

Muscle hypertrophy in men and women

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ABSTRACT

CURETON, K. J., M. A. COLLINS, D. W. HILL, and F. M. MCELHANNON, JR. Muscle hypertrophy in men and women. *Med. Sci. Sports. Exerc.*, Vol. 20, No. 4, pp. 338-344, 1988. It is widely believed that women experience less skeletal muscle hypertrophy consequent to heavy-resistance training than men. The purpose of this study was to test this hypothesis using both traditional indirect indicators as well as a direct measure of muscle size. Seven male experimental (ME), 8 female experimental (FE), and 7 control subjects were studied before and after a 16-wk weight training program, in which ME and FE trained 3 days·wk⁻¹ at 70 to 90% of maximum voluntary contraction using exercise designed to produce hypertrophy of the upper arm and thigh. Strength increased significantly ($P < 0.05$) in ME and FE, respectively, on elbow flexion (36.2 and 59.2%), elbow extension (32.6 and 41.7%), knee flexion (12.8 and 24.4%), and knee extension (28.8 and 33.9%) tests. Absolute changes were significantly greater in ME than FE in 2 of the 4 tests, whereas percentage changes were not significantly different. Substantial muscle hypertrophy occurred in the upper arms of both ME and FE as evidenced by significant increases in upper arm circumference (7.9 and 7.9%), bone-plus-muscle (B+M) cross-sectional area (CSA) estimated by anthropometry (17.5 and 20.4%), and muscle CSA determined from computed tomography scanning (15.9 and 22.8%). Changes by ME and FE were not significantly different, except for the absolute increase in estimated B+M CSA, which was significantly greater in ME (11.2 vs 7.4 cm²). No muscle hypertrophy occurred in the thigh of either ME and FE as evidenced by non-significant changes in thigh circumference (1.7 and 2.3%), B+M CSA (4.9 and 6.1%), and muscle CSA (2.9 and 2.9%). Changes by ME and FE in body weight, fat-free weight, and fat weight were not significant. We conclude that relative changes in strength and muscle hypertrophy consequent to weight training are similar in men and women.

ANTHROPOMETRY, BODY COMPOSITION, COMPUTED TOMOGRAPHY, GENDER, SEX DIFFERENCE, SKELETAL MUSCLE, STRENGTH, WEIGHT TRAINING

It is well known that heavy-resistance training increases skeletal muscle size and mass in humans (17, 21, 27) and other animals (8, 10, 27). The increased size reflects primarily an enlargement of the diameter of existing muscle fibers through the addition of new myofibrillar and sarcomplasmic protein (8, 21, 27). A number of investigators have concluded that despite apparently similar relative increases in strength, muscle hypertrophy resulting from weight training occurs to a lesser extent in women than in men (3, 14, 26, 40). The

difference has been hypothesized to be due to the lower blood testosterone concentration of women, a supposition that has been widely accepted (38).

There is reason to question, however, whether there is a sex difference in muscle hypertrophy. In studies directly comparing the effect of weight training on men and women, absolute changes in body weight, fat-free weight (FFW), and body circumference measures resulting from weight training by women have been somewhat lower or the same as those reported for men, but percentage changes have been similar or greater for women (13, 29, 40, 41). If muscle dimensions increase in a geometrically proportional manner (1), greater absolute changes would be expected to occur in men because of their substantially greater initial muscle size. If relative strength increases are similar in men and women, but relative hypertrophy is less in women, this would suggest neural adaptations to weight training are greater in women. However, Moritani and DeVries (29) found that the relative contributions of neural and hypertrophic adaptations to strength changes in men and women are similar. Animal studies also suggest skeletal muscle hypertrophy is not necessarily greater in males than in females. No sex difference in compensatory muscle hypertrophy has been observed in rats (16, 23-25) or mice (37), and greater muscle hypertrophy following weight training has been reported for female than male cats (28). In addition, there is virtually no direct information supporting the contention that lower blood androgen levels in women prevent muscle hypertrophy from occurring to the same relative extent as in men (13, 20, 39), as is widely believed.

