Strength, Size, and Muscle Quality in the Upper Arm Following Unilateral Training in Younger and Older Males and Females

Leah C. Tanton[1], Thomas A. Cappaert[1], Paul M. Gordon[2], Robert F. Zoeller[3], Theodore J. Angelopoulos[4], Thomas B. Price[5], Paul D. Thompson[6], Niall M. Moyna[7], Richard L. Seip[6], Linda S. Pescatello[8], Joseph M. Devaney[9], Heather Gordish-Dressman[9], Eric P. Hoffman[9], and Paul S. Visich[1]

[1]Central Michigan University, Mt. Pleasant, MI, [2]University of Michigan, Ann Arbor, MI, [3]Florida Atlantic University, Davie, FL, [4]University of Central Florida, Orlando, FL, [5]Yale University, Haven, CT, [6]Hartford Hospital, Hartford, CT, [7]Dublin City University, Dublin, Ireland, [8]University of Connecticut, Storrs, CT, [9]Children's National Medical Center, Washington, DC.

Abstract

Purpose: To assess strength, size, and muscle quality differences between younger and older males and females in response to training.

Methods: The bicep and tricep of the non-dominant arm were trained for twelve weeks in younger and older males and females (n = 41). The bicep of both arms were assessed pre and post for muscle strength using one-repetition maximum (1 RM) testing, and size using magnetic resonance imaging (MRI).

Results: Strength ($p < 0.05$), mCSA ($p < 0.05$), and 1 RM MQ ($p < 0.00$) increased in response to training in all subjects regardless of age or gender. Younger and older subjects had similar increases in strength (45.49 ± 15.30% vs. 42.67 ± 26.67% respectively), mCSA (16.22 ± 7.98% vs. 19.17 ± 6.19% respectively), and 1RM MQ (25.73 ± 15.76 vs. 19.67 ± 20.66 respectively). Women increased their strength (55.59 ± 19.45% vs. 32.87 ± 15.66% $p < 0.00$ respectively), size (20.36 ± 6.29% vs. 14.72 ± 7.28% $p < 0.02$ respectively), and 1 RM MQ (29.74 ± 18.33% vs. 16.30 ± 15.59% $p < .02$) more than men. In comparing age and gender, younger females increased their strength more than older males (56.42 ± 12.92% vs. 29.17 ± 21.8% $p < .02$ respectively). Older females also increased their strength more than older males (54.68 ± 25.73 vs. 29.17 ± 21.80% respectively). Younger females increased their 1 RM MQ more than older males (.18 ± .08 kg/cm vs. .06 ± .08 kg/cm $p < .02$ respectively).

Conclusion: Strength and mCSA increases similarly in older and younger subjects. However, the overall strength and quality of the muscle seems to improve more in women than in men.

Introduction

Resistance training has been observed to promote muscular strength and endurance, and help conserve fat-free mass,[1] making it a very important component of overall physical fitness. In addition, resistance training also prevents and rehabilitates orthopedic injuries,[1,2] and maintains functional stability and independence into older age.[3,4]

The benefits of promoting resistance training in older people are especially important since the percentage of individuals 65 years and older in the U.S between 1995–2030 will increase by 107%, and those 85 and older will increase by 133%. Interestingly, those under the age of 65 will only increase by 21%.[5] Based on this aging trend in our population, we can expect to see substantial growth in the number of people with disabilities.[5] As the growth of this so called "baby boomer" generation increases in age, so does the need to educate and promote healthy lifestyles that will allow this population to maintain independence later in to life.

