

Do Sex or Race Differences Influence Strength Training Effects on Muscle or Fat?

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ABSTRACT

WALTS, C. T., E. D. HANSON, M. J. DELMONICO, L. YAO, M. Q. WANG, and B. F. HURLEY. Do Sex or Race Differences Influence Strength Training Effects on Muscle or Fat? *Med. Sci. Sports Exerc.*, Vol. 40, No. 4, pp. 669–676, 2008. **Purpose:** To examine the influence of sex and race on the effects of strength training (ST) on thigh muscle volume (MV), mid thigh subcutaneous fat (SCF), and intermuscular fat (IMF). **Methods:** One hundred eighty-one previously inactive healthy Caucasian ($N = 117$) and African American ($N = 54$) men ($N = 82$) and women ($N = 99$), aged 50–85 yr, underwent about 10 wk of unilateral knee extension ST. Ten subjects were neither Caucasian nor African American and were, therefore, not included in the race analysis. Quadriceps MV and mid thigh SCF and IMF cross-sectional area were measured with computed tomography before and after ST. Sex and race comparisons were made with a 2×2 (sex by race) analysis of covariance. **Results:** Training-induced increases in absolute MV were significantly greater ($P < 0.001$) in men than in women, though both sex groups increased MV significantly with ST ($P < 0.001$), and the relative (%) increases were similar. There were significant increases in MV within race groups ($P < 0.001$), but no significant differences between races. There were no significant changes in SCF or IMF, whether sex and racial groups were separated or combined. In addition, there was no sex by race interaction for changes in MV, SCF, or IMF with ST. **Conclusion:** Strength training does not alter subcutaneous or intermuscular fat, regardless of sex or racial differences. Although men exhibit a greater muscle hypertrophic response to strength training than do women, the difference is small. Race does not influence this response. **Key Words:** RESISTANCE TRAINING, MUSCLE VOLUME, SUBCUTANEOUS FAT, INTERMUSCULAR FAT, REGIONAL BODY COMPOSITION

The loss of muscle mass with age (sarcopenia) is associated with a rise in total body fat as well as an increase in the amount of fat that infiltrates skeletal muscle (8). Maintaining reduced levels of fat in and around the muscle is important for the aging population because of its association with functional disabilities (33). Thus, delaying the onset of sarcopenia and its related consequences has important health implications for older adults.

Variations in regional body composition and its comorbidities seem to be related to sex and race differences in age-associated dysfunction and disability. For example, women have greater muscle lipid infiltration (8), higher subcutaneous fat (SCF) area, lower limb muscle mass (18),

and lower strength levels than men (22). Despite African Americans (AA) exhibiting greater limb muscle mass than Caucasians (7), older AA have greater absolute areas of thigh SCF and intermuscular fat (IMF) than their Caucasian counterparts (8). This finding suggests that elevated fat content within and around the muscle could at least partially explain why functional ability tends to be lower in older women (19) and AA men or women (24) when sex and race are analyzed independently.

Because strength training (ST) increases metabolically active tissue in older adults, thus increasing resting metabolic rate (RMR) (25) and energy requirements (3), it is sometimes recommended for preventing gains in body fat in older adults (3). Previous studies showing decreases in total (32) and regional (31) body fat mass with ST support the hypothesis that ST could lead to reductions in SCF and IMF. Some investigators have argued that resistance exercise alone can stimulate fat oxidation (10) and that lipolysis may provide energy during heavy-resistance exercise of relatively short duration (6). Early work by Havel et al. (12) has suggested that adipose tissue cells in close anatomic relation to muscle may be able to supply FFA to muscle by simple diffusion. However, full-body ST and aerobic exercise training studies have shown that local

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fat losses are unable to rule out losses in fat stores because of the caloric deficit produced by the training program. We are unaware of any direct evidence from ST studies that would either support or refute the hypothesis that ST can reduce fat depots surrounding the specific muscle groups being trained. In this regard, ST that targets a single muscle group offers an excellent model for addressing the issue of ST-induced, region-specific fat loss.

