

Does Sex Affect the Muscle Strength and Regional Lean Tissue Mass Response to Resistance Training in Older Adults?

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This study examined if the adaptation in muscle strength and whole body and regional lean tissue mass (LM) differs in older men (M) and women (W) subsequent to a program of high-intensity resistance exercise. Ten men and six women aged 65 - 78 yr underwent 20 weeks of training, twice per week, for 3 sets of 8RM for 7 upper and lower body exercises. Dynamic muscle strength was determined by 1-RM and isometric knee extensor strength by dynamometry. Lean tissue mass was determined by dual energy X-ray absorptiometry. Following training, men and women exhibited significant ($p < 0.001$) though similar increases in dynamic upper (women, $28.9 \pm 11.7\%$; men, $32.0 \pm 11.1\%$; mean \pm SD) and lower (W, $38.4 \pm 14.7\%$; M $30.3 \pm 11.7\%$) body strength, and isometric knee extensor strength. There was a significant time effect ($p < 0.001$) for whole body LM (W, 0.85 ± 0.83 kg; M, 0.70 ± 0.70 kg), upper limb LM (W, 0.21 ± 0.16 kg; M, 0.25 ± 0.13 kg), lower limb LM (W, 0.38 ± 0.42 kg; M, 0.27 ± 0.41 kg) and trunk LM (W, 0.25 ± 0.38 kg; M 0.18 ± 0.34 kg), with no interaction ($p = 0.58 - 0.78$). These results suggest that well-functioning older men and women show similar gains in muscle strength and whole body and regional lean tissue mass indicating comparable neuromuscular and anabolic responses accompanying resistance training.

Keywords: lean tissue mass, gender, aging

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1. INTRODUCTION

Sarcopenia leads to a loss in muscle strength and is associated with a decline in physical function that compromises independent living in older adults (Rosenberg, 1997). Numerous studies have shown resistance training to be an effective intervention to counteract sarcopenia, even in very old persons (Frontera, Meredith, O'Reilly, Knuttgen, & Evans, 1988; Hakkinen, et al., 2002; Hakkinen, et al., 1998; Fiatarone, et al., 1994; Taaffe, Duret, Wheeler, & Marcus, 1999; Fiatarone, et al., 1990; Taaffe, Pruitt, Pyka, Guido, & Marcus, 1996). Less clear is the effect of sex on the strength and anabolic response to resistance exercise. The majority of studies in young adults (Cureton, Collins, Hill, & McElhannon, 1988; Abe, DeHoyos, Pollock, & Garzarella, 2000; Staron, et al., 1994; Lemmer, et al., 2000; Roth,

et al., 2001; Hurlbut et al., 2002; Lemmer et al., 2001; O'Hagan, Sale, MacDougall, & Garner, 1995) indicate that men and women experience similar relative anabolic changes assessed by fat-free mass, muscle cross-sectional area (CSA) and fiber CSA after training, though others (Ivey et al., 2000) have reported a greater response in men.

In older adults (>60 years), studies have demonstrated similar relative muscle strength and whole body lean tissue changes between men and women following training (Fiatarone et al., 1994; Roth et al., 2001; Hurlbut et al., 2002; Lemmer et al., 2001; Martel et al., 1999; Ryan et al., 2004). However, sex differences in the regional response (upper limb, lower limb, and trunk) are yet to be determined. Additionally, there is a paucity of information regarding the response between these sub-regions (e.g. upper vs. lower limbs) in older

adults. Although of biological interest, from a practical perspective it is also important to know if the regions differ in their responsiveness to training so that exercise regimens can be refined to combat sarcopenia and the debilitating consequences of this condition. Here we examined the effect of a 20-week high intensity resistance training program on upper and lower muscle strength, and whole body and regional lean tissue mass in older men and women. We hypothesized that similar relative increases in muscle strength and whole body and regional lean tissue would occur in men and women as a result of the training.

2. METHODS

2.1. Subjects

Sixteen older adults (10 men and 6 women) aged 65 to 78 years were recruited via local community newspaper advertisements to participate in the study. Subjects were required to not have any musculoskeletal, cardiovascular or neurological disorder that could inhibit them from exercising, able to undertake upper and lower limb exercise, able to walk 400 meters, willing to undertake 20 weeks of resistance training uninterrupted and not to have participated in any resistance training in the previous 12 months. Prior to participation, all subjects obtained medical clearance from their physician and completed a health history questionnaire. On a 5-point self-rated health scale from poor to excellent, all subjects reported fair to very good health. The study was approved by the University's Medical Research Ethics Committee and all subjects provided written informed consent.

