The Effects of Strength Training, Cardiovascular Training and Their Combination on Flexibility of Inactive Older Adults

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Abstract

The purpose of this study was to investigate the effects of aerobic training, strength training and their combination on joint range of motion of inactive older individuals. Thirty-two inactive older men (65–78 yr) were assigned to one of four groups (n = 8 per group): control (C), strength training (ST), cardiovascular training (CT), and combination of strength and aerobic training (SA). Subjects in the S, A, and SA trained three times a week for 16 weeks. ST included 10 resistance exercises for the major muscle groups at an intensity of 55–80% of 1-RM and CT included walking/ jogging at 50–80% of maximal heart rate. Body weight and height, physical activity level and maximal oxygen uptake ($V\dot{O}_2$max) were measured before the training period. Isokinetic (60 and 180 $deg \times sec^{-1}$) and concentric strength (1-RM in bench and leg press) were assessed prior to and at the end of the training period. Hip flexion, extension, abduction, and adduction, shoulder extension, flexion, and adduction, knee flexion, elbow flexion and sit-and-reach score were determined before and at 8 and 16 weeks of training. There were no differences between groups in $\dot{V}O_2$max, body weight, and height ($p < 0.05$). ST and SA but not CT and C increased isokinetic and concentric strength at the end of the training period ($p < 0.05$). ST and SA increased significantly ($p < 0.05$) sit-and-reach performance, elbow flexion, knee flexion, shoulder flexion and extension and hip flexion and extension both at mid- and post-training. CT increased ($p < 0.05$) only hip flexion and extension at post training. Results indicate that resistance training may be able to increase range of motion of a number of joints of inactive older individuals possibly due to an improvement in muscle strength.

Key words

Flexibility · aerobic training · resistance training · combination training · elderly

Introduction

Flexibility represents the ability to move a joint through its full range of motion [1]. Range of motion of a certain joint depends on bone, muscle and connective tissue integrity as well as other factors such as pain and the ability to produce an adequate amount of muscle force [2]. Significant losses in flexibility with aging have been well substantiated [12] in both sexes [23]. It appears that flexibility declines 20–50% between the ages of 30 and 70 years depending on the joint examined [9,40]. Flexibility losses with aging have been associated with muscle disuse and soft tissue restraints such as collagen alterations [2].

Decline of flexibility has been related to a deterioration of functional abilities [4,15] and health status [15] of older individuals leading to dysfunction and inability to perform every day activities such as getting up from a chair or bed, walking, and climbing stairs [4]. It is believed that increasing muscular activity might prevent or slow the rate of flexibility loss in older adults [41]. Increase in flexibility could lead to an improvement of several disorders of the musculoskeletal system [33]. It has been suggested that older persons who maintain high levels of muscular strength and flexibility rarely participate in long term health care programs [21].

Strength training (ST) with resistance exercises and cardiovascular training (CT) have been associated with significant improvement in both health and performance related parameters in the elderly such as cardiovascular function, muscle strength and endurance, body composition, bone quality, postural stability and fall prevention [2]. However, there is limited information regarding the effects of either ST or CT on flexibility in older persons. Moreover, most studies have examined the effects of some type of training on flexibility and have employed stretching exercises in the training protocol. The independent effects of ST or CT on flexibility of older adults have not been well established.

Only a few studies have attempted to determine whether ST or CT could improve flexibility. These studies either employed stretching exercises in the training protocol, do not mention if they used flexibility exercises [26], used only younger individuals [14, 43], utilized low-resistance exercises [32], used various types of training programs (concerning the duration, intensity and frequency of the program), or utilized different measurement techniques for assessing flexibility. In one CT study it was found that land- or water-based CT caused no improvement in flexibility [37]. Girourard [16] found that ST supplemented with stretching exercises caused only a small improvement in flexibility of older persons while a program consisting of identical flexibility exercises led to a greater change in flexibility.

The mechanism through which strength or endurance-type exercise improves flexibility has not been elucidated. It has been suggested that strength training with resistance exercises improves flexibility through the enhancement of the tensile strength of tendons and ligaments, muscle mass and contractility [30, 34]. In addition, previous findings suggested that resistance exercise protocols could reduce the tendon rupture with age [3]. Endurance-type exercise such as weight-bearing activities (walking or jogging) increased collagen synthesis substantially both in humans and animals [10, 27]. However, these findings were not confirmed by other investigations [44]. Consequently, the mechanism through which endurance training may improve joints' range of motion remains uncertain.

Therefore, most previous studies are either limited or inconclusive regarding the independent effects of ST and CT on flexibility of older adults. The purpose of this study was to determine the effects of 16 weeks of either ST alone, CT alone, or their combination on the range of motion of various joints of inactive older men.

Materials and Methods

Subjects
Thirty-two men volunteered to participate in the present study. All participants gave their written informed consent regarding their participation in the study after being informed of all risks, discomforts and benefits associated with the procedures followed in the present study. Procedures were in accordance with ethical standards of the Committee on Human Experimentation at the Institution at which the work was conducted and with the Helsinki declaration of 1975. The physical characteristics of the subjects are shown in Table **1**.

Table **1** Physical characteristics of subjects (values are means + SD)

Treatments	Age (years)	Height (m)	$\dot{V}O_2max$ (ml × kg^{-1} × min^{-1})
C (n = 8)	70.5 ± 5.9	1.66 ± 0.5	21.1 ± 3.7
CT (n = 8)	71.8 ± 2.5	1.64 ± 0.8	26.6 ± 2.7
S (n = 8)	70.3 ± 2.3	1.66 ± 0.8	21.4 ± 3.9
SA (n = 8)	69.8 ± 1.9	1.66 ± 0.3	22.2 ± 2.1

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.

