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ORIGINAL ARTICLE

Body composition, fitness, and metabolic health during strength and endurance training and their combination in middle-aged and older women

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Abstract In this study adaptations in body composition, physical fitness and metabolic health were examined during 21 weeks of endurance and/or strength training in 39- to 64-year-old healthy women. Subjects ($n = 62$) were randomized into endurance training (E), strength training (S), combined strength and endurance training (SE), or control groups (C). S and E trained 2 and SE 2 + 2 times in a week. Muscle strength and maximal oxygen uptake (VO_2max) were measured. Leg extension strength increased 9 ± 8% in S ($P < 0.001$), 12 ± 8% in SE ($P < 0.001$) and 3 ± 4% in E ($P = 0.036$), and isometric bench press 20% only in both S and SE ($P < 0.001$). VO_2max increased 23 ± 18% in E and 16 ± 12% in SE (both $P < 0.001$). The changes in the total body fat (dual X-ray absorptiometry) did not differ between groups, but significant decreases were observed in E (−5.9%, $P = 0.022$) and SE (−4.8%, $P = 0.005$). Lean mass of the legs increased 2.2–2.9% ($P = 0.004$–0.010) in S, SE and E. There were no differences between the groups in the changes in blood lipids, blood pressure or serum glucose and insulin. Total cholesterol and low-density lipoprotein cholesterol decreased and high-density lipoprotein cholesterol increased in E. Both S and SE showed small decreases in serum fasting insulin. Both endurance and strength training and their combination led to expected training-specific improvements in physical fitness, without interference in fitness or muscle mass development. All training methods led to increases in lean body mass, but decreases in body fat and modest improvements in metabolic risk factors were more evident with aerobic training than strength training.

Keywords Dual X-ray absorptiometry · Blood lipids · Oral glucose tolerance test · Muscle strength · Maximal oxygen consumption

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Introduction

Combined endurance and strength training may be more effective in improving physical fitness, body composition and metabolic health than either method alone. Endurance training among healthy older adults lead to similar specific training-induced improvements in physical fitness as those observed in younger adults (Ferketich et al. 1998; Hagberg et al. 1989; Sillanpää et al. 2008). Accordingly, moderate-to high intensity strength training can lead to marked gains in muscle strength and hypertrophy in men and women at all ages (Chilibeck et al. 1998; Tracy et al. 1999; Häkkinen et al. 1998a, 2001, 2003).

Concurrent endurance training can "interfere" with strength training-induced strength or muscle mass development during longer training periods (Häkkinen et al. 2003; Hickson 1980; Kraemer et al. 1995; Sillanpää et al. 2008). Interference is usually observed during high volume (high weekly frequency of training) and high intensity training. The interference may be related to systemic overtraining or to different or opposing metabolic or morphologic adaptations at the muscle level caused by strength or endurance training. However, most of the studies investigating concurrent training have been performed in men.

There are only limited data about how regional lean and fat mass distribution is altered with combined strength and endurance training in women. Dual X-ray absorptiometry (DXA) is an accurate method to assess regional body composition (i.e., trunk, arm and leg) (Houtkooper et al. 2000; Pritchard et al. 1993). In healthy women, there were differences in the responses to intensive military training in the lean and fat mass of the upper and lower extremities as assessed by DXA (Nindl et al. 2000). Possible differences in regional body composition changes caused by progressive strength or endurance training are important to investigate, because the location of fat deposition is more closely related to metabolic risk factors than the total percentage of body fat (fat%) (Shen et al. 2006; Wannamethee et al. 2007).

Adverse changes in abdominal obesity, insulin resistance, glucose tolerance and dyslipidemia become increasingly common in middle-aged women, particularly after menopause (Kotani et al. 1994). Insulin resistance is key in the development of the metabolic syndrome and type 2 diabetes, which are important risk factors for cardiovascular disease (Laaksonen et al. 2004). Insulin resistance is associated with ageing, but is in large part due to reduced physical activity, decreased muscle mass and accumulation of adipose tissue and ectopic fat (Lakka and Laaksonen. 2007).

Endurance training improves insulin sensitivity and glucose uptake in healthy and insulin-resistant subjects (Lakka and Laaksonen 2007; Rockl et al. 2008). This effect is due to activation of AMP-activated protein kinase, upregulation of glucose transporter 4 and glycogen synthase, changes in muscle fiber type and increased muscle capillarization (Hawley and Lessard 2008; Rockl et al. 2008). Strength training increases muscle mass and enhances insulin signaling (Braith and Stewart 2006; Holten et al. 2004). Physical exercise and contraction of skeletal muscle also acutely increases insulin sensitivity (Hawley and Lessard 2008). Both endurance and strength training may also improve blood lipid profile (Leon and Sanchez 2001; Tsuzuku et al. 2007) and decrease blood pressure (Kelley and Kelley 2000; Kelley et al. 2001). Due to different mechanisms, combined endurance and strength training may have synergistic benefits compared with either method alone.