2.2. Training Program

Both men and women undertook progressive high-intensity resistance training twice a week for 20 weeks. Several subjects had to reschedule training sessions due to illness, travel and family commitments; make-up sessions were provided and all subjects completed the 40 exercise sessions within a 22-week period. Subjects were instructed to maintain customary activity and dietary patterns during the course of the study. The training program consisted of performing the chest press, seated row, triceps extension, biceps curl, leg press, leg curl

and leg extension exercises on resistance training machines (Maximum Strength Fitness Equipment Pty Ltd, South Australia, Australia) using 3 sets with intensity set at 8-repetition maximum (8-RM). Subjects were required to adjust the training weight to ensure failure at 8-RM. All sessions were conducted in small groups of up to 6 participants under direct supervision to ensure proper technique, safety, and appropriate exercise intensity.

2.3. Muscle Strength

Before determination of dynamic muscle strength at baseline, subjects underwent two familiarization sessions that included instruction regarding correct lifting technique and practice performing all seven exercises. Dynamic muscle strength of all 7 exercises was measured using the 1-RM, as described previously (Taaffe et al., 1999). The 1-RM is the maximal weight an individual can move through a full range of motion without change in body position other than that dictated by the specific exercise motion. Muscle strength was assessed twice at baseline, separated by 5 days, with the better of 2 strength measures used as the baseline value. Dynamic muscle strength was reassessed every 5 weeks, that is, at weeks 5, 10, 15, and 20. The coefficient of variation for repeated 1-RM measures was 2.2-7.5%. In addition, isometric peak knee extensor strength at an angle of 45° was assessed using a Cybex 6000 dynamometer (Cybex Division of Lumex, Inc, NY). Measures were made on the right side of the body with the thigh and trunk secured to the dynamometer chair. Prior to testing, subjects performed several sub-maximal isometric repetitions. Three trials of 5-second maximal voluntary contractions were performed with 30 seconds between trials. The highest values for isometric torque were used in subsequent analyses. The coefficient of variation for peak isometric strength was 7.5%.

2.4. Whole Body and Regional Lean Tissue

Whole body bone mineral-free lean tissue mass (WBLM, kg), upper limb lean tissue mass (ULLM, kg), lower limb lean tissue mass (LLLM, kg) and trunk lean mass (TrLM, kg) were assessed by dual energy X-ray absorptiometry (DXA, Hologic Discovery W, Waltham, MA). In addition, percent

Table 1 Subjects characteristics at baseline (Mean \pm SD).

	Men (n = 10)	Women (n = 6)
Age (yr)	69.7 \pm 4.3	69.6 \pm 4.8
Height (cm)*	173.5 \pm 8.5	160.4 \pm 4.9
Weight (kg)*	81.5 \pm 7.4	64.5 \pm 10.6
BMI (kg/m ²)	27.2 \pm 3.4	25.0 \pm 3.8
Body fat (%)*	29.7 \pm 4.5	37.4 \pm 4.6
Medications (#)	1.6 \pm 1.4	2.0 \pm 2.6

BMI = body mass index. Significant differences between men and women at baseline. * $P < 0.01$.

Table 2 Lean tissue and muscle strength at baseline and following 20 weeks training for men and women (Mean \pm SD).