Screening
Participants were selected based on the following criteria: 1) subjects were completely inactive prior to the study. Subjects were also required to exhibit a maximal oxygen consumption ($\dot{V}O_2max$) below 25 ml × kg^{-1} × min^{-1}. According to the American College of Sports Medicine [1], men over 60 yrs of age with a $\dot{V}O_2max$ value below 26.5 ml × kg^{-1} × min^{-1} belong to the 20th percentile range of the population. 2) Subjects did not exhibit anemia, hepatic complications, thyroid disorders or kidney problems. 3) Subjects had their blood pressure measured at rest by auscultation in both arms after sitting in a quiet room during four morning visits. If these blood pressures averaged over 160/100 mmHg, subjects were excluded from the study. Subjects who were on antihypertensive medications (14 men) maintained the same medication regimen throughout the study. 4) Subjects were screened by a physician for potentially damaging orthopedic and neuromuscular problems. 5) Finally, subjects underwent a progressive diagnostic treadmill test to exhaustion (GXT) according to the Bruce protocol [8] with a resting 12-lead electrocardiogram (ECG) to determine their heart rate, blood pressure and ECG responses to submaximal and maximal exercise. Subjects were excluded if the test was terminated due to signs indicative of serious cardiovascular or respiratory complications or if blood pressure exceeded 240/110 mmHg during the exercise test [1]. Initially, 49 men volunteered to participate in the present study. Based on the selection criteria, 14 men did not qualify for participation. During the study, two more men were asked to stop because they missed more than four training sessions up to that point while one more stopped for other reasons.

Aerobic capacity
Prior to training, $\dot{V}O_2max$ was determined before training began under the supervision of a physician. $\dot{V}O_2max$ was determined during graded treadmill walking or jogging using a modified version of the Bruce protocol [7]. The ECG was monitored continuously in leads aVF, V5, and I. Brachial artery cuff pressure and a 12-lead ECG were obtained during the final 30 seconds of each exercise stage and at 2, 4, and 6 minutes into recovery. Ratings of perceived exertion (RPE; 6-20 Borg Scale) [5] were determined during the last minute of each exercise and immediately at the end of the test. $\dot{V}O_2$ was measured continuously by open circuit spirometry and averaged every 60 seconds with the use of an automated online system. Fractional concentrations of O_2 and CO_2 were sampled from a mixing chamber and quantified using electronic O_2 and CO_2 analyzers (Beckman LB-2). To ascertain that $\dot{V}O_2max$ had been attained, the following criteria had to be met: 1) no further increase in O_2 uptake with an increase in work rate

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(leveling-off criterion), 2) attainment of the age-predicted maximal heart rate (220 – age), 3) respiratory exchange ratio greater than 1.10. These criteria were met by 90% of the subjects.

Measurement of anthropometric variables

Subjects' body weight was measured while they were wearing underclothes on a balance scale (Seca 707, Hamburg, Germany) calibrated to the nearest 0.1 kg after an 8-10 hour fast (between 7.00 and 8.00). Barefoot standing height was measured to the nearest 0.1 cm by using a wall mounted stadiometer.

Strength assessment

Peak muscle torque was measured using an isokinetic dynamometer (Kin.Com 125 AP, Chattanooga, USA). Subjects performed the same tasks while in a seated position on a standard dynamometer chair with the subject's back slightly reclined and thigh well supported on the seat. Stabilization in the seated position was accomplished using pelvic strapping. The subjects were instructed to grip their hands around the chest. The axis of rotation of the knee joint and lever arm were carefully aligned. The tested dominant limb was firmly stabilized at the distal femur, the lower leg at the distal tibia above the ankle joint superior to the medial malleolus. Before the test there was a warm-up session (5 minutes) including cycling (Monark) followed by five submaximal and one maximal trial on the isokinetic dynamometer. The test protocol included one bout of 5 maximal knee extension/flexion repetitions for each tested speed (60 deg/sec and 180 deg/sec) in a random order, separated by 120 seconds rest intervals. The highest value tested for each velocity was used as the recorded value. Maximal test efforts began with the leg flexed, that is with the knee joint at 90° before flexion, and ended at full extension (0 deg). The preload was set at 50 N [11]. Correction was applied for the elimination of errors against the effect of gravity on the lower leg and lever arm. During testing there was no visual feedback or verbal encouragement. The dynamometer was calibrated prior to the testing session according to the procedures indented by the manufacturer. The coefficient of variation of the slope of ten consecutive calibrations was 0.5%. To verify the reliability of the torque measurements, the peak torque of the knee extensors at 60 deg/sec and 180 deg/sec was measured twice (within a week, at the same time of day) in the dominant leg, which was defined as the leg used to kick a ball. The intraclass correlation coefficients between the repeated measurements were found to be 0.98 and 0.95, respectively.

A Universal machine (Irvine, CA, USA) was used to measure maximal concentric strength of upper (pectoral musculature) and lower body (quadriceps) – chest press and leg press, respectively. Maximal strength was assessed before and after training using the one-repetition (1RM) test [18]. Prior to the 1 RM test, three low-resistance sessions were conducted as an accommodation period so that subjects could become familiar with the equipment and proper exercise techniques. This was also used to help control for large gains in strength measurements because of motor learning during the initial stages of training. Subjects were given at least a 5 min rest between all lifts to ensure full recovery before attempting another lift. The successful maximal load was recorded as the maximum weight lifted and usually occurred within 3-4 attempts. The intraclass correlation coefficient estimated for test-retest trials within the same week was 0.90 and 0.94 for chest and leg press, respectively.

Each strength assessment was preceded by a cycling warm-up session (5 minutes at 40–50% of HR_{max}). Post training strength measurements were made at the end of the training period following exactly the same procedures. Strength measurements were performed before and after the training period. Qualified personnel conducted all strength measurements.