However, little is known about how prolonged combined endurance and strength training influences metabolic health, especially in women (Asikainen et al. 2004). Therefore, the purpose of this randomized controlled trial was to compare effects of 21 weeks of combined endurance and strength training to those resulting from endurance or strength training alone on body composition, physical fitness and metabolic health in middle-aged and older healthy women.

Materials and methods

Subjects

Women (mean 51 years, range 39–64 years) living in the Jyväskylä city region were selected as subjects. A newspaper advertisement in the local free newspaper was published. The 64 volunteers who fulfilled the inclusion criteria and passed the baseline physical examination were randomly assigned, with stratification for age, BMI and menopausal status (pre- or post-menopausal), to the three training groups and one control group. The project was approved by the Ethics Committee of the Central Finland Health Care District. All subjects were carefully informed about possible risks and benefits of the project both verbally and in writing, and they signed a consent form before participation. One person withdrew from the study because she did not want to belong to the control group, and one person from the endurance training group dropped out due to personal reasons, reducing the number of women completing the study to 62. For reasons that included technical problems during maximal aerobic testing, complete data on the VO_2max tests were available for 55 participants. This work was a part of a larger project, and data on submaximal and maximal aerobic performance will be published in detail later with a larger number of subjects (Karavirta et al., unpublished data).

Exclusion criteria

All physical or psychological diseases, which may have precluded ability to perform the requested strength and endurance training and testing, including pronounced overweight or obesity (body mass index > 28 kg/m^2), impaired glucose tolerance and diabetes, and medications known to influence physical performance or interpretation of the findings were used as exclusion criteria. Subjects with a background in moderate to high intensity endurance or strength training more than once a week during the last year before the study were also excluded.

Medication

Three of the subjects used blood pressure medication (one from group E and two from group C), five subjects used cholesterol medication (one subject from groups S, SE and C and two subjects from group E). Seven subjects used estrogen replacement therapy (two from group E, three from group S and one from groups SE and C). Use of medication did not change during the study.

Study design

The subjects were randomized into the endurance training (E, $n = 15$), strength training (S, $n = 17$), combined strength and endurance training (SE, $n = 18$) or control group (C, $n = 12$). Subject characteristics are presented in Table 1. The measurements for all subjects took place twice before training at weeks −1 and 0 (a control period with no experimental training) and after 21 weeks of training. Measurements for the body composition by dual X-ray absorptiometry (DXA), maximal oxygen uptake and oral glucose tolerance tests were performed only once before and after the study period. The study design is presented in Fig. 1. Some of the variables for the three training groups were measured also in the middle of the training period (10 weeks). During the 21-week training period, both strength and endurance groups trained two times a week and the combined strength and endurance group trained two times a week for strength and two times a week for endurance. All training sessions were supervised by MSc students in the Department of Biology of Physical activity specialized in the major of Science of Sport Coaching and Fitness Testing. Missed training sessions were made up during subsequent training weeks so that the total

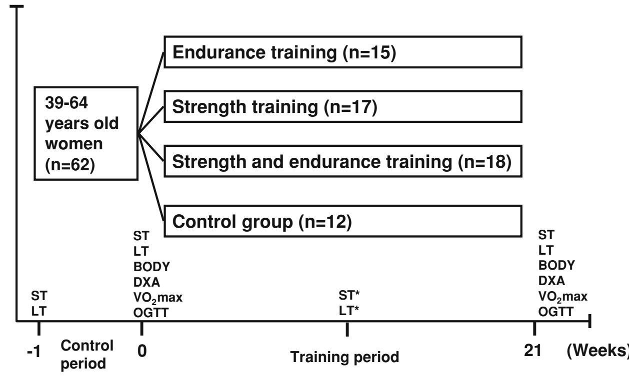

Fig. 1 Study design. *ST* strength tests, *BODY* body composition, weight and waist measurements; *LT* laboratory tests, blood lipids and lipoproteins and blood pressure; *DXA* dual energy X-ray absorptiometry, *VO_2max* maximal oxygen uptake, *OGTT* oral glucose tolerance test. *Measurements for exercise groups only

amount of training sessions was reached. All subjects were instructed to continue their habitual physical activities as before.

Training programs

Endurance training

The intensity of bicycle training was based on the aerobic performance tests (aerobic and anaerobic threshold) and controlled by heart rate monitoring (Häkkinen et al. 2006; Aunola and Rusko 1986). Training was periodized into the three training cycles and training intensity was progressively increased. During the first training cycle (weeks 1–7) the subjects trained 30 min two times a week under the level of their aerobic threshold. These sessions included also a few 10-min sessions above the aerobic threshold to accustom to higher intensity. The second training cycle (weeks 8–14) included 45-min training sessions, which were divided into the loading intervals varying in intensity

Table 1 Demographic and physical fitness characteristics at baseline in the subject groups