Most previous research directly comparing the effect of weight training on muscle development in men and women (13, 29, 40, 41) has been severely limited by the use of only gross indirect indicators of muscle size, such as body weight, FFW, or body circumference measures. All of these measures, because they include the weight or size of a number of tissues in addition to muscle, may mask or incorrectly measure changes in muscle that result from heavy-resistance training. More direct measures of size are needed to resolve the ques-

tion of whether there is a sex difference in muscle hypertrophy in humans.

The purpose of the present study was to compare skeletal muscle hypertrophy resulting from heavy-resistance training in men and women, using both traditional indirect indicators (anthropometric and body composition measures) as well as a direct measure (computed tomography scan) of muscle size.

METHODS

Subjects. The subjects were 22 young men and women, 22 to 37 yr of age. Seven men and 8 women were recruited for the male experimental (ME) and female experimental (FE) groups, respectively, and 3 men and 4 women served as a control group (C). Only a single relatively small control group was utilized because of concern by the Institutional Review Board over any unnecessary radiation exposure to subjects. Because of time commitment required of the subjects who trained, random assignment of subjects to experimental and control groups was not possible.

Subject physical characteristics are summarized in Table 1. None of the subjects had participated in weight training for 6 months prior to the start of the study. Six of ME and six of FE had participated in weight training in the past for limited periods of time (<2 yr). Although there were no apparent differences between ME and FE in recent or past history of regular participation in heavy-resistance exercise, precise quantification of this experience was not possible. Written informed consent was obtained from all subjects.

Experimental design. Subjects in ME and FE participated in 16 wk of individualized progressive heavy-resistance weight training, designed to produce hypertrophy of the flexor and extensor muscles of the upper arms and thighs. During this time, C did not participate in any systematic heavy-resistance training. Training was three alternate days \cdot wk⁻¹, and consisted of 1 to 3 sets of a variety of weight training exercises involving flexion and extension of the arms and legs performed with free weights and weight machines. The exercises for the arms included several types of curls with one and two arms, elbow extensions performed with a latissimus machine and dumbbells, and bench press. The exercises for the legs included curls and knee extensions performed on a leg machine, several types of squats,

and leg press. The training volume for the arms and legs was similar. For each exercise, as many repetitions as possible were performed with weight requiring 70 to 90% of one repetition maximum (RM). On a given day, all participants (male and female) performed exactly the same exercise, utilizing weights that elicited the same percentage of the 1 RM. One RM tests were administered every 2 wk and used, in part, to adjust the relative training intensity. The absolute and relative intensity of the training were increased progressively from 70% of 1 RM initially to approximately 80 to 90% of 1 RM toward the end of the experiment following a periodization protocol (36). Training duration varied between 30 and 60 min \cdot session⁻¹. The relative intensity, duration, and frequency of training were exactly the same for men and women. Strength, direct and indirect measures of muscle size, and body composition were assessed prior to and following the weight training program.

Strength measures. Strength of the elbow flexors and extensors, and knee flexors and extensors was assessed using 1 RM tests. The specific tests were the two-arm curl (elbow flexion) performed with free weights, the triceps pushdown (elbow extension) performed with a latissimus machine, and the leg curl (knee flexion) and leg (knee) extension performed with a leg machine. These tests were selected because they were used routinely in the training. Subjects were familiarized with the tests on several occasions prior to collecting the pre-training data. The 1 RM for each test was determined through trial-and-error by progressively incrementing the weight lifted. When a lift was unsuccessful, two additional attempts were allowed. Approximately 1 min intervened between trials. The four tests were administered in succession, with approximately 15 min rest in between, using a balanced-order design. Procedures were identical at the pre-test and post-test. Strength was measured twice on two different days both before and after training. A Subjects \times Trials ANOVA revealed that mean scores were significantly ($P < 0.05$) higher on 3 of the 4 tests on day 2 of the pre-test and on two of the tests on day 2 of the post-test. Therefore, following the recommendations of Baumgartner and Jackson (2) for selecting a criterion score for multiple-trial physical performance tests, the strength scores from the second test day, which maximized the group mean for the majority of tests, were used as the criterion for both the pre-training and post-training data. Intra-class reliability coefficients for test scores on a single day for the four tests were high, ranging from 0.90 to 0.97 at the pre-test and from 0.97 to 0.99 at the post-test.