Measurement of flexibility

Hip, shoulder, knee, elbow and low back flexibility were assessed before and after 8 and 16 weeks of the training program at the same time of day when no other testing was performed. A 3-minute warm-up on a Monark stationary bicycle preceded flexibility testing. Range of motion for hip flexion, hip extension, hip abduction, hip adduction, shoulder extension, shoulder flexion, shoulder adduction, knee extension/flexion and elbow extension/flexion was determined by the use of a goniometer as described by Norkin and White [31]. The low back and hamstring flexibility was evaluated by the modified sit-and-reach test [1]. It has been found that for adult males the sit-reach-test correlated well with hamstring flexibility (0.89) and moderately well with low back flexibility (0.59) [19]. Following warm-up, three consecutive measurements on each test were taken and the best score was recorded. The coefficients of variation for test-retest trials were 3.5% (n = 28) for shoulder extension, 6.5% (n = 28) for shoulder flexion, 1.6% (n = 28) for shoulder abduction, 6.9% (n = 32) for hip flexion, 3.5% (n = 32) for hip extension, 2.4% (n = 32) for hip abduction and adduction, 1.8% (n = 32) for elbow flexion/extension, 2.1% (n = 32) for knee flexion/extension, and 4.2% for modified sit and reach test. Qualified personnel conducted all flexibility measurements.

Training treatments

The subjects were randomly assigned to one of four groups: a) control group (C, n = 8), b) cardiovascular training group (CT, n = 8), c) strength training group with resistance exercises (S, n = 8), and d) combination of strength and cardiovascular training group (SA, n = 8). The subjects in the control group did not train and participated only in the measurement procedures. All three exercise groups trained three times a week for 16 weeks. Subjects always completed a 3 to 5 minute warm-up, consisting of either walking (CT) or cycling (ST) at approximately 40% of their HR_{max} before starting their training protocol. The duration of each training session ranged between 45 and 50 minutes. Training sessions were supervised at all times.

Cardiovascular training protocol consisted of walking or jogging on a treadmill (Startrac TR 3500, Tustin, CA, USA). The grade of the treadmill was set at 0%. Training intensity and duration were progressively increased within the 16 wk period. Exercise duration was limited to 12 minutes during the first week and it increased 2 minutes every week thereafter (subjects walked for 42 minutes during the last week of training). Training intensity was set at 50% in weeks 1 and 2, 55% in weeks 3 and 4, 60% - 65% in weeks 5 and 6, 70% in weeks 7 through 10, and 80% for the rest of the training period (weeks 11 through 16). Blood arterial pressure was measured manually (mercury sphygmomanometer, Baum Co., Inc., Standby model 0250, NY, USA) before exercise began, every 5 minutes during exercise and every 2 minutes after the end of exercise until it stabilized to pre-exercise levels. Heart rate was recorded continuously (coded transmission by Polar Heart Rate Monitor, M21, Adelaide, Australia).

Subjects in the strength training group exercised on 8 Universal resistance exercise machines (Irvine, CA, USA), selected to stress the major muscle groups and completed in the following order: chest press, leg extension, shoulder press, leg curls, latissimus pull down, leg press, arm curls, and triceps extension. Participants in this group also performed abdominal crunches and low back exercises (2 sets of 6 repetitions each in weeks 1 through 8, 3 sets of 8 repetitions each in weeks 9 through 12, and 4 sets of 10 repetitions each in weeks 13 through 16). 1RM on each resistance exercise was measured at the beginning of the training period and every week thereafter until the training period was completed. The 1-RM intraclass correlation coefficient between repeated measurements was measured between 0.89 and 0.95 in all exercises performed. During weeks 1 through 4, subjects exercised at 55%-60% of 1-RM in two sets (14 and 12 repetitions in the first and second set, respectively). In the remaining training period, subjects performed 3 sets. Intensity was set at 60%-70% in weeks 5 through 8 (12 repetitions in the first two sets and 10 repetitions in the third set), at 70%-80% in weeks 9 through 12 (10 repetitions in the first two sets and 8 repetitions in the third set), and at 80% in weeks 13 through 16 (8 repetitions/ set). Participants were instructed to perform each repetition in 6-9 seconds. They were told to raise the weight in 2 seconds, pause briefly for 2-3 seconds and to slowly lower the weight during the eccentric phase of the contraction for 2-3 s [13]. They paused for 5 s between repetitions and 2 minutes between sets.

Subjects in the combination group followed exactly the same exercise regimens. Subjects first performed the resistance exercise program, and, after a 60 minute rest, the aerobic training program.

Statistical analysis

Data were analyzed using the SPSS PC (version 9.0) program for windows. Means ± SD were calculated. One-way ANOVA was conducted initially to examine if there were differences among the four groups in the pre-measurement values of each dependent variable. MANOVA repeated measures (3 × 4, time by treatment) was performed on each dependent variable to detect differences in each group for each time point. When F ratios were significant, post hoc comparisons of means were analyzed with Scheffe's multiple comparison tests. In order to compare the four treatments' effectiveness to change the status of each dependent variable at each time point of measurement, a one-way ANOVA (with treatment as the independent factor) was applied on the delta differences between different time point measurements. When F ratios were significant, post hoc comparisons of means were analyzed with Scheffe's multiple comparison tests. Statistical significance was accepted at $p < 0.05$.

