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Age and Sex Differentially Affect Regional Changes in One Repetition Maximum Strength

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Abstract. Lemmer, J.T., G.F. Martel, D.E. Hurlbut, and B.F. Hurley. Age and sex differentially affect regional changes in 1 repetition maximum strength. *J. Strength Cond. Res. 21(3):731–737. 2007.*—To assess the influences of age and sex on regional changes in 1 repetition maximum (1RM) strength, 10 young men (20–30 years), 8 young women (20–30 years), 11 older men (65–75 years), and 10 older women (65–75 years) were studied before and after a 24-week whole-body strength training program. Changes in 1RM strength were analyzed for each individual exercise, as well as by calculating a total body score (TBS), an upper body score (UBS), and a lower body score (LBS). The effect of age and sex on changes in 1RM strength was analyzed using a repeated measures analysis of variance. When changes in strength for individual exercises were analyzed, the chest press, lat pulldown, shoulder press, and triceps pushdown were affected by both age ($p < 0.05$) and sex ($p < 0.05$), while the biceps curls were only influenced by age ($p < 0.05$). For the lower body, the leg press changes in 1RM strength were influenced by age ($p < 0.0001$), while leg extension was influenced by sex ($p < 0.05$). Total body score, UBS, and LBS showed significant increases with 24 weeks of ST ($p < 0.001$, all). Changes in TBS and UBS were affected by age ($p < 0.001$, both) and sex ($p < 0.05$ and $p < 0.001$, respectively). Younger subjects showed a greater increase in strength than older subjects, and men showed a greater increase in strength compared with women. Changes in LBS were affected by age ($p < 0.001$), with younger subjects showing a greater increase in strength compared with the older subjects, but not by sex ($p = 0.464$). These data indicate that regional increases in strength are differentially affected by age and sex.

Key Words. resistance training, gender, weight training, aging

Introduction

Aging is characterized by a reduction in skeletal muscle mass (sarcopenia) (7, 9, 22, 33), which has been associated with declines in muscular strength (9, 22). Reduced strength in turn has been associated with an increased risk of falls (4, 21) and functional disability (3, 11). Consequently, sarcopenia has a negative impact on muscular strength and quality of life in older individuals.

Although sarcopenia manifests itself in older men and women, there is evidence that sex influences the rate of muscle mass loss (1, 7, 23, 33). In this regard, Visser et al. (33) demonstrated a decline in appendicular muscle mass over 2 years in older men but not older women. Additionally, older men demonstrate a greater rate of decline in lower appendicular muscle mass compared with women (7, 33).

There is also evidence for regional effects of sarcopenia, with lower appendicular muscle mass showing a greater rate of decline compared with the upper appendicular muscle mass (7, 22, 33). These sex and regional differences in sarcopenia may explain the reported sex and regional differences in declines in strength that occur with age (9, 13, 22).

Strength training (ST) has become a widely accepted intervention for the prevention and treatment of sarcopenia because of its safety and efficacy in older men and women (6, 10, 18, 19, 26, 27, 29, 30, 32), whereas this has not been shown consistently with other interventions (2). Currently, there are few studies that have included older and younger men and women to investigate the affect of age and sex on ST-induced increases in strength (14, 18, 19). We have previously reported using unilateral knee extension (18) and bilateral leg press (19) that increases in lower limb strength are affected by age but not sex. Furthermore, when changes in unilateral knee extension strength were controlled for changes in muscle mass, there was no affect of age or sex, thus indicating that nonmuscular factors contribute to changes in strength (12).

In contrast to the changes in lower limb strength, we previously showed that both age and sex influenced upper body increases in strength with ST (19). This suggests that age and sex differentially affect changes in strength between the upper and lower body. Furthermore, Jozsi et al. (14) showed that age differentially affected changes in strength when comparing multiple upper and lower body ST exercises. Thus, there is currently limited and conflicting information on the effect of age and sex on regional increases in strength with ST.

The practical implication of these regional effects on changes in strength is with the interpretation of studies that report strength changes by creating summation scores that combine lower and upper body strength measurements (25, 29, 31). These summation scores may lead to spurious conclusions about the effect of age and/or sex on changes in muscular strength, if increases in strength do differ between the upper and lower body (14, 18, 19). Additionally, it will provide evidence about whether the underlying biological influences of age and sex on strength declines affect the efficacy of ST in reversing these declines in strength.