Group	E	S	SE	C
Subjects (*n*)*	15	17	18	12
Age (year)	51.7 (6.9)	50.8 (7.9)	48.9 (6.8)	51.4 (7.8)
Height (cm)	161.6 (7.0)	163.7 (8.5)	163.6 (6.1)	166.2 (6.6)
Weight (kg)	62.5 (7.3)	61.2 (9.2)	61.8 (7.6)	64.2 (7.4)
BMI (kg/m^2)	23.9 (2.1)	22.7 (2.4)	23.1 (2.5)	23.2 (1.8)
1RM (kg)	97.4 (11.7)	95.1 (15.6)	97.4 (15.6)	87.9 (11.5)
Bench press (N)	327.4 (54.7)	292.6 (65.3)	352.1 (91.7)	307.1 (61.0)
VO_2max (ml/kg per min)	26.8 (5.6)	27.2 (5.3)	29.6 (4.9)	26.3 (5.1)

Values are means (SD)

E endurance, *S* strength, *SE* combined, *C* control, *1RM* one-repetition maximum, *VO_2max* maximal oxygen uptake, * except in VO_2max E, $n = 11$, S, $n = 16$, SE, $n = 17$, C, $n = 11$ and in 1RM and bench press C, $n = 11$

from below the aerobic threshold to above the anaerobic threshold and 60-min training sessions under the level of their aerobic threshold. The main focus during the third cycle (weeks 15–21) was to improve aerobic capacity. The duration of the training sessions varied from 60 to 90 min. Every other training session included 90 min of cycling at a steady pace under the aerobic threshold and every other session 60 min of cycling with intensities varying from under the aerobic threshold to over the anaerobic threshold.

Strength training

The present 21-week training program was a progressive total body program for the lower and upper extremities and trunk.

The training period consisted of three specific training cycles of 7 weeks in duration. The focus of the first training cycle was to accustom the women to strength training, to improve muscular strength and muscle endurance and to reduce total fat. Training loads used in this cycle were 40–60% of the one-repetition maximum (1RM) and the number of repetitions per set 15–20. The focus of the second cycle was to produce muscle hypertrophy and to increase the total muscle mass/fat ratio (loads of 60–80% of 1RM, repetitions 10–12) (American College of Sports Medicine 2002). During the third cycle, the goal was to optimize gains in strength of the trained muscles with higher training loads (70–90% of 1RM) and a lower number of repetitions per set (6–8) (Kraemer et al. 2004). The individual loads of strength training were determined based of the strength tests performed at baseline and in the middle of the training period. Each training session included two exercises for the leg extensor muscles (leg press and knee extension), one exercise for bilateral or unilateral knee flexion and four to five other exercises for the other main muscle groups of the body (bench press, triceps pushdown, or lateral pull-down exercise for the upper body; sit-up exercise for the trunk flexors or another exercise for the trunk extensors; and bilateral/unilateral elbow flexion exercise or leg adduction/abduction exercise). Added to these machine exercises, each session included 5-min warm up and recovery by bicycle, and some stretching exercises. The number of training sets was 3–4 during the whole training period. The supervised training sessions averaged from 60 to 90 min in length two times a week.

Measurements

Body composition

All body composition measurements were performed by the same investigator throughout the study period.

Body height, weight and body mass index (BMI) Height was measured by an inelastic plastic tape measure with the subjects standing barefoot. Body weight was measured with the calibrated electrical scale [Model 708 (d = 0.1 kg), Seca, Germany] with the subjects in their underwear. BMI was calculated by dividing weight in kilograms by the square of height in meters (kg/m^2).

Dual X-ray Absorptiometry (DXA) Whole body and regional body composition were estimated by DXA (LUNAR Prodigy, GE Medical systems). The system software (enCORE 2005, version 9.30) provides the mass of lean soft tissue, fat, and bone mineral for the whole body and specific regions (trunk and both arms and legs) (Kim et al. 2004). Appendages were isolated from the trunk and head by using DXA regional computer-generated default lines with manual adjustments (Kim et al. 2002). Body composition was analyzed by using estimated fat mass and lean mass of soft tissue without bone.

Waist circumference was measured at mid-way between the lateral lower ribs and the iliac crest. An average of three measurements was used in calculations.

Physical fitness

Aerobic performance

The graded exercise test was carried out by using the Monark E839 (Monark Oy, Sweden) bicycle ergometer to determinate maximal oxygen uptake as well as aerobic and anaerobic thresholds. Aerobic and anaerobic thresholds were determined from the respiratory gas analysis and blood lactate values (Aunola and Rusko 1986). Blood samples were taken from the fingertip and analyzed with Lactate Pro LT-1710 analyzer (Arkray Inc., Kyoto, Japan). Oxygen uptake was measured breath-by-breath continuously (SensorMedics® Vmax229). VO_2max was determined at the highest 1-min average of VO_2 during the test. Heart rate and continuous electrocardiogram (ECG) were monitored during the test as well as blood pressure every second minute by the manual sphygmomanometer (Gamma G-5, Heine, Germany). A physician supervised the maximal test. The subjects were encouraged by the testers to continue cycling until exhaustion. In a few subjects the test was interrupted by a physician for medical reasons (pathological changes in blood pressure or ECG).