Sarcopenia, defined as the age related loss of skeletal mass,[6] may very well be one of the most important issues that health care professionals will face for this rapidly increasing older population. Sarcopenia has been associated with increases in adipose tissue[7] and 30%–50% reduction in

Correspondence: Paul S. Visich, Ph.D., Professor, School of Health Sciences, 1179 Health Professions Building, Central Michigan University, Mt. Pleasant, MI 48859. Tel: (989) 774-2687; Fax: (989) 774-2908; Email: paul.visich@cmich.edu

muscle strength and mass between the ages of 30 and 80.[8]

Loss of muscle mass has been linked with lower walking velocity and less leg strength than in individuals that remain stable or gain fat mass without muscle loss.[9] Reduced lower extremity strength has been associated with reduction in functional tasks such as walking speed, balance, stair climbing ability, and getting up from a seated position.[10] This loss in muscular strength and size leads to a decline in the overall quality of life, increases difficulty in the ability to be physically active, decreases energy expenditure both at rest as well as during exercise, and increases the body's fat content which increases dyslipidemia and reduces insulin sensitivity.[11] In addition, decreased muscular strength and size also increase the risk of falling, skeletal injury, pain and discomfort, osteoporosis, loss of functional capacity, frailty, disability, obesity, and diabetes.[6,9–15]

Assessment of strength changes following resistance training can be expressed many ways including one repetition maximum (1 RM), isometric strength, muscle cross sectional area (mCSA), and muscle quality (MQ). When reviewing past literature that has used these techniques, there appears to be a great deal of differences in the results from one study to the next. The majority of these differences can be related to the methods used to assess changes, along with gender, age, training period, and training protocols. For example, mCSA, has been observed to increase from 5.5% to 62% in older individuals in response to resistance training, depending on the technique used.[11,16–21]

Of these different methods of assessing strength changes, muscle quality (MQ), the ratio between muscle strength and size,[19] assists to more accurately indicate the amount of neuromuscular versus hypertrophic contribution that is involved in the loss of strength with aging.[16] For this reason, MQ may be a better indicator of overall muscle function than just strength or size alone.[22] There is some evidence that a larger loss in muscle strength than muscle size occurs with aging[23–25] making it reasonable to suggest that the overall quality of muscle is reduced. It appears that MQ increases in males and females of all ages with resistance training when tested using 1 RM as an indicator of strength.[16,26] It also is suggested that individuals that have larger hypertrophic responses to training have a shunted ability of force production capability due to altered muscle architecture.[27] When no training stimulus is presented, MQ is found to be lower in older males than in younger males, most likely due to a decreased amount of muscle mass.[22,25]

Past research on resistance training interventions in older adults has focused primarily on lower body mCSA and 1 RM strength, and evaluated older adults separately from younger adults. Without completing the same training protocol, comparisons made between these two age groups becomes difficult. Therefore, the purpose of this investigation was to assess 1 RM strength, mCSA, and 1 RM MQ in response to the same 12 week training stimulus of the non-dominant arm in younger and older males and females.

Methods

Subjects

Subjects were recruited via newspaper advertisements, fliers, and announcements made at local facilities, and school papers. The subjects were comprised of healthy, but sedentary, 18–39 and 65–86 year olds, that had the ability to obtain physician clearance for participation, and were willing and able to provide their own transportation to and from the testing/training facility. The current study is a modified version of the original FAMuSS (Funtional SNPs Associated with Muscular Strength and Size) study protocol in which the younger age group was selected to avoid studying men ≥40 who may have experienced a decrease in testosterone levels. The older group designated in the current research was used to keep the same span of years between ages as the younger group. The starting age of 65 was set in attempt to select a group that was likely to start showing sarcopenic effects.

Individuals that had a job or daily activity that required repetitive use of their arms, had participated in weight lifting within one year of the study, took medications that may have altered metabolism or musculature (lipid, hypertension, particular allergy medications, diuretics, or steroids), had pacemakers or metal implants in their upper body, or consumed dietary supplements (other than daily vitamins) such as protein or creatine, were excluded from the sample. Subjects that had any pre-existing conditions that may be considered "at risk" for partaking in maximal resistance testing (1 RM), such as CAD, uncontrolled hypertension, or recent