Taking into account that sex influences regional reductions in muscle mass and strength and our previous finding that regional increases in strength are differentially affected by age and sex (18, 19), we hypothesized that in response to the same training program, age would affect increases in upper and lower body strength while sex would only affect upper body strength changes. In order to address this question, we analyzed the age and sex effects on 1 repetition maximum (1RM) strength for the biceps curl, chest press, lat pulldown, shoulder press, triceps pushdown, knee extension, and leg press exercises in response to 24 weeks of whole-body ST.

TABLE 1. Body composition changes for individual age and sex groups (mean ± *SE*).*

	Older men (n = 11)		Older women (n = 10)		Younger men (n = 10)		Younger women (n = 8)	
	Pre-ST	Post-ST	Pre-ST	Post-ST	Pre-ST	Post-ST	Pre-ST	Post-ST
Body mass (kg)	80.8 ± 3.0†	81.1 ± 2.9	69.9 ± 2.1	71.1 ± 2.3	84.4 ± 5.5	84.6 ± 5.3	65.4 ± 5.2	67.2 ± 5.6
Fat-free mass (kg)	56.5 ± 1.1	57.5 ± 1.0	41.1 ± 1.1§	42.0 ± 1.0	62.9 ± 2.4§	64.9 ± 2.4	43.2 ± 2.2‖	45.0 ± 2.5
Fat mass (kg)	24.3 ± 2.2	23.6 ± 2.1	28.8 ± 1.4	29.1 ± 1.8	21.9 ± 4.0	19.7 ± 3.4	22.2 ± 3.1	22.3 ± 3.1

* ST = strength training.
† Significantly different from younger women ($p < 0.001$).
‡ Significantly different from younger men ($p < 0.05$).
§ Significantly different from older men ($p < 0.05$).
‖ Significantly different from older women ($p < 0.05$).

TABLE 2. Body composition changes by age and sex (mean ± *SE*).*

	Older (n = 21)		Young (n = 18)		Men (n = 21)		Women (n = 18)	
	Pre-ST	Post-ST	Pre-ST	Post-ST	Pre-ST	Post-ST	Pre-ST	Post-ST
Body mass (kg)	75.4 ± 2.2	76.1 ± 2.1	76.1 ± 4.4	77.0 ± 4.3	82.5 ± 3.0	82.7 ± 2.9	68.1 ± 2.4	69.5 ± 2.6†
Fat-free mass (kg)	48.8 ± 1.9	49.7 ± 1.9‡	54.3 ± 3.0	56.1 ± 3.0‡	59.6 ± 1.4	61.0 ± 1.5‡	42.0 ± 1.1	43.2 ± 1.2‡
Fat mass (kg)	26.5 ± 1.4	26.3 ± 1.5	22.0 ± 2.5	20.8 ± 2.3	23.1 ± 2.2	21.7 ± 2.0†	26.1 ± 1.7	26.2 ± 1.8

* ST = strength training.
† Significant change from pre-ST with training ($p < 0.05$).
‡ Significant change from pre-ST with training ($p < 0.001$).

METHODS

Experimental Approach to the Problem

In order to test the effect of age and sex on regional changes in muscular strength in response to 24 weeks of ST, we recruited young (20–30 years) and older (65–75 years) men and women. To make sure that we were testing changes in muscular strength independent of neurological changes, subjects performed 6 familiarization sessions prior to their initial 1RM strength test. We trained subjects on Keiser K-300 air-powered equipment (Keiser, Fresno, CA) because it allowed for easy modulation of the resistance during the training sessions, thus allowing us to train the subjects with near-maximal contractions for higher repetitions. Free-weight biceps curls were used for training of the arm flexor muscles due to lack of proper equipment for the Keiser machines. For the training period, we decided to use a standard 3 days per week training regime that exercised all the major muscle groups of the body. This whole-body approach to training was utilized because a primary goal of this research project was assessing the health benefits of whole-body ST. Subjects performed all sets to failure so that each set was normalized between subjects. In order to prevent a plateau in muscular strength gains, we had subjects perform a modified periodization protocol that divided the 24 weeks of ST into 2 12-week periods of training. During the first 12 weeks of training, subjects started at their 5RM resistance and then progressively lowered the resistance until a 15RM was completed. During the second 12 weeks of training, subjects started each set at 50% of their 1RM value and increased the resistance on the machines until failure occurred at 15RM.