Neuromuscular performance

A David 210 dynamometer (David Fitness and Medical, Outokumpu, Finland) was used to measure maximal bilateral concentric force production of the leg extensors (hip, knee, and ankle extensors) in a horizontal leg press exercise (Häkkinen et al. 1998a). The subject was in a seated position so that the hip angle was 110°. On verbal command, the subject performed a concentric leg extension starting from a flexed position of 70°, trying to reach a full extension of 180° against the resistance determined by the loads chosen on the weight stack. In the testing of the maximal load, separate 1RM contractions were performed. After each repetition, the load was increased until the subject was unable to extend the legs to the required position. The last acceptable extension with the highest possible load was determined as 1RM. A modified David 200 dynamometer was applied for the recording of the bilateral isometric force of the bench press action (including triceps brachii, anterior deltoid and pectoralis major muscles) (Häkkinen et al. 1998b). Subjects sat on the dynamometer and pushed with their upper arms against a horizontal bar with their elbows at 90°.

Metabolic risk factors

All blood samples were taken after 12 h fast between 7:00 and 9:00 a.m. The preceding day was a rest day from any strenuous physical activity and the participants were asked to rest at least 8 h during the previous night. All blood samples were drawn from the antecubital vein and handled according to standardized laboratory practice. Serum samples were stored frozen at −80°C until analyzed.

Blood lipids and lipoproteins Total cholesterol, HDL cholesterol (HDL-C) and triglycerides were measured by using Vitros DT60 dry chemistry system (Ortho-Clinical Diagnostics, Inc., USA). LDL cholesterol (LDL-C, mmol/l) was estimated using the Friedewald equation: LDL-C = total cholesterol − HDL-C − (triglycerides/2.2) (Friedewald et al. 1972).

Blood pressure Systolic (SBP) and diastolic blood pressure (DBP) were taken as the lower of two measurements in the supine position after a rest of 5 min using an automatic sphygmomanometer (Omron, model HEM-705C, Omron Corporation, Hamburg, Germany).

Glucose metabolism was assessed with an oral glucose tolerance test (OGTT). Samples were taken while fasting at 0 min and 60 and 120 min after a glucose load (75 g). Glucose and insulin areas under the curve (AUC) were calculated using a trapezoid model. Blood glucose samples were analyzed with the Hemocue Glucose Analyzer (B-Glucose Photometer, HemoCue AB, Ängelholm, Sweden). Insulin concentrations were assayed using time-resolved immuno-fluorometric assays (TR-IFMA), B080-101 and an AutoDELFIA fluorometer (Wallac, Turku, Finland).

Statistical methods

SPSS version 14.0 for Windows was used for statistical analyses (SPSS, Inc., Chicago, IL). The changes in study variables between the groups were compared with the analysis of covariance (ANCOVA) using the baseline values (week 0) as the covariate. If necessary, the data were transformed logarithmically before ANCOVA to fulfill the criterion of normal distribution. When there were no group effects, the time-effect was analyzed in the total group of trained subjects using multivariate analysis of variances (MANOVA). Within group analyses were performed with paired samples *t* tests. Glucose and insulin AUCs during the OGTT were measured with following equation: AUC = [(baseline 0 + 1 h concentrations)/2 + (1-h concentrations + 2-h concentrations)/2].The relationships between different variables at baseline were assessed with the Pearson's correlation test and the relations between the changes in variables during the intervention were studied using partial correlation analysis with adjustment for group. Statistical significance was assessed at the level of $P \leq 0.05$.

Results

Body composition

There were no differences between the groups in demographic characteristics at baseline (Table 1). No significant differences occurred in the changes of body weight or waist circumference between the groups. Body weight decreased significantly only in E (−1.0 ± 1.7 kg, $P = 0.038$) and C (−0.4 ± 0.6 kg, $P = 0.033$) during the training period, while S (0.0 ± 1.4 kg, $P = 0.97$) and SE (−0.1 ± 1.7 kg, $P = 0.77$) showed no changes. Waist circumference decreased during training in E (−1.9 ± 2.1 cm, $P = 0.003$) and SE (−1.6 ± 2.1 cm, $P = 0.007$) with no changes in S (−0.5 ± 2.0 cm, $P = 0.30$) or C (−0.5 ± 1.4 cm, $P = 0.23$).

The groups did not differ in fat% changes over the experimental period. Both E and SE showed significant decreases in fat%, total fat mass and fat mass of the arms, legs and trunk, while S and C showed no changes (Table 2). The changes in fat mass of the arms differed significantly between the control group and the total group of trained subjects ($P = 0.008$).