MI or stroke, were excluded. Individuals with metabolic syndrome, recent cancer or surgery, orthopedic limitations, consumed >2 alchoholic beverages a day, or any other factor that could have an adverse effect on muscular development also were excluded. The subjects were each given a verbal set of questions over the phone or in person to validate their inclusion into the sample. The answers to each question were documented, and each prospect was rejected or accepted based off of the previously mentioned exclusionary criteria. A total of 41 subjects qualified and agreed to participate in the 12-week weight lifting study. Upon acceptance, and throughout the study, individuals were continually reminded not to partake in any new activities, especially those that required repetitive use of their arms. They also completed pre-and post Paffenberger Activity Questionnaires to re-assure the verbal non-activity agreement made prior to their acceptance in the study. None of the subjects stated any significant changes to their normal daily activity from beginning to end of the research time period. Thus, all 41 subjects completed the study, making participation and completion rates 100%. Subject groups consisted of 12 younger females (21.83 ± 5.43), 11 younger males (23.27 ± 5.), 9 older females (71.11 ± 5.88), and 9 older males (73 ± 3.74).

Testing

A one repetition maximum (1 RM) strength test was completed on the preacher curl (Yukon International Inc., Cleveland, Ohio) using a Powerblock (Intellbell, Inc., Owatonna, MN) at baseline, as well as at the end of the study. Each subject began with a 5–10 repetition warm-up using 40%–60% of their predicted 1 RM weight. One minute of rest was given and a second warm-up weight of 60%–80% of the subject's predicted 1 RM was then lifted 3–5 times. After a three minute rest, a predicted 1 RM weight was given to the subject with their arm in the "up position" of the preacher curl. A predicted 1 RM chart (based off of the formula 0.2 $*$ body weight—1.36 kgs) was used to set the first 1 RM attempt weight for each subject based off of their body weight. Each successful 1 RM attempt led to an increase of 2.5 pounds for females and 5 pounds for males, per 25 pound increase of body weight. This test was continued until the subject could no longer lift the weight in good form. The amount of weight used on the last successful repetition before failure was recorded as the 1 RM weight, and the test was then repeated on the opposite arm. One successful repetition was defined by extending the arm down as far as possible without locking out the elbow joint and then curling the weight all the way back up again.

A Magnetic Resonance Imaging unit (MRI) was used before and after exercise training to assess changes in the biceps brachialis mCSA. Post-training mCSA data was compared with pre-training values to determine training-induced increases. Pre and post-training MRI images were obtained separately from both the dominant (untrained) and non-dominant (trained) arms.

MRI of each arm was performed at the maximum circumference of the upper arm (i.e. in the belly of the muscle). The maximum circumference was identified with the arm abducted 90 degrees at the shoulder, flexed 90 degrees at the elbow, and the biceps maximally contracted. This location was marked on the subject's skin using a radiographic bead (Beekley Spots, Beekley Corp., Bristol, CT) and the circumference of the arm was measured with a vinyl, non-stretchable tension tape measure.

Subjects were scanned in the supine position with the arm of interest at their side and their palm facing up and held in place on the scanner bed surface. The radiographic bead was centered to the alignment light of the MRI. A sagital scout image (6–9 slices) was obtained to locate the long axis of the humerus. Fifteen serial fast spoiled gradient images of each arm were obtained (TE = 1.9 sec, TR = 200 msec, flow artifact suppression, 30° flip angle) using the radiographic bead as the center most point. These axial/oblique image slices (i.e. perpendicular to the humerus) began at the top of the arm and proceeded toward the elbow such that the belly of the muscle occurred at slices 8 and 9. The slices were 16 mm thick with a 0 mm inter-slice gap, 256 × 192 matrix resolution, 22 cm × 22 cm field of view, number of acquisitions (NEX) = 6. Subjects were re-positioned for each arm so that the arm was centered in the magnet. This method imaged a 24 cm length of each arm.[28]

Images were analyzed using a custom-designed interactive processing and visualization program that operates in Matlab (The Math Works, Inc., Natick, MA). This software enables the user to assign regions of interest (ROI) in an image set by tracing region borders with a mouse. Muscle is easily identifiable on MRI images and its CSA is measured using this computerized planimetry technique. Once the ROI is defined, the program reports the number of pixels contained in the selected ROI. Based upon the MRI acquisition data (i.e. field of view and matrix resolution), the mCSA (cm^2) of the defined ROI is then calculated. When the pre-training mCSA (cm^2) is subtracted from the post-training mCSA (cm^2), the training effect can be compared within subjects.[28]

Training

The week following baseline 1 RM testing marked the first week of training. Training commenced twice a week for each subject. Training sessions were separated by at least one day. A total of 24 training sessions were completed by the end of a consecutive 12 weeks.