	Men (n = 10)			Women (n = 6)		
	Baseline	Week 20	Percent Change (%)	Baseline	Week 20	Percent Change (%)
<i>Lean Tissue</i>						
WBLM (kg)*	53.9 \pm 3.8	54.6 \pm 3.6	1.3 \pm 1.3	37.7 \pm 4.1	38.6 \pm 3.5	2.3 \pm 2.3
ULLM (kg)*	6.1 \pm 0.6	6.4 \pm 0.6	4.0 \pm 2.1	3.6 \pm 0.4	3.8 \pm 0.3	5.8 \pm 5.4
LLLM (kg)*	17.8 \pm 1.8	18.0 \pm 1.7	1.5 \pm 2.2	11.9 \pm 1.4	12.3 \pm 1.3	3.2 \pm 3.5
TrLM (kg)*	26.4 \pm 1.9	26.6 \pm 1.8	0.7 \pm 0.5	19.1 \pm 2.2	19.4 \pm 1.9	1.5 \pm 1.4
ASM (kg)*	23.9 \pm 2.3	24.4 \pm 2.2	2.2 \pm 1.8	15.6 \pm 1.7	16.2 \pm 1.5	3.8 \pm 3.5
<i>Muscle strength</i>						
Upper body (1-RM, kg)*	38.8 \pm 4.4	47.5 \pm 5.1	32.0 \pm 11.1	20.5 \pm 4.5	26.5 \pm 4.0	38.4 \pm 14.7
Lower body (1-RM, kg)*	68.4 \pm 12.4	85.3 \pm 13.4	30.3 \pm 13.7	45.7 \pm 7.1	56.5 \pm 5.3	28.9 \pm 11.7
Whole body (1-RM, kg)*	51.6 \pm 7.6	64.1 \pm 8.3	31.4 \pm 9.1	31.0 \pm 5.4	39.3 \pm 3.9	35.7 \pm 15.1
KE isometric (Nm)*	151.7 \pm 35.4	172.6 \pm 32.9	14.7 \pm 14.0	100.5 \pm 15.0	129.2 \pm 14.9	33.2 \pm 12.9

WBLM = whole body bone mineral-free tissue mass, ULLM = upper body bone mineral-free tissue mass, LLLM = lower body bone mineral-free tissue mass, TrLM = trunk lean mass, ASM = appendicular skeletal muscle, 1-RM = one-repetition maximum, KE = knee extensors. Significant time effect, * $P < 0.001$.

body fat was also derived from the whole body scan. Regional analysis was derived by manipulating segmental lines according to specific anatomic landmarks (Taaffe et al., 2001; Taaffe, Lewis, & Marcus, 1994). A vertical line extended between the head of the humerus and the glenoid fossa separated the upper limbs from the trunk, while an oblique line through the femoral neck separated the lower limbs from the pelvis. Upper limb and lower limb lean tissue mass represent the sum of left and right extremities. ULLM and LLLM were then combined to derive appendicular skeletal muscle (ASM), which has been validated as an estimate of skeletal muscle mass (Heymsfield et al., 1990; Wang et al., 1996). Coefficients of variation (duplicate scans with repositioning) for WBLM, ULLM, LLLM, TrLM and ASM were 0.3%, 2.1%, 0.8%, 0.7% and 0.3%, respectively.

2.5. Statistical Analyses

Data were analyzed using the SPSS (SPSS Inc., Chicago, IL) statistical software package. Normality

of the distribution for outcome measures was tested using the Kolmogorov-Smirnov test. Analyses included standard descriptive statistics, independent and paired two-tailed Student's t-tests, and two-way (group \times time) analysis of variance. All tests were two-tailed and an alpha level of $p < 0.05$ was used as the criterion for significance. Results are given as the mean \pm SD, unless stated otherwise.

3. RESULTS

As expected, height and weight were greater in men than in women (**Table 1**). Whole body, regional lean mass and ASM were greater ($p < 0.01$) in men than in women (**Table 2**).

Following the intervention, there was a significant effect for time ($p < 0.001$) for average upper (chest press, seated row, biceps curl, triceps extension), lower (leg press, leg extension, leg curl), and whole body (chest press, seated row, biceps curl, triceps extension, leg press, leg extension, leg curl) dynamic strength with no significant interactions ($p = 0.054$ - 0.060) (**Table 2**). The time course for average