Results

There were no significant differences at baseline among the four groups for age, height, and physical activity level (Tables **1** and **3**). Subjects in all groups exhibited a very low level of aerobic fitness ($\dot{V}O_2$max < 25 ml × kg^{-1} × min^{-1}) with no significant differences among the four groups (Table **1**). Body weight and Body Mass Index (BMI) were similar in all groups at baseline (Table **2**). However, CT and SA demonstrated a significant ($p < 0.05$) decrease in body weight and BMI after training (Table **2**). SA presented the greatest ($p < 0.05$) decrease in body weight and BMI. Further-

Table 2 Subject's body weight changes with training (values are means ± SD)

| Treatments | Body Weight (kg)/Body Mass Index (kg × m²) | |
	Pre-training	Post-training
C (n = 8)	81.2 ± 10.3/29.4 ± 2.1	81.0 ± 10.1/29.4 ± 2.4
CT (n = 8)	81.8 ± 11.4/30.4 ± 3.8	76.9 ± 10.9[1,2,3]/28.6 ± 3.5[1,2,3]
S (n = 8)	80.3 ± 9.4/29.2 ± 3.1	79.1 ± 12.7/28.7 ± 3.1
SA (n = 8)	80.9 ± 11.8/29.3 ± 4.4	74.3 ± 12.4[1,3,4,5]/26.9 ± 4.1[1,3,4,5]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1] indicates significant difference between pre- and post-training values ($p < 0.05$)
[2] indicates significant difference with the control group ($p < 0.05$)
[3] indicates significant difference between the CT and S groups ($p < 0.05$)
[4] indicates significant difference between the CT and SA groups ($p < 0.05$)
[5] indicates significant difference between the S and SA groups ($p < 0.05$)

Table 3 Physical activity level according to Baecke Questionnaire for Older Adults [42] (value are means ± SD)

Treatments	Questionnaire Score	Activity Level
C (n = 8)	8.13 ± 1.29	Low
CT (n = 8)	8.10 ± 1.15	Low
S (n = 8)	8.48 ± 0.60	Low
SA (n = 8)	8.31 ± 1.20	Low

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.

Table 4 Peak torque values for leg extension in the four groups (values are means ± SD)

| Treatments | 60 deg × sec⁻¹ | | 180 deg × sec⁻¹ | |
	Pre-Training (Nm)	Post-training (Nm)	Pre-Training (Nm)	Post-training (Nm)
C (n = 8)	108.4 ± 11.2	107.5 ± 9.8	67.1 ± 5.9	66.8 ± 4.6
CT (n = 8)	106.7 ± 10.5	109.4 ± 9.6	68.7 ± 6.3	70.1 ± 7.2
S (n = 8)	109.1 ± 8.9	124.3 ± 12.1[1,2,3,5]	65.9 ± 4.8	72.9 ± 5.8[1,2,3]
SA (n = 8)	106.4 ± 9.9	126.0 ± 13.7[1,2,4,5]	69.7 ± 5.4	78.9 ± 8.1[1,2,5]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1] indicates significant difference between pre- and post-training ($p < 0.05$)
[2] indicates significant difference with the control group ($p < 0.05$)
[3] indicates significant difference between the CT and S groups ($p < 0.05$)
[4] indicates significant difference between the CT and SA groups ($p < 0.05$)
[5] indicates significant difference between the S and SA groups ($p < 0.05$)

more, CT demonstrated a greater ($p < 0.05$) decrease in body weight and BMI than C and S at the end of training.

There were no significant differences in isokinetic strength pre-training values among the four groups (Table **4**). However, significant ($p < 0.05$) differences in isokinetic strength, both for 60 deg × sec^{-1} and 180 deg × sec^{-1}, were evident in S and SA groups but not in A and CT groups after 16 weeks of training

(p < 0.05). SA group demonstrated a greater increase (p < 0.05) of peak torque than S group at 60 deg sec^{-1} but not at 180 deg × sec^{-1} (P < 0.05) (Table **4**).

There were also no significant (p < 0.05) differences in concentric strength pre-training values among the four groups (Table **5**). However, S, and SA treatments caused a significant (p < 0.05) increase of maximal strength in both chest press and leg press exercises at the end of the 16-week training period (p < 0.05) (Table **5**). The CT training group elicited a significant (p < 0.05) increase in maximal muscle strength in leg press but not in chest press. S and SA demonstrated a greater increase (p < 0.05) of maximal strength than CT and C in both exercises (Table **5**). SA elicited a greater (p < 0.05) increase of maximal strength than S in chest press but not in leg press (Table **5**).

There were no significant (p < 0.05) differences among the four groups for the sit & reach test score values at baseline (Table **6**). S and SA, but not CT and C, elicited a significant (p < 0.05) increase in the sit & reach score at the end of the training period (Table **6**). However, only SA was effective (p < 0.05) in increasing the sit & reach score at mid-training (Table **6**).

There were no significant (p < 0.05) differences among the four groups for the elbow and knee flexion/ extension values at baseline (Table **7**). Although C and CT did not cause any changes in both elbow and knee flexion/extension tests at all times, S and SA demonstrated a significant (p < 0.05) increase in these tests both at mid- and post-training (Tables **6**, **7**). S and SA also exhibited a significant (p < 0.05) increase in knee and elbow flexion/ extension tests from mid- to post-training (Table **7**).

There were no significant (p < 0.05) differences among the four groups for all shoulder flexibility tests at baseline (Table **8**). Neither CT nor C caused any significant (p < 0.05) change in any of the three shoulder flexibility tests (Table **8**). However, both S and SA elicited a significant (p < 0.05) increase in the shoulder flexion and extension test at mid- and post-training (Table **8**). S and SA also showed a significant (p < 0.05) improvement in shoulder flexion and extension tests from mid- to post-training (Table **8**). In contrast, there was no significant (p < 0.05) change in the shoulder adduction test by any of the treatments (Table **8**).