Each individual session consisted of three sets of repetitions with two minutes of rest in between each set. Two warm-up sets with 25%, followed by 50%, of the subject's successful 1 RM weight was given before the preacher curl and the triceps overhead extension as a warm up. The triceps exercise weight was estimated at 35%–50% of the bicep 1 RM (the warm-up weight also set accordingly from this). The first four weeks of training required twelve repetitions in each set. The next five weeks included 8 repetitions for each set, and the last three weeks consisted of six repetitions of each set. All warm-up sets throughout the study were separated by one minute of rest, and twelve repetitions throughout the study.

Only the non-dominant arm was used for exercise training throughout the entire study in order to allow use of the dominant arm as an inner-study control. The order of the exercises were as follows; 1) preacher curl 2) overhead extension 3) concentration curl 4) bent-over triceps kickbacks 5) standing bicep curls. The weight used for each exercise began with 65%–75% of the tested 1 RM (and 35%–50% of bicep 1 RM for the triceps). The weight load progressively increased throughout the 12 weeks as much as possible without pain and with the ability to maintain good form. The subjects were not informed of the amount of weight they were lifting, nor of any of the testing results until after the study was completed.

After twelve consecutive weeks of training, each subject was then asked to again complete all of the same testing that was completed at baseline. The MRI was completed within 96 hours, and no earlier than 48 hours, after the final training session. The 1 RM test was completed either directly after the MRI, or 48 hours before the MRI so as not to cause muscle damage before the MRI scan was completed.

Statistics

Percent change was calculated by taking the difference between the pre and post measurements, dividing by the baseline scores, and multiplying times 100. Muscle quality was determined by dividing 1RM in kilograms by CSA in centimeters.

Independent samples t-tests were used to observe differences between gender and age at baseline. A paired samples t-test was used to determine significance in pre- to post- training measurements in all subjects combined, and by age and gender. Multivariate tests using MANOVA were used to test between-subject effects in absolute and percent changes (pre- to post-training) using the Bonferroni corrected model at a significance level of 0.05.

Results

Baseline-non-dominant vs dominant

All baseline measurements are provided in Table 1. Subjects were stronger in their dominant arm than their non-dominant arm at baseline. However, when broken down by age and gender separately, this proved to be true only in males and in the younger group. The females and the older group were not stronger at baseline in their dominant vs. non-dominant arm. In addition to strength, the males and the younger group both had larger mCSA in their dominant arm than their non-dominant arm at baseline. There was no mCSA difference between arms in the older or the female group.

Baseline-gender

Males had larger mCSA in both arms than females. Males also had a greater 1 RM in the dominant arm than females at baseline, but there was no difference in the non-dominant arm.

Baseline-age

There were no baseline differences based upon age in any measurement.

Table 1. Baseline non-dominant vs. dominant arm, and females vs. males.

		1 RM	mCSA	1 RM MQ
Non Dominant		20.46 ± 9.27	15.26 ± 5.40	0.61 ± 0.19
Dominant		21.92 ± 9.90† D vs. ND	15.55 ± 5.39	0.63 ± 0.17
Male:	ND	27.75 ± 7.86	19.38 ± 4.26	0.67 ± 0.23
	D	29.88 ± 8.13* MD vs. MND	19.75 ± 4.11* MD vs. MND	0.69 ± 0.19
Female:	ND	13.51 ± 3.05	10.93 ± 1.95	0.55 ± 0.10
	D	14.35 ± 3.10	11.14 ± 1.81	0.57 ± 0.11
Younger:	ND	22.17 ± 9.95	15.75 ± 5.51	0.65 ± 0.21
	D	23.70 ± 10.52* YD vs. YND	16.32 ± 5.79* YD vs. YND	0.67 ± 0.20
Older:	ND	18.26 ± 8.06	14.69 ± 5.37	0.56 ± 0.14
	D	19.65 ± 8.81	14.66 ± 4.89	0.60 ± 0.11