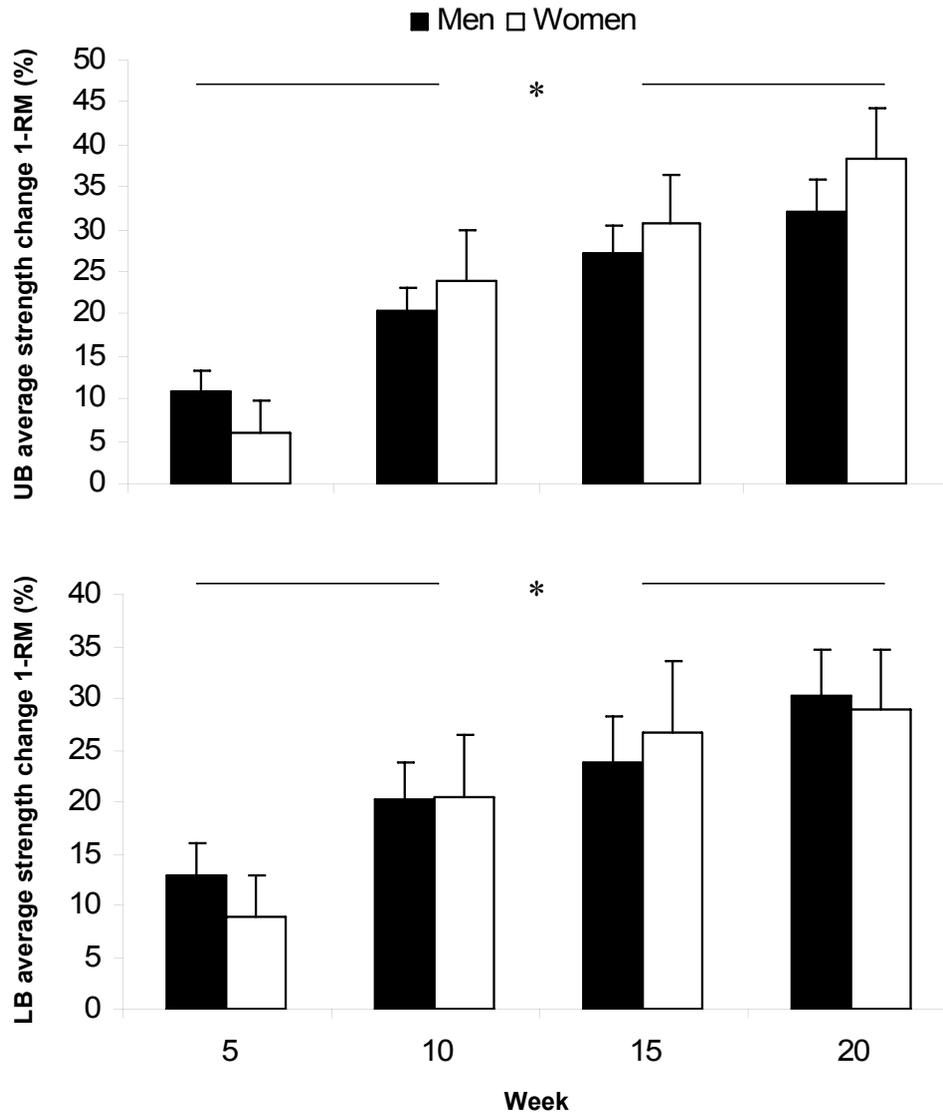


Figure 1 Time course of percentage change in 1-RM for men ($n = 10$) and women ($n = 6$). Top panel: (UB) upper body strength; bottom panel: lower body (LB) strength. Values are the mean \pm standard error. * Indicates significant time effect $p < 0.001$ for both men and women.

upper and lower body strength change is shown in **Figure 1**. In both men and women, strength increased in a systematic fashion over the 20-week period. However, considerable variation existed in the muscle strength response as shown in **Figure 2**. Isometric peak force of the knee extensors also increased (time effect, $p < 0.001$) for both men and women with no significant interaction ($p = 0.31$).

For both men and women, the resistance training program resulted in increased (time effect, $p < 0.001$) WBLM (0.85 ± 0.83 kg, women; 0.70 ± 0.70 kg, men), ULLM (0.21 ± 0.16 kg, women; 0.25 ± 0.13 kg, men), LLLM (0.38 ± 0.42 kg, women; 0.27 ± 0.41 kg, men), TrLM (0.25 ± 0.38 kg, women; 0.18 ± 0.34 kg, men) and ASM (0.59 ± 0.54 kg, women;

0.52 ± 0.44 kg, men). No group \times time interactions were detected (WBLM, $p = 0.78$; ULLM, $p = 0.58$; LLLM, $p = 0.60$; TrLM, $p = 0.70$; ASM, $p = 0.78$) indicating similar changes for both men and women. Individual responses for both men and women in appendicular skeletal muscle are provided in **Figure 3**. As there were no group \times time interactions for lean mass, men and women were pooled when comparing the magnitude of change of the sub-regions. The increase in ULLM was greater than that for the lower limb ($p < 0.05$) or for the trunk ($p < 0.001$).