The changes of lean mass of the arms ($P = 0.015$) and trunk ($P = 0.015$) differed significantly between the groups after training (Table 2; Fig. 2a, b). The total group of trained subjects differed from the control group significantly in total body lean mass ($P = 0.044$). Both E ($P = 0.019$) and SE ($P = 0.024$) increased total body lean

Table 2 Body composition as measured by dual X-ray absorptiometry (DXA) and their changes with training

Group	Baseline	Change 0–21 weeks	Between groups *P* value
Percentage of fat (%)			
E	35.5 (4.8)	−2.1 (2.2)**	0.095
S	32.0 (7.1)	−0.9 (1.8)	
SE	30.9 (6.1)	−1.9 (1.7)***	
C	32.6 (6.8)	−0.6 (1.5)	
Fat mass (g)			
Total			
E	21,528 (4,826)	−1,262 (1,904)*	0.242
S	19,115 (6,286)	−430 (1417)	
SE	19,785 (6,171)	−943 (1,226)**	
C	20,309 (5,227)	−196 (1,027)	
Arms			
E	2,117 (564)	−119 (212)*	0.061
S	1,846 (667)	−75 (196)	
SE	1,968 (719)	−125 (185)*	
C	2,098 (736)	33 (137)	
Legs			
E	8,251 (2,128)	−544 (779)*	0.234
S	7,571 (2,574)	−228 (600)	
SE	7,487 (2,569)	−412 (409)**	
C	8,138 (2,636)	−147 (313)	
Trunk			
E	10,500 (2,605)	−561 (1003)*	0.476
S	9,109 (3,386)	−110 (796)	
SE	9,697 (3,510)	−375 (750)*	
C	9,422 (2,960)	−70 (700)	
Lean mass (g)			
Total			
E	38,804 (3,678)	728 (1065)*	0.165
S	40,064 (4,880)	399 (964)	
SE	41,602 (3,732)	672 (1151)*	
C	41,508 (3,416)	−136 (849)	
Trunk			
E	19,270 (2,125)	430 (825)	0.015
S	19,657 (2,289)	57 (724)	
SE	20,786 (1,689)	198 (748)	
C	20,564 (1,982)	−98 (611)	

Values are means (SD). Lean mass of the legs and arms are shown in Fig. 1

E endurance ($n = 15$), *S* strength ($n = 17$), *SE* combined ($n = 18$), *C* control ($n = 12$)

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$ significant difference within group from week 0 to week 21

mass. Lean mass of the legs increased significantly in all three training groups and lean mass of the arms increased only in the SE group ($P = 0.021$).

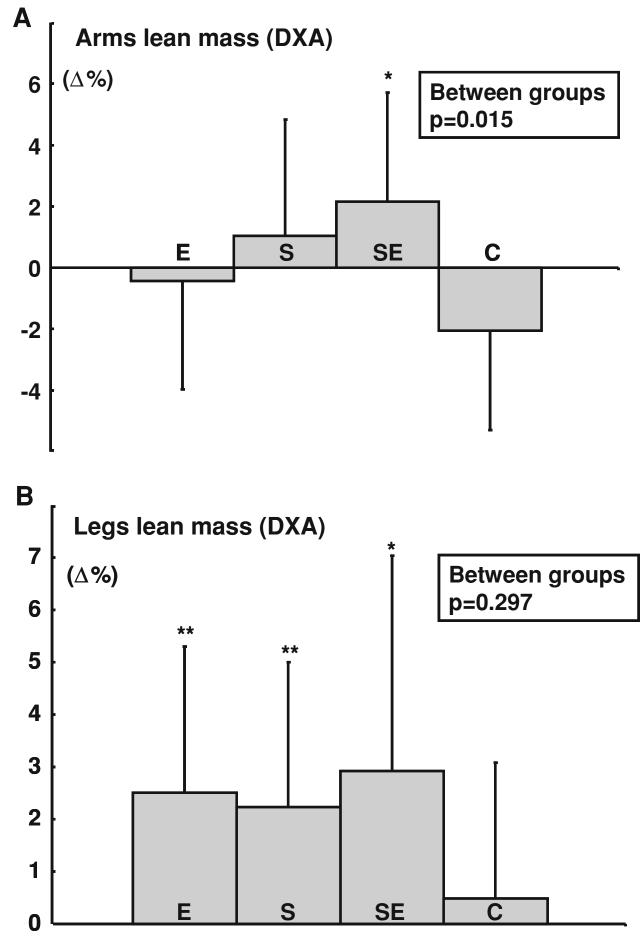

Fig. 2 **a**, **b** Changes (mean ± SD) in lean mass of the arms and legs during the 21-week training period. *E* endurance training group ($n = 15$), *S* strength training group ($n = 17$), *SE* combined training group ($n = 18$), *C* control group ($n = 12$). *$P < 0.05$, **$P < 0.01$ significant difference within group from week 0 to week 21

Physical Fitness

Baseline values of physical fitness are presented in Table 1. The differences in the changes in leg press ($P = 0.001$) and isometric bench press ($P < 0.001$) between the groups were significant (Fig. 3a, b). The increases in leg extension strength were 9 ± 8% in S ($P < 0.001$) and 12 ± 8% in SE ($P < 0.001$) and in isometric bench press 20% in both groups ($P < 0.001$). E showed a small increase of 3 ± 4% in leg extension 1RM ($P = 0.036$) and no change in isometric bench press. The changes in C were not significant. There was a significant difference between the groups in the changes of maximal oxygen consumption ($P < 0.001$) (Figs. 3c, 4). The increases in VO_2max were 23 ± 18% in E and 16 ± 12% in SE (both $P < 0.001$) and there were no changes in S or C.