Muscle size measures. The cross-sectional areas (CSAs) of the musculature of the non-dominant upper arm and thigh were measured directly from computed axial tomography (CAT) scans obtained with GE model

TABLE 1. Subject physical characteristics (mean \pm SD).

Variable	Training		Control	
	Men (N = 7)	Women (N = 8)	Men (N = 3)	Women (N = 4)
Age (yr)	24.7 \pm 2.1	25.5 \pm 2.3	31.0 \pm 4.6	24.8 \pm 2.1
Height (cm)	176.1 \pm 6.1	165.1 \pm 7.8	176.6 \pm 10.6	162.3 \pm 4.6
Weight (kg)	77.0 \pm 5.5	56.7 \pm 7.0	81.0 \pm 8.0	56.3 \pm 7.4
Percent fat	17.5 \pm 5.7	22.5 \pm 4.7	19.2 \pm 3.3	22.0 \pm 4.7

8800 scanner. A 1-cm wide scan (120 kVp, 40 to 480 mas) perpendicular to the longitudinal axis of the limb was taken at 40% of the distance between the lateral epicondyle of the humerus and the acromion process of the scapula on the arm, and at 50% of the distance between the greater trochanter of the femur and popliteal crease on the thigh. Limb distances were measured using a digital anthropometer. Muscle, bone, and subcutaneous fat-plus-skin CSAs were measured using the computerized digitizer of the scanner. Flexor and extensor muscle areas were not measured separately because they could not be accurately distinguished in all scans. Window levels and widths utilized to visualize the images varied to maximize clarity of the bone-muscle and muscle-fat interfaces. Based on the work of Koehler et al. (18), technical error due to differences in the window levels and widths utilized in the pre-training and post-training scans was estimated to be less than 3.5% for the muscle and fat CSAs of the arm and leg.

Reproducibility of the muscle CSA measures was assessed by scanning 12 subjects twice, approximately 5 min apart, with the subject removed from the scanner and then repositioned for the second scan. The test-retest correlations for the arm and leg, respectively, were both 0.99, with mean (\pm SE) differences of 0.2 ± 0.2 and 0.0 ± 0.4 cm². Based on *t*-test for correlated data, the mean difference for the arm was not statistically significant. These data are consistent with those of Hudash et al. (15), who reported high reproducibility and validity for CAT scans of thigh muscle CSA.

Body composition. Body density was measured using underwater weighing with simultaneous measurement of residual lung volume. Residual volume was measured using an oxygen-rebreathing nitrogen-dilution method modified from Goldman and Buskirk (9). Percent fat was estimated from body density using the Siri (35) equation. FFW was calculated from body weight and the estimate of percent fat.

Statistical analysis. The significance of absolute changes in the dependent variables was evaluated using a 3×2 (Group \times Test) analysis of variance with repeated measures on the second factor. In instances in which a significant Group \times Test interaction was obtained, tests for partial (two group) interactions and for simple main effects were performed. Differences between groups in percentage changes on the dependent variables were tested using an analysis of variance and the Tukey *post-hoc* test. An α -level of 0.05 was used for all significance tests.