Table **5**   1-RM changes for chest press and leg press in the four groups (values are means ± SD)

	Chest Press		Leg Press	
Treatments	Pre-training (kg)	Post-training (kg)	Pre-training (kg)	Post-training (kg)
C (n = 8)	32.4 ± 10.2	32.6 ± 9.8	64.8 ± 8.4	66.5 ± 8.5
CT (n = 8)	31.3 ± 12.3	32.6 ± 12.4	61.9 ± 12.4	72.3 ± 12.2[1,2]
S (n = 8)	32.1 ± 5.5	68.7 ± 8.0[1,2,3,5]	65.5 ± 7.0	116.1 ± 9.8[1,2,3]
SA (n = 8)	30.1 ± 11.6	57.43 ± 16.8[1,2,4,5]	64.5 ± 8.1	113.6 ± 13.5[1,2,4]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1]   indicates significant difference between pre- and post-training (p < 0.05)
[2]   indicates significant difference with the control group (p < 0.05)
[3]   indicates significant difference between the CT and S groups (p < 0.05)
[4]   indicates significant difference between the CT and SA groups (p < 0.05)
[5]   indicates significant difference between the S and SA groups (p < 0.05)

Table **6**   Baseline, mid-training, and post-training values in the sit & reach test in the four groups (values are means ± SD)

Treatments	Pre-training (cm)	Mid-training (cm)	Post-training (cm)
C (n = 8)	18.0 ± 5.3	18.1 ± 5.6	18.0 ± 5.4
CT (n = 8)	17.2 ± 5.9	17.5 ± 4.8	18.1 ± 4.8
S (n = 8)	17.5 ± 4.4	18.3 ± 4.5[4]	19.4 ± 3.8[2,3,4,5]
SA (n = 8)	18.5 ± 4.6	19.6 ± 4.1[1,4]	20.7 ± 4.1[2,3,4,6]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group. 'Mid-training' and 'post-training' represent 8 and 16 weeks, respectively.
[1]   indicates significant difference between pre- and mid-training values (p < 0.05)
[2]   indicates significant difference between pre- and post-training values (p < 0.05)
[3]   indicates significant difference between mid- and post-training values (p < 0.05)
[4]   indicates significant difference with the control group (p < 0.05)
[5]   indicates significant difference between the CT and S groups (p < 0.05)
[6]   indicates significant difference between the CT and SA groups (p < 0.05)

Table **7**   Baseline, mid-training, and post-training values in the elbow and knee flexion/extension test in the four groups before (PRE), after 8 weeks (MID), and after 16 weeks (POST) (values are means ± SD)

		C (n = 8)	CT (n = 8)	S (n = 8)	SA (n = 8)
Elbow Flexion/Extension (deg)	PRE	127.3 ± 10.1	128.7 ± 11.5	126.3 ± 7.5	130.0 ± 13.7
	MID	126.7 ± 10.4	128.7 ± 9.86	130.4 ± 6.3[1,4,5]	133.9 ± 13.0[1,4,6]
	POST	127.0 ± 8.5	129.4 ± 11.3	135.4 ± 7.7[2,3,4,5]	138.1 ± 11.7[2,3,4,6]
Knee Flexion/Extension (deg)	PRE	120.5 ± 5.9	122.6 ± 9.1	124.4 ± 6.8	121.6 ± 6.2
	MID	119.7 ± 4.9	122.0 ± 7.1	129.4 ± 7.0[1,4,5]	125.7 ± 5.5[1,4,5]
	POST	121.3 ± 7.2	123.4 ± 8.2	133.0 ± 8.5[2,3,4,6]	130.9 ± 5.6[2,3,4,6]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1]   indicates significant difference between pre- and mid-training values (p < 0.05)
[2]   indicates significant difference between pre- and post-training values (p < 0.05)
[3]   indicates significant difference between mid- and post-training values (p < 0.05)
[4]   indicates significant difference with the control group (p < 0.05)
[5]   indicates significant difference between the CT and S groups (p < 0.05)
[6]   indicates significant difference between the CT and SA groups (p < 0.05)

Table **8** Baseline, mid-training, and post-training values in the shoulder flexibility tests in the four groups before (PRE), after 8 weeks (MID), and after 16 weeks (POST) (values are means ± SD)

		C (n = 8)	CT (n = 8)	S (n = 8)	SA (n = 8)
Shoulder Flexion (deg)	PRE	120.4 ± 5.8	118.6 ± 5.5	121.4 ± 5.8	122.1 ± 9.1
	MID	121.4 ± 4.4	120.1 ± 4.1	129.4 ± 4.9[1,4,5]	129.0 ± 8.7[1,4,5]
	POST	121.8 ± 4.1	120.8 ± 4.9	139.5 ± 3.1[2,3,4,6]	138.7 ± 8.6[2,3,4,6]
Shoulder Extension (deg)	PRE	45.0 ± 3.9	46.9 ± 7.6	48.1 ± 4.5	44.7 ± 4.6
	MID	45.6 ± 4.5	47.1 ± 6.1	54.4 ± 3.2[1,4,5]	50.6 ± 3.1[1,4,5]
	POST	46.1 ± 3.8	48.3 ± 5.6	63.3 ± 3.2[2,3,4,6]	57.8 ± 3.3[2,3,4,6]
Shoulder Adduction (deg)	PRE	132.1 ± 8.6	128.9 ± 7.7	130.4 ± 8.6	127.3 ± 12.3
	MID	131.4 ± 4.4	129.4 ± 5.7	132.7 ± 6.7	129.3 ± 11.0
	POST	121.8 ± 4.2	130.1 ± 5.5	133.2 ± 7.8[4]	130.1 ± 11.4[4]

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1] indicates significant difference between pre- and mid-training values (p < 0.05)
[2] indicates significant difference between pre- and post-training values (p < 0.05)
[3] indicates significant difference between mid- and post-training values (p < 0.05)
[4] indicates significant difference with the control group (p < 0.05)
[5] indicates significant difference between the CT and S groups (p < 0.05)
[6] indicates significant difference between the CT and SA groups (p < 0.05)