Subjects

Older (65–75 years) and younger (20–30 years) men and women were recruited for this study. Thirty-nine people volunteered to participate in this study after being screened via a telephone interview, medical history, and thorough physical examination. Prior to their participation, subjects had all procedures and risks explained to them and signed a written informed consent that was approved by the institutional review boards at the University of Maryland, College Park, University of Maryland Medical School, Baltimore, and the Johns Hopkins School of Medicine. Subjects were compensated for their participation in the study. Subjects showed similar levels of physical activity at the beginning of the study, which did not change with the training (19).

Subjects consisted of 10 young men (age: 26.0 ± 0.8 years; height: 179.0 ± 2.3 cm), 8 young women (age: 26.7 ± 0.4 years; height: 169.0 ± 1.6 cm), 11 older men (age: 70.2 ± 0.8 years; height: 173.7 ± 1.6 cm), and 10 older women (age: 68.0 ± 1.1 years; height: 161.0 ± 2.2 cm). Changes in body composition for each group are presented in Table 1, and changes in body composition by age and sex are presented in Table 2.

At baseline, young and older men had more fat-free mass (FFM) than young and older women ($p < 0.001$). Young men had more FFM compared with older men ($p < 0.05$), while young and older women exhibited similar levels of FFM. Training induced a significant increase in FFM in all groups ($p < 0.001$) that was not affected by age or sex. However, older men and women increased FFM by half that of the young men and women (0.9 kg vs. 1.8 kg).

Fat mass was similar between all groups of subjects both before and after 24 weeks of ST. There was a time by sex interaction ($p < 0.05$) for changes in fat mass that resulted from a nonsignificant increase in women and a significant decrease in men ($p < 0.05$).

Body mass at baseline was similar between young and older men, as well as between young and older women. Men were significantly heavier compared with women ($p < 0.05$), and there was a significant increase in body mass with ST ($p < 0.05$). Body mass showed a significant increase for all subjects with training ($p < 0.05$), with no effects of age or sex.

Procedures

Fat-free mass and fat mass were measured using a Lunar DPXL dual-energy x-ray absorptiometer, as previously described (31). Subjects refrained from eating or drinking after midnight the night prior to the test. The instrument was calibrated daily using a known calibration standard. Scanning accuracy was assured by scanning a phantom of 41% oil and 59% water on a monthly basis.

To assess the effectiveness of the ST program, 1RM testing was conducted before and after the 24 weeks of training. Prior to conducting the 1RM test, subjects performed 6 familiarization sessions on the ST equipment using a light resistance to orient the subjects to the machines, to learn proper lifting technique, and to prevent injury and muscle soreness after the ST. Moreover, this procedure controls for the large increases in strength that occur due to motor unit recruitment efficiency and skill acquisition that happen during the initial stages of training.

The 1RM test was performed on Keiser K-300 leg press, leg extension, chest press, lat pulldown, shoulder press, and triceps pushdown machines. Additionally, 1RM of the biceps was measured using dumbbell biceps curls. Leg strength was tested unilaterally, but the summed values were used in the analysis. In addition to the 1RM test, a 5RM test was performed for each machine listed above, as well as for the Keiser leg curl, upperback, and abdominal machines. Straps and belts were used to stabilize subjects in order to minimize recruitment of outside muscle groups. The 1RM tests before and after training were conducted by the same investigator.

Before each 1RM testing session, subjects warmed up on a cycle ergometer for 3 minutes and performed supervised stretching of all the major muscle groups. The 1RM test began with a light 5-repetition warm-up, and then a resistance was chosen that was estimated to be just below the subject's 1RM strength. The subject lifted the weight 1 time through a full range of motion. If the subject was able to lift the resistance through the full range of motion, the resistance was increased and another attempt was made after 60 seconds of rest. This process was continued until the subject could no longer lift the prescribed resistance through a full range of motion. The highest weight lifted was recorded as the 1RM value. A similar process was conducted for the 5RM test, except that the subject was asked to lift the weight for 5 repetitions instead of 1.