4. DISCUSSION

In the present study, 20 weeks of resistance

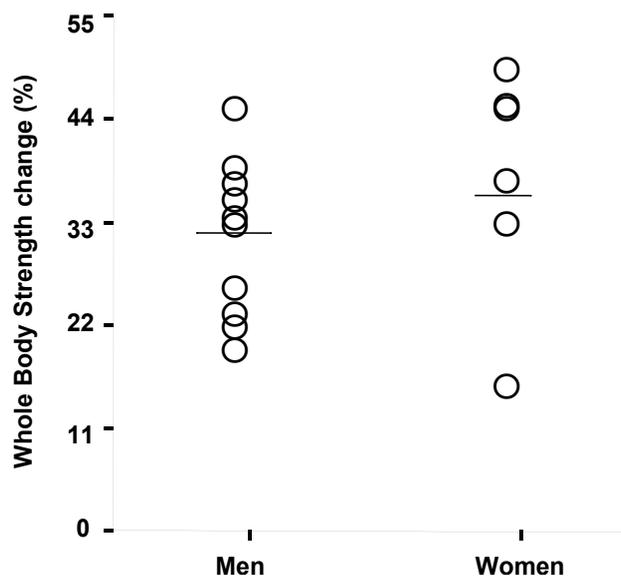


Figure 2 Individual changes for average whole body strength in men ($n = 10$) and women ($n = 6$) after 20 weeks of resistance training (- indicates means).

training resulted in comparable gains in whole body and regional (upper limb, lower limb, and trunk) lean mass as determined by DXA as well as upper and lower body muscle strength for apparently healthy, community-dwelling men and women. These findings extend those previously reported in older adults which found comparable whole body lean mass changes subsequent to resistance exercise (Hurlbut, et al., 2002; Lemmer, et al., 2001; Ryan, et al., 2004). Moreover, a greater variation in response was observed in women than men. In addition, we found that the relative gain in lean mass was greater for the upper limbs than for other segments of the body and may relate to differences in habitual activity patterns among the body segments.

Changes in whole body lean mass accretion with training were modest in our cohort being in the order of 1.3 to 2.3% for men and women, but are in agreement with most studies using similar training protocols in this age group (Hurlbut, et al., 2002; Lemmer, et al., 2001; Ryan, et al., 2004). For instance, Lemmer and colleagues (Lemmer, et al., 2001) reported that older men and women increased fat-free mass by 1.7 to 2.1% after 24 weeks of whole body resistance training ($p < 0.05$), with no significant difference by sex. Similarly, Hurlbut and associates (2002) found increases in fat-free mass of 1.5% ($p < 0.05$) for men and 2.2% for women, which approached statistical significance

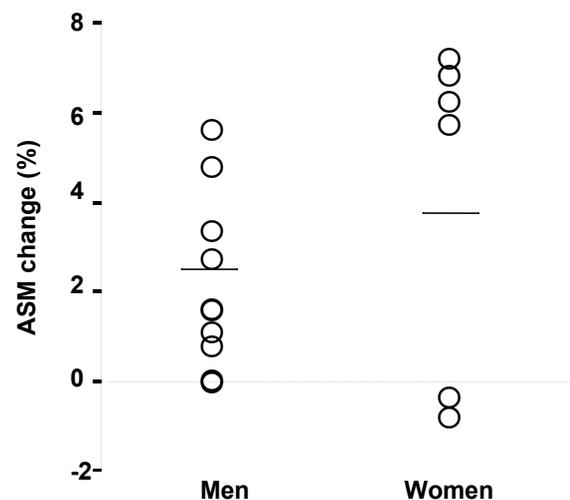


Figure 3 Individual changes in appendicular skeletal muscle (ASM) in men ($n = 10$) and women ($n = 6$) after 20 weeks of resistance training (- indicates means).

($p = 0.06$) following 24 weeks training. Recently, Ryan, et al., (2004) reported that a 24-week whole body resistance training program resulted in no significant change in fat-free mass for older women (1.7%) whereas the increase for older men of 1.6% was statistically significant. Interestingly, while percentage change in these studies (Hurlbut, et al., 2002; Ryan, et al., 2004) for fat-free mass was similar between men and women, the later group did not achieve statistical significance perhaps indicating a greater within-group variance. The current study also showed a greater variation among women than men for ASM and strength changes as shown in **Figures 2** and **3** indicating that women may not demonstrate as consistent a change in response to resistance training as men. It is also worthy to note that changes in LM were modest compared to the gains in muscle strength, indicating the dominant role of non-hypertrophic related factors, that is, neural adaptation (Sale, 1988), and possibly also alterations in muscle architecture (Narici, Roi, Landoni, Minetti, & Cerretelli, 1989), in enhancement of voluntary strength.