Ross et al. (26,27) conclude that ST is just as effective as aerobic training for reducing regional fat stores after observing reductions in SCF measured by MRI in both upper- and lower-body compartments when combined with a controlled diet. Treuth et al. (32) also have observed significant reductions in regional (arms, legs, and trunk) and total body fat mass with ST in middle-aged and older men. In a separate study, Treuth et al. (31) report a significant decline in intraabdominal fat with ST in postmenopausal women. Similar findings have been demonstrated by Hunter et al. (13) in older women, but they found no significant reduction in intraabdominal fat or SCF in older men. In contrast to the findings of Ross et al. (26,27), Treuth et al. (31,32), and Hunter et al. (13), Binder et al. (2) have found no significant changes in trunk, intraabdominal, or SCF mass with ST in either men or women. Data from our lab show that change in IMF with ST is influenced by the adrenergic receptor genotype (34). However, sex and race comparisons were not made, and SCF was not measured in this study. More recently, Kostek et al. (16) compared sex differences in SCF responses to arm ST in young people and found no significant differences when assessed by MRI. Nevertheless, the sex and racial influence on the effects of ST on muscle fat (IMF and SCF) have not been reported in older adults, and there are inconsistent findings on the influence of sex on muscle size response to ST (15,16,28,29). Moreover, the racial influence on the effects of ST on muscle size is unknown.

In an effort to help resolve the conflicts and provide some of the missing information described above, this study was designed to determine the influence of sex and race differences on the effects of ST on regional body composition. To achieve this purpose, MV of the trained musculature and midthigh IMF and SCF were assessed in the trained and untrained leg before and after ST in healthy middle-aged and older adults. Our primary hypothesis is that men (of both racial groups) and Caucasians (of both sexes) will experience significantly greater decreases in midthigh IMF and SCF when expressed in absolute terms than women or AA in response to ST.

METHODS

Subjects. One-hundred eighty-one relatively healthy, physically inactive volunteers (82 men (63 ± 0.9 yr), 99 women (63 ± 0.9 yr); 117 Caucasians (64 ± 0.8 yr) and 54 AA (61 ± 1.0 yr)) were studied before and after an ST program. Ten of these subjects were of a racial

classification other than Caucasian or AA and were not included in race analysis, because of the small number of subjects. Physically inactive was defined as not having participated in aerobic exercise more than one time per week for more than 20 min. Subjects reported that they had not participated in a regular ST program for at least 6 months before the study. All subjects underwent a phone-screening interview where race was self-reported, received medical clearance from their primary care physician, and completed a detailed medical history before participating in this study. They were nonsmokers and were free of significant cardiovascular, metabolic, or musculoskeletal disorders that would affect their ability to safely perform heavy resistance exercise. Subjects who were already taking medications for at least 3 wk before the start of the study were permitted into the study, provided they did not change medications or dosages at any time throughout the study. After all methods and procedures were explained, subjects read and signed a written consent form, which was approved by the institutional review board of the University of Maryland, College Park. All subjects were reminded throughout the study not to alter physical activity levels or dietary habits for the duration of the study. Body weight was monitored weekly throughout the study to ensure compliance in maintaining a stable diet. All subject information is kept confidential.

Strength testing. The one-repetition maximum (1RM) strength test was performed for both legs on a knee extension (KE) exercise before and after a unilateral (one-legged) KE ST program, using an air-powered resistance machine (Keiser A-300 Leg Extension machine, Keiser Sports/Health Equip. Co., Inc., Fresno, CA). Before the ST program and the 1RM test, subjects performed at least one familiarization session in which they completed the training program exercise with little or no resistance and were instructed on proper warm-up, stretching, and exercise technique. This low-resistance training session was conducted to familiarize the subjects with the equipment, help prevent injuries, and reduce muscle soreness from strength testing and ST. Furthermore, the familiarization helped to control for 1RM increases attributable to skill (motor learning) acquisition during the initial stages of training. After a warm-up consisting of 2 min of light cycling, subjects were positioned with a pelvis strap to minimize the involvement of other muscle groups. Arms were placed either across their chest or on their thighs during exercise, but positioning was consistent from pre- to posttesting within subjects. The 1RM was achieved by gradually increasing the resistance after each successful repetition until the maximal load was obtained. A light system was used to indicate a successful attempt when the knee was extended to the full range of motion (ROM) of 165° of extension. For each leg, approximately the same number of trials (6–8) and similar rest periods between trials (~1 min) were used to reach the 1RM after training as before training. Subjects' ratings of perceived exertion and

pain/discomfort were monitored and recorded throughout the test. Standardized procedures with consistency of seat adjustment, body position, and level of vocal encouragement were used.