Subjects performed whole-body ST for 1 hour per day, 3 days per week, for 24 weeks using Keiser K-300 air-powered exercise equipment. This equipment allows for easy modulation of the resistance within an exercise set. The ST sessions exercised all major muscle groups of the body and included unilateral leg press, leg curl and leg extension, chest press, lat pulldown, military press, upper back, and triceps pushdown machines. Biceps curls were performed unilaterally using free-weight dumbbells, while abdominal muscles were exercised with both the Keiser abdominal machine and abdominal crunches.

A modified periodization program was employed during this study in order to maximize strength gains during the 24 weeks of training by dividing the training into 2 12-week periods. During the first 12 weeks of training, subjects performed 1 set for all upper body exercises and 2 sets for the lower body exercises. After a warm-up at 50% of their 1RM, all exercises, except the biceps curls, started with a 5RM resistance. When a subject reached failure (fourth to fifth repetition), the subject used the hand triggers to lower the resistance just enough to perform 1 or 2 additional repetitions. This process of lowering the resistance at failure was repeated every 1 to 2 repetitions for all subsequent repetitions until 15 continuous repetitions were completed by the subject. This procedure allowed subjects to exert near-maximal effort on all repetitions in an individualized fashion. When a subject was able to perform more than 5 repetitions at the initial 5RM resistance, the resistance was increased for the next training session. The concentric phase of each repetition was performed in ~2 seconds and the eccentric in ~3 seconds.

During the second 12 weeks of training, subjects warmed up at 50% of their 1RM and gradually increased the resistance every 1 to 2 repetitions until failure occurred. This resulted in subjects' reaching failure at a 15RM set. Subjects were monitored to ensure that their resistance at failure was progressing with the training. During this period, the following training schedule was performed. On Mondays, subjects performed 1 set of the chest press, lat pulldown, and shoulder press exercises and 2 sets of the 3 leg exercises. On Wednesdays, subjects performed 1 set of all upper and lower body exercises. On Fridays, the ST session consisted of 1 set of triceps, upper back, abdominal crunches, and biceps curls and 2 sets of the leg exercises. Biceps curls and abdominal crunches were performed in the same manner as during the first 12 weeks of training. Abdominal crunches were performed on all training days.

During each phase of training, the beginning and ending weights were recorded in order to assess the increases in muscular strength that were occurring. All subjects were given 2 to 3 minutes of rest between sets throughout the entire ST program.

Statistical Analyses

Changes in 1RM strength with 24 weeks of whole-body ST were analyzed using a repeated measures analysis of variance. Sex and age were used as between subjects factors to determine the influence of these factors on 1RM strength changes with ST. Posthoc analysis for differences in body composition between individual subject groups was performed using Tukey's HSD, while age and sex effects were determined using paired and unpaired t-tests. All data are presented as mean ± SE.

Increases in 1RM strength were analyzed by creating 3 summation scores. The first score was a total body score (TBS) that was a sum of the 1RM scores for the 7 exercises measured in this study. Regional changes in strength were assessed by creating an upper body score (UBS) and a lower body score (LBS). The UBS was calculated by summing the 1RM values for the biceps curl, chest press, lat pulldown, shoulder press, and triceps curl. The LBS was calculated by summing the 1RM values for the leg press and knee extension. Lastly, the influence of age and sex on each exercise was determined.

RESULTS

Effects of Age and Sex on Changes in 1RM Strength

The effects of 24 weeks of ST, age, and sex on the increases in 1RM strength for each exercise are presented in Tables 3 and 4, respectively. Subjects showed significant increases in strength for all exercises ($p \le 0.001$).

Analysis for the upper-body exercises showed significant increases in 1RM strength with the 24 weeks of ST ($p < 0.001$ all exercises; Tables 3 and 4) that were influenced by age (Table 3) and sex (Table 4). Posthoc analysis showed that age (Table 3) affected the response for the biceps curls ($p < 0.001$), triceps pushdown ($p < 0.01$), chest press ($p < 0.001$), lat pulldown ($p < 0.05$), and

TABLE 3. Changes in 1 repetition maximum strength by age (mean ± *SE*).