RESULTS

Strength. Pre-training and post-training means for the four strength tests in the three groups are presented in Figure 1. Strength increased significantly in ME and FE, respectively, on the elbow flexion (36.2 and 59.2%),

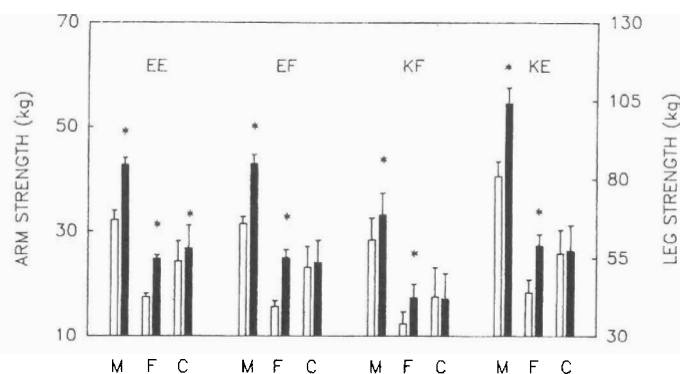


Figure 1—Mean (\pm SE) elbow extension (EE), elbow flexion (EF), knee extension (KE), and knee flexion (KF) strength in the ME (M), FE (F), and C groups before (*open bars*) and after (*solid bars*) heavy-resistance training. *Pre-training to post-training change significant at $P < 0.05$.

elbow extension (32.6 and 41.7%), knee flexion (12.8 and 24.4%), and knee extension (28.8 and 33.9%) tests. Changes for the C were small and non-significant, except for a significant increase in elbow-extension strength. The significant change by C may have reflected improved skill in performing this test. Absolute changes for ME and FE were significantly greater than for C for all tests. Increases in ME and FE were not significantly different for the elbow and knee flexion tests, but absolute changes by ME were significantly greater than FE on the elbow and leg extension tests. Percentage changes by ME and FE were not significantly different on any of the tests.

Muscle CSA. Mean pre-training and post-training upper arm and thigh muscle CSAs determined from the CAT scans are presented in Figure 2. Considerable muscle hypertrophy occurred in the upper arm, with muscle CSA increases averaging 16% for ME and 23% for FE. Absolute changes in muscle CSA for ME and FE were statistically significant and greater than for C, but not significantly different from each other. Percentage changes in muscle CSA by ME and FE were not significantly different. Changes in bone and fat CSA in ME, FE, and C were not statistically significant.

No muscle hypertrophy occurred in the thigh. Changes in thigh muscle CSA by ME, FE, and C were less than 3% and not significantly different. Changes in bone and fat CSA by ME, FE, and C were small and not significant.

Anthropometric measures. The pattern of findings for the anthropometric indicators of muscle size was almost identical to that obtained from the CAT scans. Changes in arm circumference and estimated muscle+bone (M+B) CSA (Fig. 3) for ME and FE were statistically significant and greater than for C, averaging 8% and 18 to 20%, respectively. The absolute changes in arm circumference for ME and FE were not significantly different, but the change in bone+muscle CSA was greater in men. Percentage changes in ME and FE

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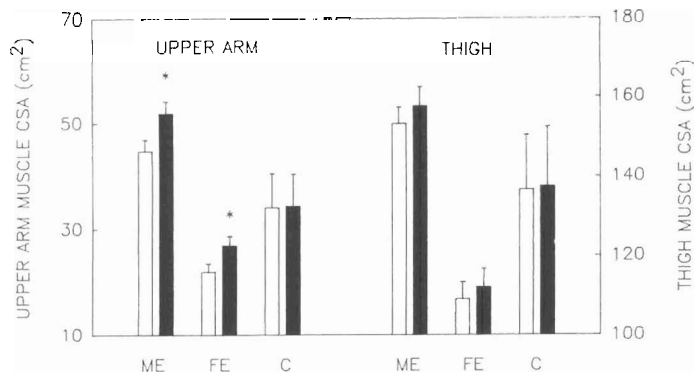


Figure 2—Mean (\pm SE) upper arm and thigh muscle CSAs determined from CAT scans in the ME, FE, and C groups before (*open bars*) and after (*solid bars*) heavy-resistance training. *Pre-training to post-training change significant at $P < 0.05$.