Regional body composition assessment. To quantify quadriceps MV, computed tomography (CT) imaging of the trained and untrained thighs was performed (GE Lightspeed Qxi, General Electric, Milwaukee, WI) at baseline and during the final week of the 10-wk unilateral ST program. Axial sections of both thighs were obtained, starting at the most distal point of the ischial tuberosity, down to the most proximal part of the patella, with the subjects in a supine position. Section thickness was fixed at 10 mm, with 40 mm separating each section, based on previous work in our laboratory by Tracy et al. (30). Quadriceps MV was estimated using a 4-cm interval between the center of each section. Each CT image was obtained at 120 kVp, with the scanning time set for 1 s at 40 mA. A 48-cm field of view and a 512×512 matrix were used to obtain a pixel resolution of 0.94 mm. Using MIPAV software (NIH, Bethesda, MD), technicians analyzed CT scans for each subject. They were blinded to subject identification, date of scan, and training status, for both baseline and posttraining scans. For each axial section, the cross-sectional area (CSA) of the quadriceps muscle group was manually outlined as a region of interest. The quadriceps CSA was outlined in every 10-mm axial image from the first section closest to the superior border of the patella to a point where the quadriceps muscle group is no longer reliably distinguishable from the adductor and hip flexor groups. The same number of sections proximal from the patella was measured for a particular subject before and after training, to ensure within-subject measurement replication. Final MV was calculated using the truncated cone formula as reported by Tracy et al. (30) and described by Ross et al. (27). Based on previous work in our lab (5), combined with recent analysis, coefficients of variation (CV) were calculated on the basis of repeated measures of selected axial sections of one subject on two separate days. Signifying within-investigator reliability, average intra-investigator CV was 1.6%.

To quantify midthigh SCF and IMF CSA, CT imaging of the trained and untrained midthighs was performed at baseline and during the last week of the 10-wk unilateral ST program. All scans were performed at least 24 h after the last exercise training session. Midthigh was defined as the midpoint of the most distal end of the ischial tuberosity and the most proximal part of the patella, while subjects were in a supine position. After the midthigh slice was selected, the same number of sections proximal from the patella was selected for the posttraining assessments, to ensure identical within-subject measurement replication. The CT equipment, MIPAV software, section thickness, and imaging procedure were the same as for MV measurements.

For each scan, technicians manually outlined the deep fascial plane surrounding the thigh muscles. Similar to MV

analysis, the technicians were blinded to subject identification, date of scan, and training status, for both baseline and posttraining scans. SCF was assessed by additionally outlining the entire midthigh and subtracting the area inside the deep fascial plane from the midthigh area. The IMF was distinguished by excluding the bone marrow fat from the deep fascial plane (9). The IMF was then segmented into a separate image, in which it was identified on the basis of Hounsfield units (HU), where IMF ranged from -190 to -30 , as previously described (9). Repeated-measurement CV was calculated for each investigator on the basis of repeated measures of a selected axial selection of one subject on two separate days. The average intrainvestigator CV was 0.9% for SCF and 4.3% for IMF.

Training-induced changes were calculated by subtracting the differences between pre- and posttest measures in the control leg from those in the trained leg. Measurements in the untrained leg served as a control for variation of MV, SCF, and IMF attributable to seasonal, methodological, motivational, attention, biological, and genetic factors.

Muscle quality. The 1RM value in kilograms of the dominant leg was divided by the MV of the dominant leg to determine the muscle quality (MQ) value, similar to previous work from our lab. MQ in this case is, therefore, representative of strength per unit of MV ($\text{kg} \cdot \text{cm}^{-3}$).

Total body composition assessment. Body composition was estimated by dual-energy x-ray absorptiometry (DXA) using the fan-beam technology (model QDR 4500A, Hologic, Waltham, MA). A total body scan was performed at baseline and again within a week after the ST program. A standardized procedure for patient positioning and use of the QDR software was used. Total-body fat-free mass (FFM), fat mass, and percent fat were analyzed using Hologic version 8.21 software for tissue area assessment. Total-body FFM was defined as lean soft-tissue mass plus total-body bone mineral content. The CV for all DXA measures of body composition were calculated from repeated scans of 10 subjects who were scanned three consecutive times with repositioning. The CV was 0.6% for FFM and 1.0% for percent fat (5). The scanner was calibrated daily against a spine calibration block and step phantom block supplied by the manufacturer. In addition, a whole-body phantom was scanned weekly to assess any machine drift over time.

Body weight was measured to the nearest 0.1 kg with subjects dressed in medical scrubs, and height was measured to the nearest 0.1 cm using a stadiometer (Harpender, Holtain, Wales, UK). Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

ST. The training program consisted of unilateral training of the knee extensors of the dominant leg, three times per week, for about 10 wk. This protocol has been demonstrated to effectively increase knee extensor strength and MV in sedentary men and women, 65–75 yr of age (5,15,28,29,34). Training was performed on a Keiser A-300 air-powered KE machine, which allowed for ease of

changing the resistance without interrupting the cadence of the exercise. The untrained control leg was kept in a relaxed position throughout the training program.