	Young ($n = 18$)			Older ($n = 21$)		
	Pre-ST	Post-ST	%Δ	Pre-ST	Post-ST	%Δ
Biceps curl (kg)‡	26.1 ± 3.1	36.8 ± 3.4§	52.3	21.6 ± 1.6	28.0 ± 1.8§	32.9
Chest press (kg)‡*	55.8 ± 5.4	69.7 ± 6.7§	25.6	36.8 ± 2.4	43.3 ± 2.9§	18.1
Lat pulldown (kg)†	57.0 ± 5.8	70.7 ± 6.9§	26.5	40.4 ± 2.6	50.0 ± 3.3§	24.6
Shoulder press (kg)†	46.6 ± 3.8	55.8 ± 5.5§	18.1	32.4 ± 1.9	36.5 ± 2.3§	12.3
Triceps pushdown (kg)‡	64.6 ± 6.3	85.7 ± 8.8§	32.1	42.3 ± 2.8	54.3 ± 3.7§	29.3
Knee extension (kg)*	98.1 ± 7.8	122.8 ± 8.9§	31.6	63.0 ± 4.4	80.9 ± 5.6§	24.1
Leg press (kg)****	578.8 ± 38.5	749.7 ± 45.4§	29.5	447.8 ± 27.6	544.9 ± 27.2§	26.4

* The increase in strength with strength training (ST) was significantly influenced by age ($p < 0.05$).
† The increase in strength with ST was significantly influenced by age ($p < 0.01$).
‡ The increase in strength with ST was significantly influenced by age ($p < 0.001$).
§ The exercise showed a significant increase in 1RM strength with 24 weeks of ST ($p \leq 0.001$).

TABLE 4. Changes in 1 repetition maximum strength by sex (mean ± *SE*).

	Men ($n = 21$)			Women ($n = 18$)		
	Pre-ST	Post-ST	%Δ	Pre-ST	Post-ST	%Δ
Biceps curl (kg)	31.2 ± 1.9	40.5 ± 2.2§	31.4	15.0 ± 0.8	22.2 ± 0.9§	54.1
Chest press (kg)†	58.3 ± 4.0	70.9 ± 5.3§	21.2	30.7 ± 1.5	37.5 ± 2.2§	22.0
Lat pulldown (kg)‡	62.0 ± 3.8	76.7 ± 4.6§	24.0	31.7 ± 1.6	39.5 ± 1.8§	27.1
Shoulder press (kg) ‡	47.4 ± 3.1	57.3 ± 4.3§	20.5	29.0 ± 1.2	31.6 ± 1.5§	8.5
Triceps pushdown (kg)‡	65.9 ± 5.0	88.0 ± 6.9§	33.3	37.1 ± 2.3	46.5 ± 2.7§	27.5
Knee extension (kg)*	97.4 ± 6.3	123.4 ± 6.7§	21.7	58.0 ± 4.6	73.2 ± 5.9§	34.3
Leg press (kg)	613.4 ± 24.7	747.4 ± 33.3§	29.0	385.6 ± 24.2	513.5 ± 34.0§	26.9

* The increase in strength with strength training (ST) was significantly influenced by sex ($p < 0.05$).
† The increase in strength with ST was significantly influenced by sex ($p < 0.01$).
‡ The increase in strength with ST was significantly influenced by sex ($p < 0.001$).
§ The exercise showed a significant increase in 1RM strength with 24 weeks of ST ($p \leq 0.001$).

shoulder press ($p < 0.05$), with young subjects demonstrating a greater increase in 1RM strength with 24 weeks of ST compared with older subjects. The greater absolute increases in the younger subjects also translated in greater relative changes in strength when compared with the older subjects.

Posthoc analysis for the sex effect showed that both men and women increased strength with the 24 weeks of training ($p < 0.001$ all exercises; Table 4). Moreover, the sex interaction for the 4 upper body exercises resulted from a greater increase in strength in men compared with women (Table 4). Relative changes in strength were similar for men and women for the chest press, lat pulldown, and triceps pushdown (Table 4). However, men showed a greater relative increase for the shoulder press, while women showed a greater relative increase in strength for the biceps curl (Table 4).

Lower body exercises showed significant increases in strength with 24 weeks of ST (both $p \leq 0.001$; Tables 3 and 4). Moreover, changes in knee extension 1RM strength were influenced by sex ($p < 0.05$), but not age ($p = 0.120$), with men showing a greater increase in strength compared with women. While men showed greater absolute increases in 1RM strength for both the leg press and knee extension machines, women showed a greater relative increase for the knee extension compared with men. Men and women showed similar relative changes in 1RM strength for the leg press exercise. Changes in leg press 1RM strength were influenced by age ($p < 0.001$) but not sex ($p = 0.839$). The effect of age on changes in 1RM strength for the leg press resulted from the young subjects' having greater increases in strength than older subjects (Table 3).