Values are presented as mean ± SD.
Comparisons are made between the non-dominant (ND) vs dominant arm (D), using an independent T test.
ND vs. D *($p < 0.05$) †($p < 0.00$).
Units: 1 repetition maximum (1 RM) lbs., muscle cross sectional area (mCSA) cm, 1 repetition maximum muscle quality (1 RM MQ) kg/cm, male dominant (MD), male non-dominant (MND), younger dominant (YD), younger non-dominant (YND).

Baseline-age and gender-non-dominant and dominant arm

When comparing all four groups at baseline, younger males were stronger in 1 RM than younger females and had larger cross sectional areas than younger females in both arms. Younger males were also stronger than older females, and had larger mCSA than older females in both arms. However, there were no baseline differences between younger and older males, or younger and older females at baseline, nor did any of the groups show baseline differences in 1 RM muscle quality in either arm.

Older males started out stronger than younger females and with larger mCSAs than younger females in both arms. Older males were also stronger than older females and had larger baseline mCSAs in both arms than older females.

Training response-all

All pre to post 1 RM strength, MQ, and mCSA measurements are presented in Table 2. All subjects increased their non-dominant mCSA, 1 RM strength, and 1 RM MQ of their trained arm in response to 12 weeks of resistance training. Interestingly, subjects also had a small increase in the 1 RM strength of their dominant arm in response to training stimulus.

Gender

When assessing differences by gender, it was found that females increased their non-dominant arm 1 RM strength and their mCSA more than males. This larger relative 1 RM increase in females was not accompanied by a larger absolute increase. 1 RM MQ also increased more in females than males both by absolute as well as relative changes. There were no other absolute or relative differences between genders found.

The dominant arm 1 RM increase previously noted was due to both absolute as well as relative increases in females versus males, respectively. There were no other dominant arm differences between genders.

Age

The only differences pre to post found between the different ages was in absolute 1 RM strength. Younger subjects increased their absolute 1 RM in response to training more than older subjects in the non-dominant arm, however, there was no difference found in the relative strength gained from baseline between age groups.

Age and gender

All comparisons in combined age and gender groups are presented in Table 3. When the subjects were compared based upon both age and gender, it was found that the non-dominant arm absolute differences found in 1 RM based on age were a result of younger males increasing their strength more than older males and older females. Despite the higher absolute changes in younger males, there were no relative strength differences from baseline found between younger

Table 2. Pre to post non-dominant and dominant arm; overall, males, females, young, and old.

		1 RM	mCSA	1 RM MQ
ND:	Pre	20.46 ± 9.27	15.26 ± 5.40	0.61 ± 0.19
	Post	28.29 ± 10.67† NDPo vs. NDPr	17.54 ± 5.56† NDPo vs. NDPr	0.73 ± 0.18† NDPo vs. NDPr
Dom:	Pre	21.92 ± 9.90	15.55 ± 5.39	0.63 ± 0.17
	Post	22.76 ± 9.83* DPo vs. DPr	15.48 ± 5.04	0.65 ± 0.16
Male:	ND Pre	27.75 ± 7.86	19.38 ± 4.26	0.67 ± 0.23
	ND Post	36.38 ± 9.23† MNDPo vs. MNDPr	22.02 ± 4.36† MNDPo vs. MNDPr	0.76 ± 0.22† MNDPo vs. MNDPr
	D Pre	29.88 ± 8.13	19.75 ± 4.11	0.69 ± 0.19
	D Post	30.79 ± 7.68	19.58 ± 3.98	0.72 ± 0.19
Female:	ND Pre	13.51 ± 3.05	10.93 ± 1.95	0.55 ± 0.10
	ND Post	20.60 ± 4.39† FNDPo vs. FNDPr	13.27 ± 2.16† FNDPo vs. FNDPr	0.70 ± 0.13† FNDPo vs. FNDPr
	D Pre	14.35 ± 3.10	11.14 ± 1.81	0.57 ± 0.11
	D Post	15.12 ± 3.42* FDPo vs. FDPr	11.57 ± 1.72	0.59 ± 0.10
Younger:	ND Pre	22.17 ± 9.95	15.75 ± 5.51	0.65 ± 0.21
	ND Post	31.20 ± 11.72† YNDPo vs. YNDPr	17.98 ± 5.35† YNDPo vs. YNDPr	0.80 ± 0.19† YNDPo vs. YNDPr
	D Pre	23.70 ± 10.52	16.32 ± 5.79	0.67 ± 0.20
	D Post	24.57 ± 10.16	16.28 ± 5.39	0.69 ± 0.18
Older:	ND Pre	18.26 ± 8.06	14.69 ± 5.37	0.56 ± 0.14
	ND Post	24.58 ± 8.01† ONDPo vs. ONDPr	16.96 ± 5.94† ONDPo vs. ONDPr	0.65 ± 0.13† ONDPo vs. ONDPr
	D Pre	19.65 ± 8.81	14.66 ± 4.89	0.60 ± 0.11
	D Post	20.46 ± 9.16* ODPo vs. ODPr	14.43 ± 4.49	0.60 ± 0.12