After a light warm-up (~2 min) on a stationary bicycle, the training consisted of five sets of KE exercise for those < 75 yr of age and four sets for those ≥ 75 yr of age. We did not have subjects ≥ 75 yr of age perform the last set because of concern that performing 50 repetitions at near-maximal effort for this age group would cause overtraining, possibly resulting in a reduction of strength gains. The protocol was designed to combine heavy resistance with high volume while eliciting near-maximal effort on all repetitions. The first set was considered a warm-up set and consisted of five repetitions at 50% of the previously determined 1RM strength value. The second set consisted of five repetitions at the current 5RM value. The 5RM value was originally set to 85% of the 1RM and was increased continually throughout the training program to reflect increases in strength. The first four or five repetitions of the third set were performed at the current 5RM value, and then the resistance was lowered just enough to complete one or two more repetitions before reaching muscular fatigue. This process was repeated until a total of 10 repetitions were completed. This same procedure was used for the fourth and fifth sets, but the total number of repetitions was increased in these sets to 15 and 20, respectively. The second, third, fourth, and fifth sets were preceded by rest periods lasting 30, 90, 150, and 180 s, respectively. A red light indicator was visible to the subject and flashed only when the full ROM was reached. The shortening phase of the exercise (formerly called the concentric phase) was performed in approximately 2 s, and the lengthening phase (formerly called the eccentric phase) lasted approximately 3 s. A seat belt was worn throughout the exercise session, and subjects placed their arms across their chest during exercise to minimize the involvement of assisting muscles. Subjects performed supervised stretching of the knee extensors and knee flexors after each training session. Trained research assistants carefully monitored the workouts of each participant for every training session during the approximately 10

wk of training. Resistance was adjusted accordingly within the set and for the following training session, to ensure that each repetition was performed using the proper resistance and form through the full ROM.

Statistical analysis. All statistical analysis was performed with SAS software (SAS version 9.1, SAS Institute, Inc., Cary, NC). The change in MV, SCF, and IMF was calculated by subtracting the change with ST in the untrained leg from the change in the trained leg. For each dependent variable, assumptions of normality were satisfied for residuals, and the large sample size allowed the analysis of covariance (ANCOVA) to be robust for deviations from the assumption of equal variance. Pearson correlations were used to determine the change with training covariates, which were analyzed because of their potential for having physiological effects on MV, SCF, and IMF. A potential covariate, medication use, was classified into four categories: diuretics, ACE inhibitors, hormone therapy, and antiinflammatory/pain reducers. However, only height was significantly correlated with MV change and was added to the model as a covariate.

The influence of ST on combined-group MV, SCF, and IMF was determined by a one-way ANOVA for each dependent variable. The influence of sex (men vs women) and race (Caucasian vs AA), along with the interaction of the two, on the response MV, SCF, and IMF had with ST, was determined by a 2×2 (sex $\times$ race) ANCOVA for each dependent variable. Statistical significance was set at $P < 0.05$, and data comparisons were expressed as least squared means $\pm$ SE.

RESULTS

Subject characteristics. Data were only analyzed from subjects who completed both pre- and posttesting. Overall compliance for the subjects who completed the ST intervention was 90.6%. Subjects were required to have a minimum compliance of 70% by the end of the 10 wk. Missing data were attributed to a combination of subjects being unavailable for certain tests, injuries, and equipment failure. Table 1 displays the physical characteristics before

TABLE 1. Physical characteristics at baseline and after strength training (ST) in men and women combined (overall) and separated.