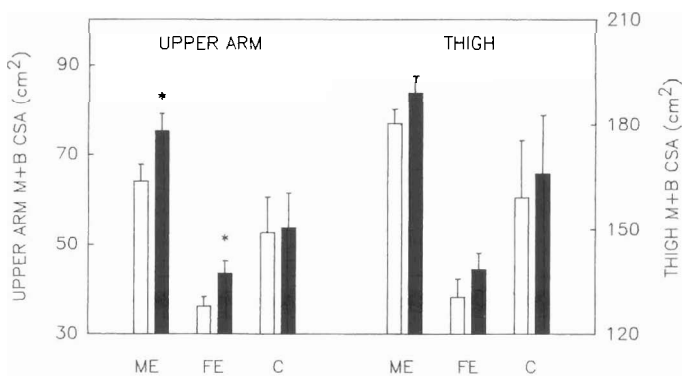


Figure 3—Mean (\pm SE) upper arm and thigh M+B CSAs estimated from anthropometric measures in the ME, FE, and C groups before (*open bars*) and after (*solid bars*) heavy-resistance training. *Pre-training to post-training change significant at $P < 0.05$.

were not significantly different. Changes in thigh circumference and M+B CSA in ME, FE, and C averaged 2 to 6%, and were not significantly different.

Body composition. There were no significant differences among groups in changes for body weight, FFW, or fat weight (Fig. 4). FFW, the primary variable of interest in relation to muscle hypertrophy, was essentially unchanged for both ME and FE.

DISCUSSION

The question of whether muscle development (hypertrophy) resulting from weight training occurs to the same extent in men and women is important for at least two reasons. First, the potential for increasing strength is in part linked to the potential for increasing muscle size (17, 27, 29). Increasing strength is important for improving some types of sport performance and for qualifying individuals for tasks in the military and in occupations such as law enforcement and fire fighting that require high levels of strength. Integration of women into physically demanding roles has been hampered by their lower levels of strength compared to

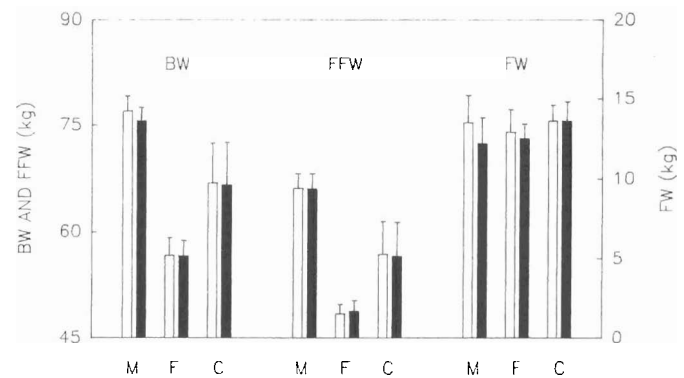


Figure 4—Mean (\pm SE) body weight (BW), FFW, and fat weight (FW) in the ME (M), FE (F), and C groups before (*open bars*) and after (*solid bars*) heavy-resistance training. *Pre-training to post-training change significant at $P < 0.05$.

men. And second, women have traditionally avoided weight training and other forms of heavy-resistance exercise for fear of developing large, defined muscles and appearing masculine. Accurate information concerning the effect of gender on muscle hypertrophy consequent to weight training is thus particularly important to women.

Most previous studies investigating the effect of weight training on women (3, 5, 26) or men and women (13, 29, 40, 41) have relied on body circumference and composition (FFW) measurements to indicate changes in muscle size. These measures are limited because changes in sub-cutaneous fat over the muscles of interest or alterations in non-muscular components of the fat-free body may mask or incorrectly indicate changes in muscle. Studies involving development (with weight training) and wasting of the quadriceps muscles have shown that changes in quadriceps CSA measured by ultrasound were underestimated and largely concealed by measures of thigh circumference (42, 43). CAT scanning, in contrast, provides an accurate, direct measure of limb muscle CSA (4, 12, 15) that should more validly quantify changes in muscle size consequent to heavy-resistance training. CAT scanning has been used to assess upper arm and thigh muscle CSA in a number of recent studies (11, 22, 31–34).