The analyses for TBS, UBS, and LBS showed no time

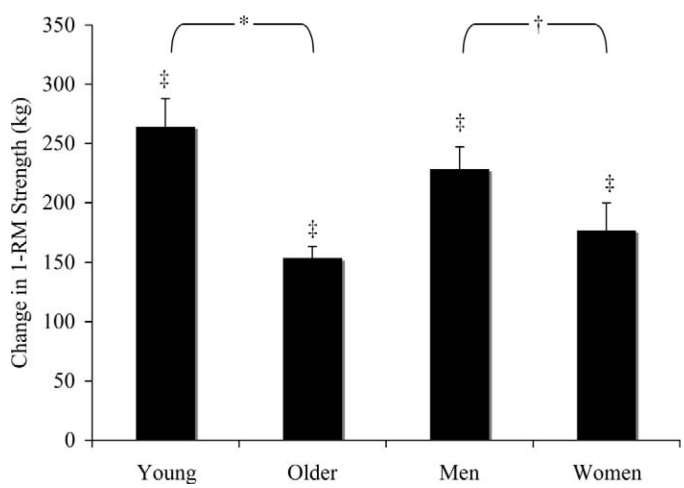

FIGURE 1. Changes in total body score (TBS) 1 repetition maximum (1RM) strength with 6 months of strength training (ST). The TBS is a summed value of the 1RM for all exercises. Samples sizes for each group are young ($n = 18$), older ($n = 21$), men ($n = 21$), and women ($n = 18$). Data are expressed as mean ± *SE*. * Age significantly influenced the change in TBS 1RM strength ($p < 0.001$). † Sex significantly influenced the change in TBS 1RM strength ($p < 0.05$). ‡ Group showed a significant increase in strength with 24 weeks of ST ($p < 0.001$).

by sex by age interactions. The TBS showed a significant increase in strength with the 24 weeks of ST ($p < 0.001$) and demonstrated both an age by time ($p < 0.001$) and a sex by time ($p < 0.05$) interaction (Figure 1). Posthoc analysis of the sex effect revealed that men were stronger than women before ($p < 0.001$) and after ($p < 0.001$) ST.

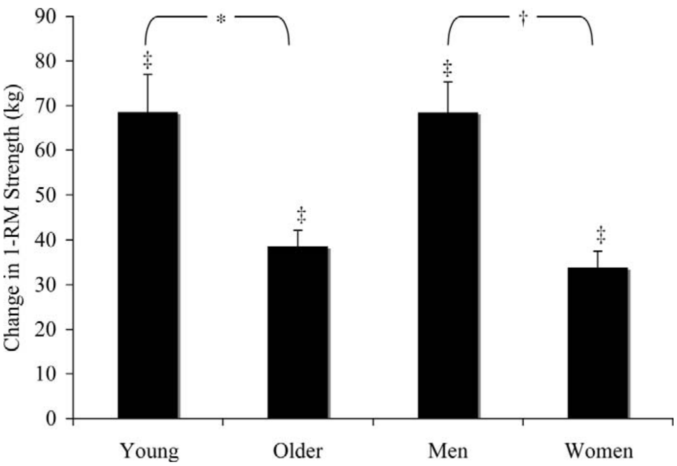

FIGURE 2. Changes in upper body score (UBS) 1RM strength with 6 months of ST. The UBS is a summed value of the 1RM for the biceps curl, chest press, lat pulldown, shoulder press, and triceps pushdown. Samples sizes for each group are young ($n = 18$), older ($n = 21$), men ($n = 21$), and women ($n = 18$). Data are expressed as mean ± *SE*. * Age significantly influenced the change in UBS 1RM strength ($p < 0.001$). † Sex significantly influenced the change in UBS 1RM strength ($p < 0.001$). ‡ Group showed a significant increase in strength with 24 weeks of ST ($p < 0.001$).