Values are presented as mean ± SD.
Pre to Post relative changes *($p < 0.05$) †($p < 0.00$).
Units: 1 repetition maximum (1 RM) lbs., muscle cross-sectional area (mCSA) cm, 1 repetition maximum muscle quality (1 RM MQ) kg/cm, non-dominant post (NDPo), non-dominant pre (NDPr), dominant post (DPo), dominant pre (DPr), male non-dominant post (MNDPo), male non-dominant pre (MNDPr), female non-dominant post (FNDPo), female non-dominant pre (FNDPr), female dominant post (FDP), female dominant pre (FDPr), younger non-dominant post (YNDPo), younger non-dominant pre (YNDPr), older non-dominant post (ONDPo), older non-dominant pre (ONDPr), older dominant post (ODPo), older dominant pre (ODPr). Comparisons are made pre to post between the non-dominant (ND) vs dominant arm (D), using paired samples T test.
ND vs. D *($p < 0.05$) †($p < 0.00$).

males and the other groups. Younger and older females increased the relative 1 RM strength of their non-dominant arm more than older males. Younger females also increased their non-dominant arm 1 RM MQ more than older males.

Discussion

With the mean age of 72 in the older group of subjects, it was expected that there would have been at least a 30% decrease in baseline strength compared to the younger group as previous literature has observed declines of 15% per decade in the 6th and 7th decades of life, and 30% thereafter.[6] Muscle size also has been observed to decrease with age (by varying amounts depending on activity levels of subjects).[11,17,29–32] However, there were no differences between our younger vs. older subjects at baseline in any measurement.

Table 3. Pre and post absolute and percent differences in the non-dominant arm.

		1 RM	mCSA	1 RM MQ
Younger Females:	Pre	14.25 ± 2.65	11.26 ± 1.05	0.58 ± 0.11
	Post	22.27 ± 4.25	13.63 ± 1.56	0.75 ± 0.15
	Absolute	8.00 ± 2.30	2.08 ± .77	0.18 ± 0.08* YF vs. OM
	Percent	56.42 ± 12.92* YF vs. OM	18.61 ± 6.76	32.44 ± 15.71
Younger Males:	Pre	30.45 ± 8.13	19.83 ± 4.62	0.72 ± 0.26
	Post	40.91 ± 9.24	22.33 ± 4.00	0.84 ± 0.22
	Absolute	10.45 ± 2.45* YM vs. OF and OM	2.5 ± 1.19	0.12 ± 0.08
	Percent	35.57 ± 9.48	14.05 ± 8.67	19.63 ± 13.82
Older Females:	Pre	12.08 ± 3.19	10.56 ± 2.65	0.52 ± 0.08
	Post	18.33 ± 3.94	12.84 ± 2.76	0.65 ± 0.06
	Absolute	6.25 ± 2.4* OF vs. YM	2.28 ± .47	0.13 ± 0.1
	Percent	54.68 ± 25.73* OF vs. OM	22.3 ± 5.43	26.73 ± 21.5
Older Males:	Pre	24.44 ± 6.47	18.83 ± 3.97	0.60 ± 0.18
	Post	30.00 ± 5.51	21.60 ± 5.05	0.65 ± 0.18
	Absolute	5.94 ± 2.29* OM vs. YM	2.92 ± 1.28	0.06 ± 0.08* OM vs. YF
	Percent	29.17 ± 21.80* OM vs. YF OF	15.65 ± 5.21	11.73 ± 17.64