Table **9** Baseline, mid-training, and post-training values in the hip flexibility tests in the four groups before (PRE), after 8 weeks (MID), and after 16 weeks (POST) (values are means ± SD)

		C (n = 8)	CT (n = 8)	S (n = 8)	SA (n = 8)
Hip Flexion (deg)	PRE	98.1 ± 7.0	95.6 ± 6.3	96.9 ± 6.8	94.0 ± 5.9
	MID	97.6 ± 5.3	96.9 ± 6.4	100.4 ± 7.2[1,4,5]	98.6 ± 4.3[1,4]
	POST	98.9 ± 7.6	98.6 ± 4.4[3,4]	106.1 ± 6.7[2,3,4,6]	105.4 ± 4.8[2,3,4,6]
Hip Extension (deg)	PRE	15.5 ± 2.8	13.9 ± 3.0	16.4 ± 3.9	15.9 ± 2.7
	MID	16.0 ± 3.4	15.4 ± 4.2	18.9 ± 3.8[1,4,5]	18.7 ± 2.3[1,4,5]
	POST	15.1 ± 1.9	16.3 ± 3.4[3,4]	22.7 ± 5.2[2,3,4,5]	23.0 ± 2.5[2,3,4,6]
Hip Abduction (deg)	PRE	18.6 ± 3.9	17.1 ± 3.8	17.9 ± 3.9	16.7 ± 3.3
	MID	18.7 ± 3.6	18.1 ± 3.0	18.7 ± 2.7	18.1 ± 2.1
	POST	19.1 ± 2.8	18.9 ± 2.5	19.3 ± 2.7	18.7 ± 1.9
Hip Adduction (deg)	PRE	28.4 ± 6.6	26.9 ± 6.5	29.1 ± 7.5	27.0 ± 6.2
	MID	27.9 ± 7.1	28.1 ± 4.9	31.4 ± 7.5	28.1 ± 4.2
	POST	28.7 ± 5.7	28.7 ± 5.3	32.0 ± 6.1	29.3 ± 4.5

C indicates the control group, CT indicates the cardiovascular training group, S indicates the strength training group, and SA indicates the combination of strength and cardiovascular training group.
[1] indicates significant difference between pre- and mid-training values (p < 0.05)
[2] indicates significant difference between pre- and post-training values (p < 0.05)
[3] indicates significant difference between mid- and post-training values (p < 0.05)
[4] indicates significant difference with the control group (p < 0.05)
[5] indicates significant difference between the CT and S groups (p < 0.05)
[6] indicates significant difference between the CT and SA groups (p < 0.05)

There were no significant (p < 0.05) differences among the four groups for all hip flexibility tests at baseline (Table **9**). C did not present any changes in any of the tests (Table **9**). CT elicited a significant (p < 0.05) change in two of the four tests at post-training, the hip extension and flexion tests (Table **9**). However, S and SA produced a significant increase (p < 0.05) in hip extension and flexion tests both at mid- and post-training (Table **9**) while there was no effect (p < 0.05) on hip abduction and adduction test scores (Table **9**). S and SA were more effective (p < 0.05) than CT in increasing hip flexion and extension ability at post-training (Table **9**). S and SA also demonstrated a significant (p < 0.05) increase in shoulder flexion/ extension tests from mid- to post-training (Table **9**).

Discussion

Flexibility is maintained in a joint by using that joint and by participating in physical activities that stretch the muscles across that joint [34]. When a joint is relatively unused, the muscles that cross it shorten, thus reducing its range of motion [34]. However, there is limited information available regarding the independent and combined effects of strength or aerobic exercise on flexibility development of older adults. The present study indicates that resistance exercises and their combination cardiovascular training (CT), but not CT alone, are able to independently enhance flexibility of inactive older adults.

The present study showed that resistance training increased flexibility in certain joints independently of stretching exercises. Strength training caused an 11 % increase in the sit & reach score, a 7 % increase in elbow and knee flexion, a 15 % increase in shoulder flexion, a 30 % increase in shoulder extension, a 9.5 % increase in hip flexion and a 38 % increase in hip extension after 16 weeks of training. However, in most cases strength training increased range of motion significantly by the eighth week of training indicating that this type of training can cause early gains in flexibility development of older inactive adults. It is possible that range of motion of these joints might continue to increase if training exceeds 16 weeks, since in shoulder flexion and extension, in hip flexion and extension as well as in elbow flexion the largest increase was noted during the 8 final weeks of training. Increases of the same magnitude have previously been observed [6].

Previous research has produced non-uniform results concerning the effects of resistance exercises on flexibility improvement. It has been suggested that resistance training may significantly increase the flexibility if exercises are performed through the full range of motion, both the agonist and antagonist muscle groups are trained and stretching exercises are utilized [35]. Progressive resistance training increased flexibility in both young and old subjects [9]. Furthermore, it has been observed that regular mobilization explains increased hip flexibility suggesting that resistance training through the full range of motion may increase flexibility [17]. When a weight training protocol was used on young subjects for eight weeks, flexibility increased in 27 of 30 measures with three measures showing no change [24]. In another study [38], college-age men trained with three sets of eight repetitions at 70-80 % of 1RM (with the core exercises consisting of leg squat and bench press) and a significant increase in ankle and shoulder flexibility was observed. Jensen and Fischer [20] reported that among athletes, Olympic weightlifters were second only to gymnasts in a composite score of several flexibility tests. In contrast, Girouard et al. [16] suggested that strength training might even have a negative impact on flexibility development achieved through a training program consisting of stretching exercises. Massey and Chaudet [26] also noticed a decline in shoulder flexibility with strength training despite the fact that they did not include exercises for this type of movement in their training regimen. Raab et al. [32] observed a reduction in shoulder abduction when a resistance was used. However, no previous investigations have been reported on the independent effects of total body resistance training (without stretching exercises) on joint range of motion in older individuals. The few studies reported so far on the effects of strength training on measures of flexibility have used either low-resistance exercise only [32], young subjects only [14, 24 – 26, 38], have not specified whether stretching exercises were used [24, 26], have included aerobic activities in the training program [25, 28, 29, 32], or have not controlled for other factors that can have an impact on flexibility outcome [24, 26, 43]. Therefore, it is not surprising that previous literature have reported increases [9, 29, 43], losses [16, 26] and no changes [14, 25, 26] in flexibility measures with strength training.