	Overall (N = 171–181) ^a		Men (N = 78–82) ^a		Women (N = 92–99) ^a	
	Baseline	After ST	Baseline	After ST	Baseline	After ST
Age (yr)	63 $\pm$ 0.7	—	63 $\pm$ 0.9	—	63 $\pm$ 0.9	—
Height (cm)	168.1 $\pm$ 0.7	—	174.8 $\pm$ 0.8	—	162.3 $\pm$ 0.6	—
Body mass (kg)	80.6 $\pm$ 1.2	80.8 $\pm$ 1.2	88.2 $\pm$ 1.5	88.3 $\pm$ 1.5	74.4 $\pm$ 1.6	74.6 $\pm$ 1.6
BMI (kg·m ⁻²)	28.5 $\pm$ 0.4	28.6 $\pm$ 0.4	28.9 $\pm$ 0.5	29 $\pm$ 0.5	28.2 $\pm$ 0.6	28.3 $\pm$ 0.6
% fat	34.2 $\pm$ 0.6	33.5 $\pm$ 0.6*	27.9 $\pm$ 0.6	27.6 $\pm$ 0.6	39.3 $\pm$ 0.6	38.7 $\pm$ 0.6*
FFM (kg)	50.5 $\pm$ 0.9	51.1 $\pm$ 0.9*	60.3 $\pm$ 0.9	60.8 $\pm$ 0.9*	42.5 $\pm$ 0.7	42.9 $\pm$ 0.7*
1RM (kg)	25 $\pm$ 1	32 $\pm$ 1†	34 $\pm$ 1	42 $\pm$ 1††	18 $\pm$ 1	23 $\pm$ 1†
MQ (kg·cm ⁻³) $\times$ 10 ⁻²	1.7 $\pm$ 0.03	1.9 $\pm$ 0.03†	1.8 $\pm$ 0.04	2.1 $\pm$ 0.04†	1.5 $\pm$ 0.03	1.8 $\pm$ 0.03†

Values are means $\pm$ SE.

^a A range of sample sizes are provided to represent the range of subjects who completed baseline and post-ST testing for all variables. Missing data resulted from various reasons including injuries, missed testing sessions, and equipment failure.

BMI, body mass index; FFM, fat-free mass; 1RM, one-repetition maximum for knee extension in trained leg; MQ, muscle quality in trained leg.

* Significantly different from baseline ($P < 0.05$).

† Significantly different from baseline ($P < 0.001$).

‡ Within-group change in men significantly different from women ($P < 0.001$).

TABLE 2. Physical characteristics at baseline and after strength training (ST) in Caucasians and African Americans.

	Caucasians (N = 112–117) ^a		African Americans (N = 52–54) ^a	
	Baseline	After ST	Baseline	After ST
Age (yr)	64 ± 0.8	—	61 ± 1	—
Height (cm)	168.2 ± 0.9	—	168.2 ± 1.1	—
Body mass (kg)	79.2 ± 1.5	79.6 ± 1.5	83.1 ± 2.1†	83 ± 2.3†
BMI (kg·m ⁻²)	28.0 ± 0.5	28.1 ± 0.5	29.5 ± 0.7†	29.5 ± 0.7†
% fat	34.3 ± 0.7	33.7 ± 0.7	34.4 ± 1.1	33.9 ± 1.1
FFM (kg)	49.5 ± 1.1	50.1 ± 1.1	51.8 ± 1.5	52.3 ± 1.5
1RM (kg)	24 ± 1	31 ± 1*	27 ± 1	34 ± 1*
MQ (kg·cm ⁻³) × 10 ⁻²	1.7 ± 0.03	1.9 ± 0.03*	1.7 ± 0.04	1.9 ± 0.1*

Values are least squared means ± SE.

^a A range of sample sizes are provided to represent the range of subjects who completed baseline and post-ST testing for each variable.

BMI, body mass index; FFM, fat-free mass; 1RM, one-repetition maximum for knee extension in trained leg; MQ, muscle quality in trained leg.

* Significantly different from baseline ($P < 0.001$).

† Significantly different between race groups at this time point ($P < 0.05$).

and after the ST program for all subjects combined and for men and women separately. Although there was a small but significant decrease in percent fat for the overall group, there was no significant change in men and a 1.5% (0.6 of a unit) decrease ($P < 0.05$) in women with ST. There was also a small but significant increase in total-body FFM for the overall group ($P < 0.05$), but there was no significant difference between the men's and women's responses. Muscle strength (1RM) and MQ increased significantly with ST for the overall group and for both men and women analyzed separately (all $P < 0.001$). Men increased their relative 1RM strength by 23.5% compared with a 27.8% increase in women. Despite this slightly higher relative (%) mean difference for women, the men displayed significantly greater 1RM increases in absolute terms ($P < 0.001$). There were no significant differences between men and women in ST-induced MQ increases.

Table 2 shows the physical characteristics before and after the ST program for Caucasians and AA. AA had significantly greater body mass and BMI than Caucasians at baseline and after ST ($P < 0.05$). With ST, both racial groups increased relative knee extensor strength (29.2% in Caucasians and 25.9% in AA; $P < 0.001$) and MQ (11.8%

in Caucasians, 11.8% in AA; $P < 0.001$). AA had an increase in absolute strength that approached significance ($P = 0.068$) compared with the increase in Caucasians.