Values are presented as mean ± SD.
*($p < 0.05$) †($p < 0.00$).
Units: 1 repetition maximum (1 RM) lbs., muscle cross-sectional area (mCSA) cm, 1 repetition maximum muscle quality (1 RM MQ) kg/cm, younger females (YF), younger males (YM), older females (OF), older males (OM). Comparisons are made pre to post using paired samples T test. Multivariate tests using MANOVA were used between-subject effects in absolute and percent changes (pre- to post-training) using the Bonferroni corrected model at a significance levels of 0.05.

Males had larger mCSA and 1 RM than the females at baseline, but there was no difference in the quality of the muscle tissue. Overall subjects increased their 1 RM strength (43.8% ± 20.29%) more than their mCSA (17.5% ± 7.29%) and this increase was more pronounced in younger females than older males. This difference in quality was not accompanied by any muscular size differences in response to training between these four groups (younger males vs. younger females vs. older males vs. older females), but females younger and older increased their 1 RM strength more than older males, and their size more than younger and older males combined.

Not only did the females in our study have a stronger muscular adaptation in the non-dominant arm, but in the dominant arm as well. Although neither gender increased the size of their dominant arm in response to training, there was a greater mCSA response found in the untrained limb in females compared to males.

We suspect that the lack of strength and size differences between age groups at baseline was due to the strict recruitment process for our subject's inclusion into the study. Subjects were free from orthopedic injuries, cancer, thyroid disorders, arthritis, diabetes, and heart disease. It has been documented that the use of corticosteroids promotes the development of muscle atrophy and leads to the loss of strength and functional capacity in subjects with rheumatoid arthritis.[33] It is well documented that insulin resistance is a contributor to muscle wasting,[34] and 80% of subjects with rheumatoid and osteoarthritis are found to have difficulties with muscle function that are correlated with functional tests of muscle strength.[35] Subjects with heart failure or cardiovascular disease also have reduced muscle strength.[36,37]

In addition, individuals were not allowed to partake in the study if they had previously participated in resistance training or any other activities that are known to have an impact on strength (such as push-ups, racquetball, rock climbing etc.) more than once a week, or even a job that required repetitive use of the arms. Although our subjects had not participated in muscle strengthening activities within one year previous to the study, there is still a heightened strength response from normal baseline levels in older adults, even when training has been abstained from for as long as 36 months.[26,31,38] This may in be due to the increase in growth hormone production from physical fitness and regular training.[39]

The heightened response in mCSA in females above males was not found amongst the four groups separated by age and by gender, thus indicating that the mCSAs of older and younger males and females do adapt similarly to 12 weeks of non-dominant arm resistance training. In agreement with our findings, Hakkinen et al.[17] found that middle aged females increased their mCSA more than middle aged and older males, and older females more than older males. Others have reported no differences in size between genders in response to training.[40,41] Ivey et al.[26] found that males increased their mCSA more than females, but they only reported absolute values. Other studies have also found either a larger,[41] or the same strength responses in females vs. males.[16,31] When a larger increase was observed, it was suggested that it was due to lower baseline strength levels in females over males.[41]

The lack of difference between age and gender groups in MQ at baseline was not expected. Other studies have shown MQ to be lower in older males than in younger males, most likely due to a decreased amount of muscle mass.[22,25] The fact that there was no MQ difference found between our groups indicates that both neurological as well as motor unit recruitment availability decreases in proportion as our older adults aged. However, this discrepancy in findings may also be due to the vast difference in testing. Overend evaluated muscle quality using isometric and isokinetic evaluation at 0 and 120 degrees of angle on the knee extensors[25] and Lynch used an isokinetic dynamometer.[22] It would be reasonable to suggest that the increase in 1 RM MQ in our females corresponds to greater neurological developments due to the type of training used. This indicates that it is not age, but rather gender that seems to impact this difference in 1 RM MQ, which would suggest that females had a larger portion of neurological development contributing to the MQ gains found than hypertrophy.

