than both the older and young men ($P < 0.05$) but similar to the young women.

DISCUSSION

The results of this study show for the first time that age affects changes in 1 RM strength with ST, whereas gender does not. In response to 9 wk of ST, young subjects showed greater increases in 1 RM strength compared with the older subjects (34 $\pm$ 3% vs 28 $\pm$ 3%, respectively) Although these changes in 1 RM strength are significantly different between young and older subjects, both groups made substantial strength gains. In contrast to the changes in 1 RM strength with training, changes in 1 RM strength during 12 wk of detraining showed no differences between young and older subjects, or between men and women. Even after controlling for changes in the untrained leg, there was no age or gender effects on declines in 1 RM strength with 12 wk of detraining. However, young subjects did show smaller declines in 1 RM strength over the full 31 wk of detraining. This resulted from the older subjects demonstrating a greater loss of 1 RM strength than young subjects between 12 and 31 wk of detraining.

Our finding that gender does not affect 1 RM strength gains in response to ST is consistent with previous studies in young (5,6) and older (4,9) individuals. However, the finding that men show greater increases in 1 RM strength than women, when controlling for changes in the untrained leg, has not been reported previously to our knowledge. Why this gender difference appears after controlling for the changes in the untrained leg is unclear. The gender difference in the T-UT data appears to be the result of the large difference in T-UT values between the young men and older women.

Despite within group differences between men and women for strength declines during detraining, there was no gender $\times$ time interaction for changes in 1 RM strength with either training or detraining. Therefore, the reductions in strength with detraining was not significantly different between men and women (11 and 10%, respectively).

Interestingly, age and gender differences in response to ST may be in opposite directions for strength compared with muscle mass. We recently showed that increases in muscle mass in these same subjects were affected by gender, but not by age (16), with men increasing their muscle mass twice as much as women. This differential strength and muscle mass response to ST suggests that the neural adaptations to ST may be affected by age and/or gender. Some support for this hypothesis comes from the varying changes in cross-education between groups in the untrained leg, as well as the strength results in the trained leg from the nontraining specific isokinetic tests. In this regard, cross-education effects and strength increases that are specific to the training apparatus are thought to be good indicators of neural adaptations with ST. In our study, the older men and young women both demonstrated a cross-education effect and no significant change in isokinetic strength, suggesting that some of the increases in 1 RM strength in the trained leg in these two groups are likely due to neurological adaptations, perhaps alterations in motor unit recruitment patterns. In contrast, neither the young men nor older women showed a significant cross-education effect when comparing baseline 1 RM strength values with after training values. In addition, only the young men showed a significant increase in isokinetic PT after training, suggesting fewer alterations in motor unit recruitment patterns.

Previous research has shown that despite the higher baseline strength values in young compared with older individuals, the ST-induced increases in strength are similar between young and older subjects, ranging from ~ 30 to 44% increase (7,17,26,38). In the present study, we demonstrated that young subjects increased their 1 RM strength significantly more than older subjects both before and after accounting for changes in the untrained leg. The increases for the young and older groups were 34 $\pm$ 3% and 28 $\pm$ 3% respectively, which amounted to ~ 24 kg average increases in young subjects compared with ~16 kg in the older subjects.

We have no data in the present investigation to determine the mechanism for the smaller increase in 1 RM strength in response to ST in the older compared with young subjects. However, one possible mechanism could be related to the age-associated loss of Type II fiber number (19) and size (21) that have been reported previously. Lexell et al. (20) showed a selective increase in Type II fiber area in older men and women in response to ST, whereas Taaffe and Marcus (31) showed an increase in both Type I and II fiber area. Whether there is a reduced number and size of Type II fibers in the older subjects that could contribute to their decreased ability to increase their 1 RM strength in response to ST is unknown. Regardless of the mechanism that would explain this age difference in response to training, it should be emphasized that the relative increases in strength between the age groups were not substantially different. Furthermore, frail older individuals, the subset most likely to benefit from ST, have demonstrated very large relative increases in strength from such programs (9). The 28% increase in strength in our older subjects in the present study represents a reversal of ~ 30 yr of the age-associated decline in strength.

Our finding that 1 RM strength is maintained during 12 wk of detraining is consistent with some previous studies in both young (35,36) and older individuals (20,31). The finding that older individuals decrease 1 RM strength more than young individuals after 31 wk of detraining has not been reported previously. The young subjects decreased their 1 RM strength by 6 ± 2%, between 12 and 31 wk of detraining, whereas the older subjects decreased 1 RM strength by 13 ± 2% during the same time period. Thus, the 8 ± 2% total strength decrease in the young group compared with the 14 ± 2% decrease in 1 RM strength of the older subjects during the full 31 wk of detraining was explained primarily by this differential loss in strength between 12 and 31 wk of detraining. Possible explanations for this unequal loss of strength between 12 and 31 wk of detraining could include a greater decrease in fiber size with detraining and a greater loss of motor unit recruitment efficiency by the older subjects. Taaffe and Marcus (31) demonstrated that with 12 wk of detraining, 1 RM strength values decreased 5% and ST-induced increases in Type I and II fiber area had reverted to baseline values. In the current study, 1 RM strength showed no significant changes for young and older subjects over a similar time period as Taaffe and Marcus (31).

The lack of a gender effect for both young and older subjects with 31 wk of detraining is consistent with previous data in young men (6) and young women (30), demonstrating strength maintenance through 31 wk of detraining. It also extends the findings of Lexell et al. (20) who showed that a group of older Scandinavian men and women were able to maintain their gains in strength for 27 wk after training. The study by Lexell et al. (20) did not assess whether changes in strength during a period of detraining differed between genders. Thus, although previous findings are in accordance with the results of the current study, which show that strength can be maintained during a period of detraining in both young and older men and women, this is the first study that we are aware of that has shown no significant gender effect for the loss of strength with detraining.

Our analysis of the relationship between strength gains with ST and strength losses with detraining revealed the following: a) no significant relationship between gains in strength in response to ST and losses during 12 to 31 wk of detraining, b) losses in 1 RM strength during the full 31 wk of training were strongly associated with the losses in strength between 12 and 31 wk, and c) the losses during the first 12 wk of detraining were not related to the losses that occurred between 12 and 31 wk when all subjects were combined, but were strongly related in older subjects. Thus providing further support for our finding that losses in strength during detraining are influenced by age.

In summary, the results of this study show that age does influence the changes in 1 RM strength during both ST and detraining, whereas gender does not. However, after 31 wk of detraining, strength values were reduced to below the level observed right after training in men, but this difference did not quite reach statistical significance in women. The findings in the present study along with our other report (16) suggests that disuse atrophy does not entirely explain the decreases in muscular strength with advancing age. Nevertheless, the results do reinforce the idea that older individuals can respond well to ST, and maintain ST-induced increases in muscular strength just as well as young individuals for at least 12 wk after training has ceased.

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