The present study examined the range of motion of five different joints and 10 different types of movement of completely inactive older men. Participants were classified as inactive based on their scores on the physical activity questionnaire and their $\dot{V}O_2$max performance. In addition, their scores on the sit & reach flexibility test classified them at the lowest 20 % of the over 60 year old population [1]. Both strength training and the combination training resulted in a significant improvement of range of motion in seven out of ten joint movements examined. Only shoulder adduction and hip abduction and adduction remained unaffected. Interestingly enough, these three specific movements were not included in the strength training program. It is likely that the exercise program emphasized movement of those joints in which flexibility was improved while excluding those in which no changes in flexibility were seen. This finding might reflect a movement specific adaptation from strength training.

The results of the present study do not answer how strength exercise protocols enhance flexibility of older adults. It has been previously suggested that resistive exercise enhances the tensile strength of tendons and ligaments [34], and increases muscle mass and contractility [30], thus allowing a greater range of motion. In compensatory overload models, a substantial increase in the number of active fibroblasts in the tendon, enhanced collagen synthesis, intensive membrane renewal and recycling and an increase in muscle strength have been reported [45]. In the present study, all muscle groups, crossing the joints that increased their range of motion, increased their isokinetic and concentric strength ($p < 0.05$). It has been found that the strength of the bone-ligament junction is closely related to the type of exercise regimen and not only to the duration of the exercise [39]. Physical activity, and specifically strength training, apparently maintains tendon and ligament strength and integrity and reduces the probability of tendon rupture with age [3].

On the other hand, aerobic training (walking/jogging) did not affect flexibility measures except in the case of hip flexion and extension. Furthermore, the combination treatment of strength and cardiovascular training did not cause a greater impact than strength treatment in any of the seven flexibility measures. This suggests that cardiovascular training did not add to the positive flexibility effects of strength training. The independent effects of aerobic training on flexibility, however, are not well established. Two previous studies that used aerobic training found either no improvement [25] or an increase in flexibility of older adults [29]. Taunton et al. [37], without including stretching exercises in their training program, found no improvement in flexibility with either land- or water-based aerobic training. Mice that were exercised for one week on a treadmill increased the number and size of their collagen fibers more than did sedentary controls [27]. Aerobically trained swine did not improve the collagen's mechanical properties or cross-sectional area [44]. However, it has been observed that weight-bearing activities (such as walking or jogging used in the present study) increased collagen synthesis dramatically without altering Achilles tendon dry weight and collagen concentration, suggesting that synthesis matched degradation [10]. In the present study cardiovascular training improved only hip flexion and extension. The modest increase of hip flexion and extension range of motion seen in this study might have been due to the increase of muscle and collagen strength of the lower limbs. The fact that no changes were observed in hip abduction and adduction with aerobic training might indicate a specificity effect of aerobic training.

A significant decrease of body weight was observed in the endurance-trained groups of this study. However, it seems that improvement of flexibility seen in the present study is not related to changes in body weight since the CT demonstrated a significant decrease of body weight and limited improvement of flexibility of most joints examined. Furthermore, body weight did not change in S and yet flexibility was improved in most joints in that group.

Flexibility is considered an essential component of physical fitness. However, adults lose a significant amount of flexibility as they age. The loss of flexibility not only reduces the amount and nature of movement that can be made at a joint, it also increases the possibility of injury to the joint or to the muscles crossing the joint and the likelihood of falls due to loss of balance and stability. The present study demonstrates that strength and combined strength and cardiovascular training increase flexibility in inactive older adults. The physiological mechanisms underlying these positive adaptations remain to be determined.

Acknowledgements

References

1 American College of Sports Medicine. Guidelines for exercise testing and prescription. Philadelphia: Lippincott Williams & Wilkins, 2000: 85

2 American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 1998; 30: 992–1008

3 Barfred T. Achilles tendon rupture: aetiology and pathogenesis of subcutaneous rupture assessed on the basis of the literature and rupture experiments on rats. Acta Orthop Scand 1973; 152

4 Bergstrom G, Aniansson A, Bjelle A, Grimby G, Lundgren-Lidquist B, Svanborg A. Functional consequences of joint impairment at age 79. Scan J Rehab Med 1985; 17: 183–190

5 Borg G, Linderholm H. Perceived exertion and pulse rate during graded exercise in various age groups. Acta Med Scand 1967; 472: 194–206

6 Brown M, Holloszy JO. Effects of a low-intensity exercise program on selected physical performance characteristics of 60- to 71-year-olds. Aging 1991; 3: 129–139

7 Bruce RA, Cooper MN, Gey GO, Fischer LD, Peterson DR. Variations in responses to maximal exercise in health and cardiovascular disease. Angiology 1973; 24: 691–702

8 Bruce RA, Hornsten TR. Exercise stress testing in evaluation of patients with ischemic heart disease. Prog Cardiovasc Dis 1969; 11: 371–390

9 Chapman E, deVries H, Swezey R. Joint stiffness: effects of exercise on young and old men. J Gerontol 1972; 27: 218–221

10 Curwin FL, Vailas AC, Wood J. Immature tendon adaptation to strenuous exercise. J Appl Physiol 1988; 65: 2297–2301

11 Duncan PW, Chandler JM, Gavanaugh DK. Mode and speed specificity of eccentric and concentric exercise training. J Orthop Sports Phys Ther, 1989; 11: 70–75