The primary finding of this study is that percentage changes in muscle hypertrophy consequent to heavy-resistance training were similar in men and women, although absolute changes tended to be larger in men. Absolute and percentage increases in upper arm muscle CSA determined from CAT scans were substantial and not significantly different in men (7 cm² or 15%) and women (5 cm² or 23%). The mean percentage increases in upper arm bone+muscle CSA estimated from anthropometric measures were similar to those for muscle CSA and not significantly different in men (18%) and women (20%), although the percentage changes for these two measures were only moderately correlated ($r = 0.67$). The absolute increase in estimated upper arm

M+B CSA was, however, significantly greater in men (11.2 cm²) than in women (7.4 cm²).

Similar percentage changes in men and women, but greater absolute changes in men, is an expected pattern of adaptation. Because muscle fiber and total muscle CSA of women typically average 60 to 85% that of men (7, 32–34), absolute changes in muscle size with training would be expected to be less in women and in proportion to their smaller dimensions (1). The differences in muscle CSA in untrained men and women are due to differences in both muscle fiber CSA and fiber number (32), or in some muscles, only differences in muscle fiber CSA (33, 34). The difference in muscle fiber number is probably an intrinsic, genetically based gender difference whereas the difference in muscle fiber CSA may reflect both a genetic gender difference and a behavioral difference in physical activity patterns. Heavy-resistance training appears to increase muscle fiber size to a similar relative extent in men and women, accounting for the similar relative change in muscle CSA (31), assuming no significant hyperplasia (21). The larger initial muscle fiber size plus a greater number of fibers undergoing hypertrophy in some muscles should account for the larger absolute change in men.

Although it has been hypothesized that lower blood androgen levels of women cause less relative exercise-induced muscle hypertrophy in women compared to men (3, 14, 26, 38, 40), the similar percentage changes in upper arm muscle CSA in the present study suggest this does not occur. This conclusion is consistent with studies that have found no relation between naturally occurring blood androgen levels and the extent of muscle hypertrophy consequent to weight training in men and women (13, 20, 39).

No muscle hypertrophy occurred in the thigh of either the men or women. The changes in muscle CSA determined from the CAT scans and anthropometric estimates M+B CSA in the men and women who trained were not significantly different than for the controls. This finding was unexpected. Other studies have reported significant increases in young men and women in thigh muscle CSA measured using ultrasound following weight training (6, 43). However, significant increases in upper arm circumference, but not in thigh or calf circumference, have been observed in other studies investigating the effect of weight training in women and men (13, 26, 40). We are uncertain why the training effect was so much smaller in the thigh than in the upper arm. Apparently, the training was simply an insufficient over-load to produce an adaptation in the legs, despite the fact that the relative intensity of and time spent on training of the arms and legs were similar. It is possible that a greater relative training stimulus was needed for the legs because the musculature of the arms was less trained and muscle fibers less hypertrophied at the initiation of the training. As for

the arms, however, there was no evidence that the adaptation to training was different in men and women.

The finding that FFW did not change consequent to weight training is contrary to most research. Typically, FFW will increase 1 to 2 kg in unconditioned men and women following 8 to 24 wk of weight training (3, 13, 26, 40, 41). The extent to which this change reflects a change in muscle tissue (hypertrophy) is unknown, however. Our data indicate that FFW will not necessarily increase despite considerable hypertrophy of the arm musculature. Decreases in other portions of the fat-free body may have offset the increase in arm muscle. This explanation is particularly plausible for ME, in whom body weight decreased 1.4 kg over the course of the experiment. It is also possible that the measurement of FFW was too insensitive to detect relatively small changes in arm muscle.