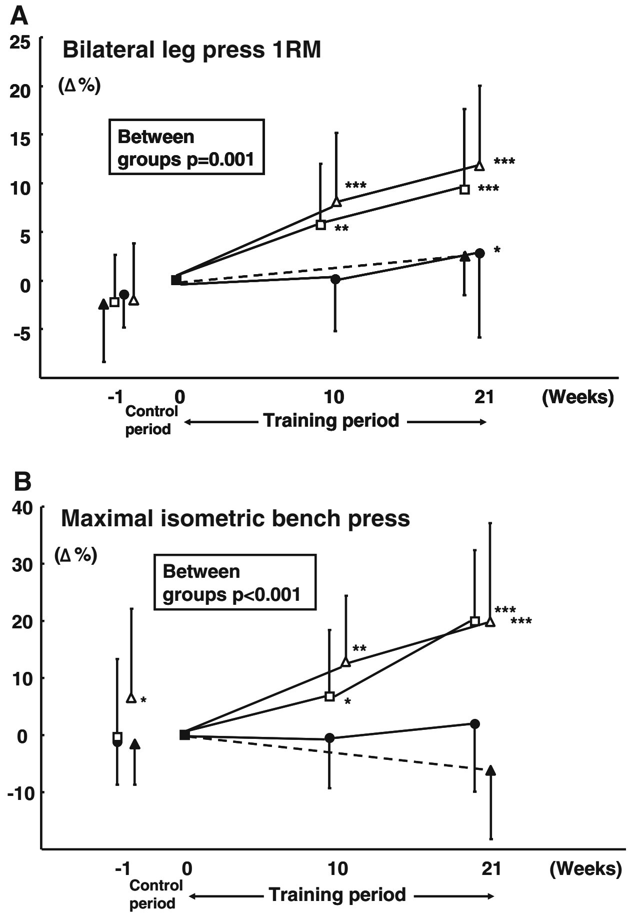

Fig. 3 **a**, **b** Relative changes (mean ± SD) in maximal leg extension strength (1RM, one-repetition maximum) and maximal isometric bench press during the 1-week control period and the 21-week training period. *Filled circle* endurance training group ($n = 15$), *open square* strength training group ($n = 17$), *open triangle* combined training group ($n = 18$), *filled triangle* control group ($n = 11$). $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$ significant difference within the group from the value at week 0

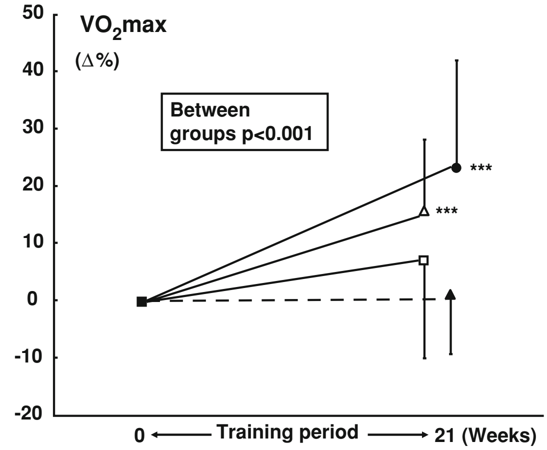

Fig. 4 Relative changes (mean ± SD) in maximal oxygen consumption before and after the 21-week training period *filled circle* endurance training group ($n = 11$), *open square* strength training group ($n = 16$), *open triangle* combined training group ($n = 17$), *filled triangle* control group ($n = 11$). $^{***}P < 0.001$ significant difference within the group after training

Metabolic risk factors

There were no differences between the groups in the changes in blood lipids or lipoproteins during the training period (Table 3). In within group analyses, E showed small decreases in total cholesterol (−0.2 ± 0.3 mmol/l, $P = 0.003$) and LDL-C (−0.3 ± 0.4 mmol/l, $P = 0.010$) and a small increase in HDL-C (0.1 ± 0.2 mmol/l, $P = 0.045$) during training. No differences occurred in resting blood pressure in any of the groups (Table 3).

The groups did not differ in the changes in blood glucose or insulin (Table 4). Both S ($P = 0.049$) and SE ($P = 0.042$) showed small decreases in serum fasting insulin and S in serum glucose 2-h concentration during training ($P = 0.038$). Moreover, there were no statistically significant changes in glucose (E −0.7 ± 1.9 mU/ml, $P = 0.16$; S −0.6 ± 1.3 mU/ml, $P = 0.076$; SE −0.7 ± 1.9 mU/ml, $P = 0.16$; and C 0.3 ± 1.5 mU/ml, $P = 0.51$) or insulin (E −16.0 ± 37.5 mU/ml, $P = 0.11$; S −5.2 ± 24.2 mU/ml, $P = 0.39$; SE −8.1 ± 20.7 mU/ml, $P = 0.11$; and C 1.2 ± 19.4, $P = 0.83$) AUCs in any of the groups.