Sex differences in regional body composition responses to ST. When all participants were combined, MV increased significantly more ($P < 0.001$) with ST in the trained leg ($128.3 \pm 5.6 \text{ cm}^3$) than the untrained leg ($5.1 \pm 3.2 \text{ cm}^3$), as expected. However, changes from baseline to post-ST in the trained leg were not significantly different from those of the untrained leg for either SCF (0.05 ± 0.3 vs $-0.6 \pm 0.3 \text{ cm}^2$; $P = 0.15$) or IMF (-1.4 ± 0.6 vs $-1.3 \pm 0.6 \text{ cm}^2$; $P = 0.9$). For MV analysis, height was a covariate.

Table 3 presents the differences between the trained and untrained legs for MV, SCF, and IMF before and after the ST program, when participants are grouped by sex (men vs women). At baseline, there were no significant differences between the trained and untrained legs in men or women for MV, SCF, or IMF. When using MV values obtained from subtracting the changes in the knee extensors of the untrained legs from those of the trained legs, the training-induced increase in absolute MV was significantly greater in men ($149.6 \pm 12.1 \text{ cm}^3$) than women ($94.4 \pm 12.5 \text{ cm}^3$; $P < 0.001$). This accounted for a 9.1% increase in men compared with a 7.5% increase in women. There were no within-sex changes or between-sex differences for SCF and IMF when using the untrained leg as a control.

Race differences in regional body composition responses to ST. Table 4 displays the differences between the trained and untrained legs in MV, SCF, and IMF before and after the ST program, when participants are grouped by race. AA had significantly greater MV ($P < 0.01$), SCF ($P < 0.05$), and IMF ($P < 0.001$) at baseline and after ST than Caucasians. Within each racial group, the change in the trained-leg MV was significantly greater than the change in the untrained leg ($P < 0.001$), as expected. However, when using the untrained leg as a control, there were no significant differences between races in MV change.

There were no significant within-race changes with ST in SCF or IMF when controlling for the untrained leg.

TABLE 3. Trained and untrained knee extensor muscle volume, subcutaneous fat, and intermuscular fat before and after strength training (ST) in men and women.

	Muscle Volume (cm ³)		Subcutaneous Fat (cm ²)		Intermuscular Fat (cm ²)	
	Baseline	After ST	Baseline	After ST	Baseline	After ST
Men (N = 78–82) ^a						
Trained leg	1845.5 ± 41.4	2015.1 ± 41.4*†	53.4 ± 2.8	54.2 ± 2.8	52.1 ± 2.6	51.6 ± 2.6
Untrained leg	1814.9 ± 40.9	1817.2 ± 40.9	54.0 ± 2.8	53.9 ± 2.8	51.2 ± 2.4	50.4 ± 2.4
Women (N = 95–98) ^a						
Trained leg	1172.8 ± 24.2	1268.7 ± 24.2*	107.7 ± 5.0	107.3 ± 5.0	58.2 ± 3.1	56.3 ± 3.1
Untrained leg	1146.0 ± 25.3	1153.4 ± 25.3	105.3 ± 4.9	104.4 ± 4.9	58.7 ± 3.1	57.1 ± 3.1

Values are least squared means ± SE.

^a A range of sample sizes are provided to represent the range of subjects who completed baseline and post-ST testing for all variables. Missing data resulted from various reasons including injuries, missed testing sessions, and equipment failure.

Muscle volume covariates: height.

* Change in the trained leg is significantly greater than change in the untrained leg ($P < 0.001$).

† Change in the trained leg minus change in the untrained leg is significantly greater than that for women ($P < 0.001$).

No significant within- or between-group changes in subcutaneous fat or intermuscular fat with ST when using the untrained leg as a control.

TABLE 4. Trained and untrained knee extensor muscle volume, subcutaneous fat, and intermuscular fat before and after strength training (ST) in Caucasians, African Americans, and others.