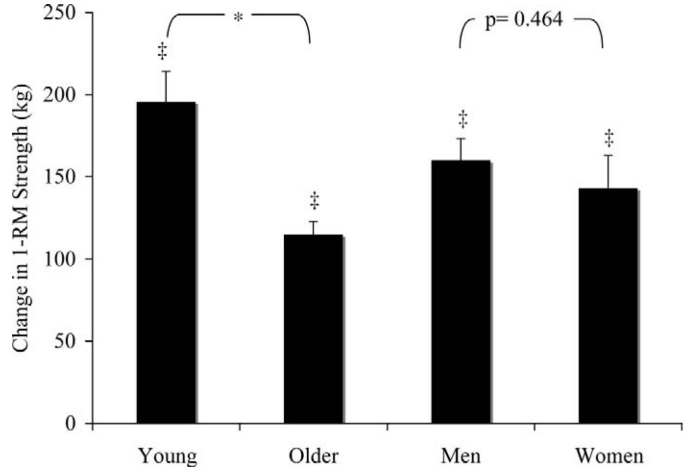

FIGURE 3. Changes in lower body score (LBS) 1RM strength with 6 months of ST. The LBS is a summed value of the 1RM for the knee extension and leg press. Samples sizes for each group are young ($n = 18$), older ($n = 21$), men ($n = 21$), and women ($n = 18$). Data are expressed as mean ± *SE*. * Age significantly influenced the change in LBS 1RM strength ($p < 0.001$). ‡ Group showed a significant increase in strength with 24 weeks of ST ($p < 0.001$).

Additionally, men compared with women demonstrated a greater increase in absolute TBS with training (Figure 1). Posthoc analysis of the age effect showed that young men and women were significantly stronger than older men and women both before ($p < 0.01$; Figure 1) and after ($p < 0.001$) ST. Additionally, younger men and women showed greater increases in TBS strength with ST compared with older men and women (Figure 1).

The analysis of changes in UBS showed significant increases with the ST ($p < 0.001$; Figure 2) and was influenced by a sex by time and an age by time interaction (both $p < 0.001$; Figure 2). Posthoc analysis of the sex by time interaction showed that men and women significantly increased UBS ($p < 0.001$, both) in response to the ST. Moreover, the sex effect resulted from men having a greater increase in their UBS compared with the women. Posthoc analysis of the effect of age on increases in UBS showed that both young and older subjects significantly increased strength with training ($p < 0.001$, both), while younger subjects increased UBS more than older subjects (Figure 2).

Similar to TBS and UBS, LBS showed a significant increase in strength in response to ST ($p < 0.001$; Figure 3). In contrast to TBS and UBS, LBS showed a time by age interaction ($p < 0.001$) but no time by sex interaction ($p = 0.464$). Posthoc analysis of the age effect showed that younger men and women increased strength more than older men and women (Figure 3).

DISCUSSION

The results of this study indicate that regional changes in muscular strength in response to 24 weeks of whole-body ST are influenced differentially by age and sex. Specifically, when the changes in strength were analyzed for age and sex effects, most upper body exercises were influenced by sex and age while the lower body exercises were differentially affected by sex and age. In this regard, the leg press showed an effect of age and the knee extension showed an effect of sex. Moreover, the summation scores for changes in UBS were influenced by both age and sex, whereas the changes in LBS were influenced only by age. Lastly, when changes in 1RM strength with the 24 weeks of ST were analyzed by summing 1RM values into a TBS, the change in strength was influenced by both age and sex. The influence of sex on TBS probably resulted from the influence of sex on the upper-body exercises. This study supports previous findings that the influence of age and sex on changes in muscular strength are muscle group dependent (14, 18, 19).

The consistent effect of age on changes in 1RM strength is not an unexpected finding and parallels the effect of age on strength declines that have been shown to occur with age (9, 13, 22). Our finding that the influence of age and sex is muscle group dependent is in accordance with the findings of Joszi et al. (14) that showed differential affects of age and sex on changes in strength between different muscle groups. However, these authors showed limited effects of age on changes in strength, which could be the result of their shorter training period compared with our study (12 vs. 24 weeks). It may take this extended time to cause the differential change in strength between younger and older men and women.

Although we did not measure regional changes in muscle mass in response to ST, it could be hypothesized that the most likely factor that caused the smaller increase in 1RM strength in the older compared with the younger subjects is a smaller increase in muscle mass. In this regard, previous studies have shown that sex and age differences on changes in muscular strength disappear after controlling for muscle mass (8, 12, 28). We analyzed changes in TBS after controlling for muscle mass and still showed that age affects changes in muscular strength (unpublished observation). This suggests that factors other than muscle mass contributed to the age effects demonstrated in this study.