Correlations between body composition and metabolic health

At baseline HDL-C ($r = -0.29$, $P = 0.024$) and triglycerides ($r = 0.28$, $P = 0.025$) correlated with waist circumference in the total group of subjects ($n = 62$). During training, the individual changes in triglycerides correlated with the changes in weight ($r = 0.35$, $P = 0.013$) and fat% ($r = 0.32$, $P = 0.026$) in the total group of trained subjects ($n = 47$).

Discussion

The present combined endurance and strength training and endurance training alone led to marked benefits in cardiorespiratory fitness and to small improvements in body composition and metabolic risk factors in healthy 39- to 64-year-old women. Compared with combined training, strength training alone was also as effective in increasing neuromuscular fitness and lean mass of the legs, but did not produce significant improvements in metabolic health.

To our knowledge, this is the first study comparing strength and endurance training alone and together on body composition, physical fitness and metabolic health in 39–64 year old, generally healthy women. Although as might be expected, the changes in glucose and lipid metabolism and blood pressure were slight in these non-obese women,

Table 3 Blood lipids and lipoproteins, resting blood pressure and their changes (in absolute values) with training

Group	Control	Baseline	Post-training	Change 0–10 weeks	Between groups *P* value	Change 0–21 weeks	Between groups *P* value
Total cholesterol (mmol/l)							
E	5.1 (0.7)	5.0 (0.6)	4.7 (0.6)	0.0 (0.3)	0.518	−0.2 (0.3)**	0.429
S	5.3 (0.6)	5.3 (0.7)	5.2 (0.7)	0.0 (0.6)		−0.1 (0.6)	
S + E	5.1 (0.7)	4.9 (0.6)	4.8 (0.6)	−0.1 (0.3)		−0.1 (0.5)	
C	5.5 (0.8)	5.4 (0.9)	5.2 (0.6)			−0.2 (0.4)	
LDL (mmol/l)							
E	3.0 (0.5)	2.9 (0.4)	2.6 (0.6)	−0.1 (0.4)	0.351	−0.3 (0.4)*	0.205
S	3.3 (0.5)	3.2 (0.6)	3.1 (0.6)	0.0 (0.5)		−0.1 (0.5)	
S + E	3.0 (0.6)	2.9 (0.5)	2.8 (0.6)	−0.1 (0.5)		0.0 (0.4)	
C	3.2 (0.6)	3.2 (0.7)	3.0 (0.6)			−0.2 (0.3)	
HDL (mmol/l)							
E	1.7 (0.4)	1.6 (0.4)	1.7 (0.3)	0.1 (0.2)*	0.175	0.1 (0.2)*	0.313
S	1.7 (0.3)	1.7 (0.3)	1.7 (0.3)	0.0 (0.3)		0.0 (0.2)	
S + E	1.7 (0.4)	1.5 (0.4)	1.6 (0.3)	0.1 (0.2)		0.0 (0.2)	
C	1.9 (0.4)	1.8 (0.3)	1.7 (0.2)			−0.1 (0.3)	
Triglycerides (mmol/l)							
E	0.8 (0.2)	0.9 (0.3)	0.8 (0.4)	0.0 (0.4)	0.104	−0.1 (0.4)	0.141
S	0.8 (0.3)	0.8 (0.3)	0.8 (0.2)	0.0 (0.3)		0.0 (0.2)	
S + E	0.9 (0.6)	1.1 (0.8)	0.9 (0.5)	−0.3 (0.5)		−0.2 (0.5)	
C	0.9 (0.3)	0.9 (0.2)	1.0 (0.3)			0.1 (0.2)	
Systolic blood pressure (mmHg)							
E	128 (16)	127 (15)	125 (16)	2 (12)	0.157	−2 (11)	0.062
S	126 (17)	119 (15)**	119 (16)	−2 (9)		0 (10)	
SE	130 (16)	125 (17)	126 (16)	3 (8)		1 (9)	
C	131 (20)	130 (18)	121 (18)			−9 (7)	
Diastolic blood pressure (mmHg)							
E	79 (11)	78 (11)	76 (9)	2 (4)	0.149	−1 (7)	0.053
S	74 (10)	71 (10)	71 (10)	−2 (8)		−1 (7)	
SE	79 (8)	75 (8)***	77 (8)	1 (6)		3 (5)	
C	73 (25)	76 (9)	73 (8)			−3 (5)	

Values are means (SD)

E endurance ($n = 15$), *S* strength ($n = 17$), *SE* combined ($n = 18$), *C* control ($n = 12$)

* $P < 0.05$, ** $P < 0.01$. Significant difference within group from week 0 to week 21

the large improvement in cardiorespiratory fitness and more modest improvement in body composition obtained by endurance and combined training may be of importance in preventing the development of the metabolic syndrome and its consequences, especially type 2 diabetes and cardiovascular disease (Jurca et al. 2005; Laaksonen et al. 2002; Lakka and Laaksonen 2007). Ageing is often accompanied by a reduction in lean body mass and an increase in fat mass, especially in the visceral depot (Pascot et al. 1999), worsening insulin resistance and glucose tolerance, dyslipidemia and hypertension. In women these changes occur particularly rapidly after menopause (Kotani et al. 1994), and increase the risk for type 2 diabetes and cardiovascular disease (Shen et al. 2006).