12 Einkauf DV, Gohdes ML, Jensen GM, Jewell MJ. Changes in spinal mobility with increasing age in women. Phys Ther 1987; 67: 370–375

13 Frontera W, Meredith CN, O'Reilly K, Knuttgen H, Evans W. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J Appl Physiol 1988; 63: 1038–1044

14 Gardner G. Effect of isometric and isotonic exercise on joint motion. Arch Phys Med Rehab 1966; 47: 24–30

15 Gehlsen C, Whaley M. Falls in the elderly: part II, balance, strength, and flexibility. Arch Phys Med Rehab 1990; 71: 739–741

16 Girouard CK, Hurley B. Does strength training inhibit gains in range of motion from flexibility training in older adults? Med Sci Sports Exerc 1995; 27: 1444–1449

17 Hartley-O'Brien SJ. Six mobilization exercises for active range of hip flexion. Res Q Exerc Sport 1980; 51: 625–635

18 Heyward VH. Advanced Fitness Assessment and Exercise Prescription. Champaign, IL: Human Kinetics, 1998

19 Jackson A, Langford NJ. The criterion-related validity of the sit and reach test: replication and extension of previous findings. Res Quart Exerc Sport 1989; 57: 183–186

20 Jensen C, Fisher G. Scientific Basis of Athletic Conditioning. Philadelphia, PA: Lea and Febiger, 1979; 2nd ed

21 Kligman E, Pepin E. Prescribing physical activity for older patients. Geriatrics 1992; 47: 33–47

22 Kovanen B. Effects of ageing and physical training on rat skeletal muscle. Acta Physiol Scand 1989; 135: 1–56

23 Kuhlman KA. Cervical range of motion in the elderly. Arch Physiol Med Rehabil 1993; 74: 1071–1079

24 Leighton JR. A study of the effect of progressive weight training on flexibility. J Assoc Phys Ment Rehabil 1964; 18: 101

25 Marcinik E, Hodgdon J, Mittleman K, O'Brien J. Aerobic/calisthenic and aerobic/ circuit weight training programs for Navy men: a comparative study. Med Sci Sports Exerc 1985; 17: 482–487

26 Massey B, Chauder N. Effects of systematic, heavy resistive exercise on range of joint movement in young male adults. Res Quart 1956; 27: 41–51

27 Michna H. Morphometric analysis of loading-induced changes in collagen-fibril populations in young tendons. Cell Tiss Res 1984; 236: 465–470.

28 Morey MC, Cowper PA, Feussner JR, Dipasquale RC, Crowley GM, Sullivan RJ. Two-year trends in physical performance following supervised exercise among community-dwelling old veterans. J Am Geriatr Soc 1991; 38: 549–554

29 Morey MC, Couper PA, Feussner JR, Dipasquale RC, Crowley GM, Samsa GP, Sullivan RJ. Two-year trends in physical performance following supervised exercise among community-dwelling older veterans. J Am Geriatr Soc 1991; 39: 986–992

30 Moritani T, deVries HA. Potential for gross muscle hypertrophy in older men. J Gerontol 1980; 5: 672–682

31 Norkin CC, White DJ. Measurement of Joint Motion: A Guide to Goniometry. Philadelphia: F. A. Davis Company, 1985

32 Raab DM, Agre JC, McAdam M, Smith EL. Light resistance and stretching exercise in elderly women: Effect upon flexibility. Arch Phys Med Rehabil 1988; 69: 268–278

33 Smith A, Stroud L, McQueen C. Flexibility and anterior knee pain in adolescent elite figure skaters. J Ped Orthoped 1991; 11: 77–82

34 Spirduso WW. Physical dimensions of aging. Champaign, IL: Human Kinetics, 1995: 79

35 Stone M, Fleck S, Triplett N, Kramer W. Health and performance related potential of resistance training. Sports Med. 1991; 11: 210–231

36 Suominen H, Heikkinen E. Enzyme activities in muscle and connective tissue of m. vastus lateralis in habitually training and sedentary 33 to 70-year-old men. Eur J Appl Physiol 1975; 34: 249–254

37 Taunton J, Rhodes E, Wolski L. Effect of land-based and water-based fitness programs on the cardiovascular fitness, strength and flexibility of women aged 65–75 years. J Gerontol 1996; 42: 204–210

38 Thrash K, Kelly B. Flexibility and strength training. J Appl Sport Sci Res 1987; 1: 74–75

39 Tipton CM, Matthes RD, Sandage DS. In situ measurements of junction strength and ligament elongation in rats. J Appl Physiol 1974; 37: 758–761

40 Vandervoot AA, Chesworth BM, Cunningham DA. Age and sex effects on mobility of the human ankle. J Gerontol 1992; 47: M17–M21

41 Voorrips L, Lemmunk K, Van Heuvellon M, Bult P, Van Stoveron W. The physical condition of elderly women differing in habitual physical activity. Med Sci Sports Exerc 1993; 25: 1152–1157

42 Voorrips LE, Ravelli ACJ, Dongelmans PCA, Deurenberg P, Van Staveren WA. A physical activity questionnaire for the elderly. Med Sci Sports Exerc 1991; 23: 974–979

43 Weltman A, Janney C, Rians C. Effects of hydraulic resistance strength training in pre-pubertal males. Med Sci Sports Exerc 1986; 18: 629–638

44 Woo SLY, Matthews JV, Akeson WH, Amiel D, Convery FR. Connective tissue response to immobility. Correlative study of biochemical measurements of normal and immobilized rabbit knees. Arthr Rheumat 1980; 18: 257–264

45 Zamora AJ, Marini JF. Tendon and myotendinous junction in an overloaded skeletal muscle of the rat. Anat Embryol 1988; 179: 89–96