Age-related reductions in total fiber number, reductions in type II muscle fibers proportions, and different hormonal responses between young and older subjects may contribute to the blunted increase in strength we demonstrated in our older subjects (15–17, 20). Additionally, there is evidence that skeletal muscle pennation angle and fascicle length change with age and could contribute to age-associated reductions in strength (24). In this study, we were not able to assess the contribution of these age-related physiological changes to the blunted strength increases in the elderly.

The effect of sex on strength increases with 24 weeks of ST shows an analogous effect to the declines in strength with advancing age in that upper-body but not lower-body changes are influenced by sex (22) and are in accordance with the findings of Joszi et al. (14). For the lower body exercise, our data did not show an effect of sex on the LBS, but when analyzed individually, the knee extension strength was influenced by sex. This finding is in accordance to the findings of Joszi et al. (14) that showed effects of sex on changes in strength with ST but is in opposition to the findings of Colliander et al. (5) that showed no effect of sex on changes in strength in response to 12 weeks of ST. The differential findings between Colliander et al. (5) and the current study may be explained by the shorter training period and the use of a 3RM in the previous study.

Although the specific aim of this project was to determine how age and sex influenced the adaptive response to a similar training protocol in young and older men and women, one limitation of this study may be the periodization program that was employed during the study. The intent of the first phase of training was to have the subjects perform each contraction at a near-maximal exertion, thus providing an optimal stimulus to the exercising muscles. The increasing resistance employed during the second phase of training did not have the subjects working at near-maximal exertions until the last few repetitions of the set, when the subjects reached fatigue. Therefore, it is possible that the second phase of training may have blunted the overall gains in strength that might have occurred if the first phase of training had continued or if a different form of periodization had been implemented.

In summary, this study shows that regional changes in 1RM strength are differentially affected by age and sex. In this regard, upper body changes in 1RM strength are influenced by both age and sex, while lower body exercises are differentially affected by age and sex. Additionally, the effect of age and sex differentially affect summation scores of 1RM strength, thus suggesting that the pooling of upper and lower body 1RM strength measures into summation scores may lead to erroneous conclusions when trying to determine the effect of age and sex on strength. Thus, we feel that these data suggest that it is more appropriate to analyze changes in strength for each individual exercise used during a ST protocol when assessing the influence of age and sex. Additionally, when designing an ST protocol for a research project, it is important to consider what muscle group is being utilized, especially if it is necessary to avoid age or sex influences on the strength response during the training period of the study.

Practical Applications

From these data, it is evident that older adults compared with younger adults have a reduced ability to increase whole-body muscular strength in response to a prolonged period of training. In this regard, the older subjects in this study showed smaller absolute and relative gains in 1RM strength with 24 weeks of training compared with the younger subjects. Because subjects performed the 1RM tests after accounting for the early neurological adaptations that occur with ST and performed all exercises to failure, this blunted response is mostly likely the result of morphological changes that occur in skeletal muscle with age and not differences in training volume.

Although men showed greater increases in absolute muscular strength compared with women for all exercises, women showed greater increase in relative strength for 2 exercises compared with men. Men showed a greater increase in relative strength for 1 of the remaining 5 exercises, while 4 of the 5 remaining exercise demonstrated similar increases in relative strength for men and women. The fact that 5 of the 7 exercises showed affects of sex supports the idea that regional changes in strength with ST are influenced by sex. Additionally, out of the 5 exercises that showed an effect of sex, 4 were upper body and 1 was lower body. This further supports the idea that regional changes in strength are sex dependent. What causes these differential sex responses is not clear from the data presented in this article. The practical implication for the personal trainer is that both age and gender should be taken into account when setting goals for their client's strength training prescriptions.

Last, the findings from our data show that use of summation scores to compare changes in muscular strength in groups that contain men and women is problematic. Specifically, conclusions about the effect of whole-body changes in strength with summation scores may be skewed due to the different regional changes between men and women. Thus, these authors suggest that the effect of age and sex on changes in strength should be determined for each individual exercise in a training program and not by summing the strength values into a composite score.

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