Finding a strength increase in the untrained arm was not unique to our study, but the heightened response in woman was. It is hypothesized that resistance training may modify the neural circuits or motor pathways involved in neurological activation of the untrained limb causing a marked increase in strength. The exact reasoning behind this cross-over of strength into the untrained limb is unclear, but the magnitude of this cross education averages approximately 7.8% of baseline strength levels in the untrained limb.[42,43] It is uncertain whether or not a specific cross-over effect is heightened in females over males as past research has focused on the contra lateral effects of unilateral training in only younger males (−2.7% to 21.6%), younger females (3.1%–19%), or in males and females combined (4% to 13.3%), rather than younger and older males and females compared to one another.[43]

One theory for these unexpected differences between males and females would be that females are less exposed to activities that tend to promote strength and size increases in muscle tissue. Due to this difference in lifestyle, females tend to start at lower baseline levels of strength and size, therefore showing more gains relative to baseline when they do partake in a training stimulus.[44] Research has found that as much as 90% of the initial strength increases obtained in the first couple weeks of training are attributed to neuromuscular development in the muscle tissue.[45] This theory would support both the larger baseline and post-training absolute strength in males, but also the larger neuromuscular adaptation in females, even in untrained limbs. Past research on contra lateral effects of unilateral training have not yet compared different age or gender groups.[43]

The limitations of the current study reflect that our subjects were free from all muscle wasting disorders, which suggests that their physical well being may have been above other "normal" adults their age. Future research may ask if using an older group that already shows lesser strength and size measures at baseline would change the outcome of this study. In addition, a longer period of time given for cessation in activities that could alter strength and muscle may have been beneficial, as it is known that training adaptations can remain even longer than the 12 months that we required to refrain from regular exercise. Due to the known neurological improvements that contribute greatly to the early phase of muscle strength, a training period greater than 12 weeks would have been beneficial to help further evaluate the influence of muscle hypertrophy on the measurements of interest (mCSA, MQ, and cross-over effect).

It is also possible that a larger sample size may have been beneficial to further verify some of the unexpected results and changes found. The effects of lifestyle differences in gender cross-over effect may also be a topic of interest for the future i.e. do females with physically challenging occupations have less of a cross-over into the untrained arm than females that have a less active lifestyle? Future exploration of this cross-over effect in females should be conducted using a separate control group to confirm or negate the observed increase in strength in the untrained arm in females.

Another gender difference that should be considered is the effect menopause has on muscle wasting in junction with muscle adaptation to a training stimulus. Although not reaching a level of significance, our younger women were slightly stronger than the older women at baseline, which would support the existing notion that menopause may heighten these sarcopenic effects in women. Future research should separate gender in addition to age as a statistical method of evaluation in the quest to understand the influence of resistance training on sarcopenia.

Conclusion

Though sarcopenia remains an important age-related topic, research leading us to future conclusions must be conducted in light of gender differences as well. Our findings suggest that females of all ages have greater room for strength improvements due to lower starting measures. Most of these increases are most likely due to enhanced neurological development in females, which was reflected in both the greater increases in muscle quality as well as cross-over effect seen in females over males.

It is encouraging to see that the older subjects in this research did not have the muscular deficits that might have been thought to be typical of their age because it helps to support the theory that sarcopenia may not be due to age alone, but rather a multitude of other circumstances (i.e. overall health, physical activity level). In individuals that are influenced by sarcopenia, initiating a resistance training program can greatly reduce strength losses with age, and ultimately help preserve one's quality of life.

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Disclosure

The authors report no conflicts of interest.

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