	Muscle Volume (cm ³)		Subcutaneous Fat (cm ²)		Intermuscular Fat (cm ²)	
	Baseline	After ST	Baseline	After ST	Baseline	After ST
Caucasians (<i>N</i> = 114) ^a						
Trained leg	1408.6 ± 26.0	1532.0 ± 26.0*†	76.6 ± 4.0	76.6 ± 4.0	49.6 ± 2.1	48.6 ± 2.1
Untrained leg	1380.0 ± 24.9	1382.8 ± 24.9	75.7 ± 4.0	75.1 ± 4.0	49.6 ± 2.1	48.6 ± 2.1
African Americans (<i>N</i> = 51–52) ^a						
Trained leg	1624.2 ± 51.7‡	1768.6 ± 51.7†‡	97.0 ± 8.0‡	97.3 ± 8.0‡	67.5 ± 4.6‡	65.5 ± 4.6‡
Untrained leg	1594.9 ± 50.3‡	1607.7 ± 50.3‡	95.7 ± 7.6‡	94.8 ± 7.6‡	67.2 ± 4.6‡	65.5 ± 4.6‡

Values are least squared means ± SE.

^a A range of sample sizes are provided to represent the range of subjects who completed baseline and post-ST testing for all variables.

Muscle volume covariates: height.

* Significantly different from baseline (*P* < 0.05).

† Change in the trained leg is significantly greater than change in the untrained leg (*P* < 0.001).

‡ Significantly different between race groups at this time point (*P* < 0.05).

None of the within-group changes in MV were different between racial groups.

No significant within- or between-group changes in subcutaneous fat or intermuscular fat with ST.

Additionally, there were no significant differences between races in SCF and IMF change with ST. There were no significant interactions (sex × race) for ST-induced changes in MV, SCF, or IMF.

DISCUSSION

To our knowledge, this is the first study to examine the influence of both sex and race differences on the effect of ST on MV, SCF, and IMF in middle-aged and older adults. The results support our hypothesis that ST increases quadriceps MV to a greater absolute extent in men than in women, independently of race. However, despite the significantly greater hypertrophic effect in men, ST induces substantial muscle hypertrophy over a relatively short period of time in both men and women, in both Caucasians and AA. Furthermore, the relative increases were similar in men (9.1%) and women (7.5%). Sex or race did not influence SCF or IMF responses to ST. Even when all subjects were combined into one group, there was no significant reduction in SCF or IMF when changes in the untrained leg were subtracted from those of the trained leg. Thus, high-volume, heavy-resistance ST does not seem to affect SCF or IMF, regardless of sex or race.

Maintaining reduced levels of fat in and around the muscle is important for the aging population because of its association with metabolic disorders and functional disabilities (8,33). Regional fat accumulation is a well-established consequence of sarcopenia, but despite ST serving as a common intervention for the prevention and treatment of the consequences of sarcopenia, information is lacking on the effects of ST on local fat stores. Given that there is evidence that full-body ST increases energy requirements (3) and RMR (25), in addition to decreasing total (32) and regional (31) body fat mass, it seems reasonable to hypothesize that this training modality could lead to reductions in SCF and IMF. In this regard, Ross and coworkers (26,27) conclude that ST is as effective as aerobic training in reducing regional fat stores. They found reduced SCF in upper- and lower-body compartments with

both ST and aerobic training when combined with a controlled diet. Moreover, intramuscular fat oxidation increases during continuous muscle contraction (35). However, there are only two reports, to our knowledge, on the effects of ST on SCF (16,17), and only one on IMF (34). We hypothesized that men would experience greater losses of these fat depots than women because, in previous studies, only men increased RMR with ST (25), and men experienced larger reductions in intramuscular lipid with aerobic exercise training than did women (35). Nevertheless, a recent report supports the findings of the present study by showing no sex differences in the effects of ST on SCF (16). Cross-sectional studies have shown a lower relative total daily energy expenditure, RMR (4), and fat-oxidation rate (23) in AA than Caucasians, but we are unaware of any reports other than the present study that have investigated differences in response to ST.

It is unclear why the ST program did not result in significant reductions in midhigh SCF or IMF in the entire group or within sex or racial groups. One possibility, however, is that the ST protocol elicited too low of an energy expenditure to account for a high-enough caloric deficit. The total exercise time, excluding rest periods, was less than 5 min of a training modality that uses primarily anaerobic energy sources. Moreover, evidence of greater reliance on glucose metabolism (20) and lack of evidence for increased mitochondrial and capillary density would not support a hypothesis for preference of fat use with ST. However, ST can increase resting levels of norepinephrine (25), which stimulates lipolysis; increase RMR (25); and decrease respiratory exchange ratio (14). Nevertheless, there is no evidence that it causes substantial elevations in free fatty acid oxidation, which is the final step required for total body or regional fat loss. However, we have previously observed reductions in IMF with ST, but these effects were genotype dependent (35). It should be noted that unlike previous studies showing women to have greater muscle lipid infiltration (8) and higher SCF area (18), men and women in the present study did not have significantly different SCF or IMF values at baseline.