Our findings related to the effect of gender on muscle hypertrophy are in basic agreement with the few other studies that have directly compared the effect of heavy-resistance exercise on men and women. Wilmore (40) found significant increases in both men and women in a number of circumference measures following 10 wk of weight training. The absolute increases were greater in the men than women for the shoulder, chest, deltoid, biceps, and forearm circumferences by 0.2 to 0.6 cm. The mean percent increases for these circumferences (calculated from the pre-test and post-test means reported) were small, however, ranging from 0.7 to 2.4%, and essentially the same in men and women. As in the present study, Wilmore observed no significant changes in circumference measures on the leg (thigh and calf) in either men or women. FFW increased a similar amount in men (1.19 kg or 1.9%) and women (1.06 kg or 2.4%). Hetrick and Wilmore (13) found 8 wk of weight training increased upper arm circumference in men (2.0 cm or 7.0%) and women (1.8 cm or 7.1%) to an extent similar to that in the present study. They also reported thigh and calf circumferences were unchanged, and FFW increased more in women (1.7 kg or 3.8%) than in men (0.2 kg or 0.3%). Moritani and DeVries (29), observed a 6% increase in upper arm M+B CSA in two men and three women who trained with progressive resistance exercise for 8 wk. Although separate male and female data for estimated M+B CSA were not reported, the authors stated that the absolute increase in upper arm M+B CSA for the females was 53% that of the males (2.24 vs 4.23 cm², respectively). Assuming the initial M+B CSA of the women was approximately 55% that of the men, as in this study, then the percentage changes would have been very similar. Young et al. (43) reported that the median quadriceps CSA increased 5.6% following 5 wk of heavy-resistance training in a group composed of 6 men and 11 women. Although not reported in their article, the median percentage changes by the men (5.2%) and

women (5.8%) were nearly identical (Young, personal communication). Sale and O'Hagan (31) found that absolute increases in elbow flexor muscle CSA measured from CAT scans following heavy-resistance training were greater in men than in women, but percentage changes were similar. Percentage changes in muscle fiber CSA were also similar in the men and women.

The pattern of changes in muscular strength was similar to that for muscle size. Absolute changes on 2 of the 4 tests were greater in men than in women, but percentage changes were not significantly different on any of the tests. These findings agree with most other recent studies that have found greater absolute, but similar or smaller percentage changes in strength in men than in women who completed an equal amount of individualized heavy-resistance training (13, 30, 38, 40). The greater relative strength gains by women in some studies are most likely due to a lower initial state of training of the women, who traditionally have not engaged in many activities involving heavy-resistance exercise. We attempted to match men and women as closely as possible, based on their reported history of weight training to minimize the effect of initial differences in training status, but because of the difficulties in quantifying intensity and amount of weight training from recall, it is possible the women began the training with somewhat greater potential for relative improvement.

Percentage increases in strength were greater than percentage changes in muscle CSA in both men and women, suggesting that strength improvements resulted from a combination of hypertrophic and neural adaptations regardless of gender (27). The ratio of mean elbow flexor-plus-extensor strength to mean upper arm

CSA increased from 1.42 to 1.65 kg (cm²)⁻¹ in men and from 1.51 to 1.85 kg (cm²)⁻¹ in women. The increases in the corresponding ratios for the legs were from 0.92 to 1.10 kg (cm²)⁻¹ and from 0.72 to 0.90 kg (cm²)⁻¹ in men and women, respectively. The changes in these ratios suggest the relative importance of neural and hypertrophic changes to increases in muscular strength were quite similar in men and women. This conclusion agrees with data of Moritani and DeVries (29) who estimated that percentage contributions by hypertrophy and neural adaptations to increases in strength at various points in time during an 8-wk weight training program were similar in men and women.

In summary, significant increases in muscle CSA measured using CAT scans and anthropometric measures occurred in the upper arms of both men and women who participated in 16 wk of heavy-resistance training. The relative magnitude of changes were similar in men and women, although the absolute changes tended to be larger in men. We conclude that relative changes in strength and muscle hypertrophy consequent to weight training are similar in men and women.

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