To our knowledge, the present study is the first to examine the lean tissue response by specific anatomical sub-regions between older men and women. The inclusion of sub-regional analyses by DXA provides additional information on body composition alterations subsequent to a program of

resistive exercise. In addition, ULLM and LLLM provide a valid estimate of skeletal muscle mass and changes resulting from exercise (Heymsfield, et al., 1990) as they are not confounded by non-skeletal muscle lean tissue. Based on this segmental analysis, we found that the increase for the upper limbs was greater than that for the lower limbs and trunk. Similarly, in younger adults, Abe and colleagues (Abe, et al., 2000) reported superior gains in muscle thickness assessed by ultrasound for the upper limb than the lower limbs following resistance training. Although the upper limbs are used in everyday activities, they are not weight-bearing and not under constant loading during standing and other mobility tasks, and as such, may be more responsive to the increased stimulus/loading resulting from resistance exercise.

Dynamic muscle strength similarly increased for the upper (32% and 38.4%), lower (30.3% and 28.9%), and whole body (31.4% and 35.7%) for both men and women, respectively. Moreover, the time course for change over the 20-week period was similar in men and women. In addition, there was no significant difference in knee extensor isometric strength between the sexes, although there was considerable within group variation and percent changes were more than double in women than men. Similar changes for average upper and lower body strength for both sexes have also been previously reported in most studies with a similar age group (Roth, et al., 2001; Lemmer, et al., 2001; Martel, et al., 1999; Ryan, et al., 2004; Tracy, et al., 1999) although not always (Bamman, et al., 2003). The majority of these studies, from 9 to 42 weeks in duration, found strength gains ranged from 20 to 40% (Hakkinen, et al., 2002; Hakkinen, et al., 1998; Lemmer, et al., 2000; Hurlbut, et al., 2002; Lemmer, et al., 2001; Martel, et al., 1999; Ryan, et al., 2004; Tracy, et al., 1999; Hunter, Bryan, Wetzstein, Zuckerman, & Bamman, 2002) for both men and women undertaking the same exercise program while some reported changes greater than 40% (Bamman, et al., 2003; Lexell, Downham, Larsson, Bruhn, & Morsing, 1995; McCartney, Hicks, Martin, & Webber, 1995). These results and ours clearly indicate that considerable adaptability to an appropriate stimulus remains in aging skeletal muscle.

It is important to note that the relatively small sample size likely limits the ability to detect

statistically significant differences between groups and should be considered when interpreting the results from this exercise trial, especially for muscle strength where the interactions for upper, lower and whole body strength approached statistical significance. Moreover, large inter-individual variation to the identical training protocol increased the standard deviation of the sample reducing the statistical power to detect differences. Future research should incorporate larger sample sizes with appropriate protocols to induce local or whole body anabolic change detectable by specific assessment techniques such as histochemistry and imaging techniques. In addition, the present study did not include a control group and a randomized controlled trial would have been a stronger design providing a higher level of evidence. Moreover, some of the improvement in muscle strength may be due to the Hawthorne effect. That is, this selected group of volunteers may have performed better just because they were part of the exercise study. However, this effect would unlikely to be a factor in the assessment of lean tissue mass due to the use of DXA as the assessment technique. Therefore, future studies should also include a control group. Lastly, subjects in this study were well-functioning older adults residing in the community, and it is unknown whether the same results would be observed in frail institutionalized elders. However, the work of Fiatarone and colleagues (Fiatarone, et al., 1994; Fiatarone, et al., 1990) indicates that this population retains the ability to adapt to resistance training in a similar fashion, if not better, than those residing in the community or younger age groups.

In summary, older men and women appear to show somewhat similar gains in upper and lower body muscle strength and whole body and regional lean tissue mass, indicating reasonably comparable neuromuscular and anabolic responses, following resistance training. Based on these findings, it appears appropriate to include older men and women in the same exercise regimen as the anabolic and muscle strength response is similar. However, it should be noted that in our cohort a greater variability in the anabolic response was observed for women than men. Future work should be conducted to determine the mechanisms underlying the greater variability in response of women to resistance exercise.

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