It could be argued that the volume of training targeted to the muscle group being analyzed in the present study is greater than those of previous studies that have demonstrated reductions in regional fat composition (31,32). However, the total metabolic cost of the training program may be a more important factor if free fatty acids mobilized from SCF and IMF must go through general systemic circulation before being oxidized by the muscle. Previous reports from our laboratory (25) and elsewhere (3) show that elevations in RMR with ST are achievable, but these studies used full-body ST protocols. It is also possible that the smaller muscle mass involvement in the current study training program may have precluded an increase in RMR, which could provide at least a partial explanation for reductions in localized fat in older women (31) and men (32) with ST in previous studies. Increases in RMR could potentially lead to greater total free fatty acid oxidation of muscle triglyceride, accounting for a greater reduction of both local and total fat.

The single-leg training protocol used in the present study serves as a good model to test the local fat reduction with ST hypothesis. The low total caloric expenditure helps rule out any effects on local fat attributed to total fat losses elicited from higher-caloric-expenditure training. In addition, none of the previous investigators reporting ST-induced reductions in total or regional fat were able to rule out dietary factors from influencing the results. However, the single-leg protocol used in the current study compares training effects to the untrained leg that was subject to the identical dietary effects as the trained leg, thus controlling for dietary factors for the first time. The use of the untrained leg also controls for normal drift in values attributable to deviations in methodology, biology, seasonal variation, genetic factors, and variations in attention and motivation between experimental and control groups.

In contrast to our findings of a sex difference in the muscle mass change with ST, Hakkinen et al. (11) have observed similar percent increases in quadriceps femoris cross-sectional area between men and women, aged 43–75 yr, after a 12-wk full-body ST program. However, this investigation did not evaluate the volume of the entire trained muscle group, as was done in the present study and in the study by Kostek et al. (16). Muscle hypertrophy has been shown to vary depending on the muscle region examined (21). Thus, measures of the trained muscle volume are recommended (30). Investigators from our group have demonstrated in a previous study that absolute increases in muscle size with ST were greater in older men than in older women following an ST protocol similar to the current one (29). Yet, when subjects were separated by age in the study by Ivey et al. (15), the difference between older men and women only approached significance ($P = 0.057$), and Roth et al. (28) show no sex influence on MV response when using a full-body ST protocol. Variations in training duration, number of exercises, number of sets, number of

exercise repetitions, level of resistance, and length of rest periods may explain some of the discrepancies for findings on the influence of sex differences on training responses. While ST has been shown to elicit significant increases in muscle mass in various age groups of men and women independently (2,3), no reports have directly compared men and women of advancing age with a sample size comparable with that of the present study and a design that controls for threats to internal validity, as was done in the present study. Thus, with the added statistical power, our data suggest that middle-aged and older men do indeed increase absolute MV to a greater extent than do women of similar age.

To our knowledge, this is the first study to examine the racial influence on the MV response to ST. We hypothesized that AA would increase their MV to a greater extent than would Caucasians, because young AA males have a greater relative amount of type IIa muscle fibers than do Caucasian males (1). Type IIa fibers were likely the predominant fiber type recruited and activated during training by this ST protocol. However, our data have failed to support our hypothesis by showing that race does not significantly alter muscle size responses to ST in middle-aged and older adults. Meanwhile, our data confirm previous reports that AA had greater muscle mass (7), SCF, and IMF (8) than Caucasians.

There are several limitations to the present study. For example, there was a wide age range (50–85 yr), and the AA were significantly younger than the Caucasians. It is possible that the younger subjects in the study could have different training responses than the older ones. Another limitation was the lack of a regulated diet between subjects. While subjects were instructed not to alter their diet or weight throughout the study, dietary consumption and caloric intake were not controlled. Also, even though HRT was in the correlation models used to determine potential covariates, the lack of analysis on menopause status could also be considered a limitation. Nonetheless, as indicated above, these effects should influence the untrained leg to the same effect as the trained leg.

In conclusion, it seems that the effects of ST on MV, SCF, and IMF are not affected by race, and SCF and IMF are not affected by sex differences in middle-aged and older adults. These data confirm previous reports from our lab that men increase MV in absolute terms to a greater extent than women with ST, though both sexes increase muscle mass significantly. Given that there seem to be racial differences among the elderly in some functional measures reported in previous studies, future studies should attempt to determine whether race plays a role in the functional or metabolic changes associated with ST.

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