In this study, both endurance and combined training decreased waist girth and also total fat mass (−5.9 and −4.8%) as measured by DXA. The decreases in regional fat mass in the arms, legs and trunk were of the same magnitude, varying from −3.9 to −6.6% in different body parts in E and SE. Nindl et al. (2000) also reported improvements in body composition after 6 months of combined aerobic and resistance training in younger women. In that study, however, there were large decreases in the fat mass of the arms, but no change in fat mass of the legs. The differential changes in regional fat and lean mass can be due to the different loading of the training programs, i.e., differences in the amount and intensity of training and the specific exercises performed,

Table 4 Serum insulin and glucose levels and their changes (in absolute values) with training

Group	Baseline	Post-training	Change 0–21 weeks	Between groups
Insulin (mIU/l)				
Pre				
E	4.6 (1.9)	3.7 (1.4)	−1.0 (2.1)	0.930
S	4.4 (1.5)	3.8 (1.3)	−0.6 (1.2)*	
SE	4.2 (1.8)	3.7 (1.5)	−0.5 (1.0)*	
C	3.9 (2.2)	3.8 (2.1)	−0.1 (2.1)	
Post 1-h				
E	55.6 (39.2)	41.4 (26.1)	−14.1 (32.2)	0.372
S	39.5 (22.4)	36.0 (17.6)	−3.6 (24.4)	
SE	40.1 (20.3)	34.0 (16.5)	−6.1 (18.5)	
C	40.2 (18.1)	41.6 (14.4)	1.4 (17.6)	
Post 2-h				
E	28.8 (10.5)	26.1 (15.2)	−2.7 (15.6)	0.670
S	22.3 (10.1)	19.6 (8.0)	−2.7 (8.8)	
SE	25.6 (8.8)	22.1 (10.1)	−3.5 (11.4)	
C	25.9 (15.4)	25.6 (14.0)	−0.3 (11.8)	
Glucose (mmol/l)				
Pre				
E	4.5 (0.5)	4.2 (0.4)	−0.3 (0.6)	0.430
S	3.9 (0.4)	3.8 (0.3)	−0.1 (0.4)	
SE	4.1 (0.7)	4.0 (0.4)	−0.1 (0.6)	
C	4.0 (0.4)	4.0 (0.3)	0.0 (0.4)	
Post 1-h				
E	4.8 (1.2)	4.5 (1.6)	−0.3 (1.4)	0.801
S	4.4 (1.1)	4.0 (1.2)	−0.4 (1.1)	
SE	4.7 (1.7)	4.3 (1.5)	−0.4 (1.5)	
C	4.0 (1.6)	4.2 (1.0)	0.3 (1.5)	
Post 2-h				
E	4.3 (0.9)	3.8 (1.0)	−0.6 (1.0)	0.643
S	3.8 (0.8)	3.4 (0.9)	−0.4 (0.7)*	
SE	4.2 (1.1)	3.8 (0.9)	−0.4 (1.0)	
C	3.5 (0.7)	3.7 (0.7)	0.1 (0.8)	

Values are means (SD)

E endurance ($n = 15$), *S* strength ($n = 17$), *SE* combined ($n = 18$), *C* control ($n = 12$)

* $P < 0.05$ significant difference within group from week 0 to week 21

or to age-related differences between young and older subjects.

We observed increases of 2.2% in lean mass in the arms only in the SE group, but the lean mass of the legs increased similarly not only in SE and S, but also in E. In contrast, we have previously found similar training-induced increases in lean mass of the legs and arms in men with strength training, but not with combined or endurance training (Sillanpää et al. 2008). In younger women (Nindl et al. 2000), increases of about 2% in total body lean mass by DXA caused by five training sessions per week of combined strength and endurance training for 24 week have been reported. We hypothesize that in these previously untrained women, also progressive endurance training by bicycle can cause a sufficient stimulus for muscle hypertrophy in the legs. In general, the training load is lower in bicycle training than in strength training, but the high amount of repetitions and high intensity of cycling training with higher loads has been shown to cause some hypertrophy of the thigh extensors (McCarthy et al. 2002). Izquerdo et al. (2005) have also reported increases of a similar magnitude in quadriceps femoris cross-sectional area caused by endurance, strength or combined training in middle-aged men, when high-load cycling was used for endurance training. However, typical aerobic training such as walking or jogging, which is recommended to improve metabolic health in elderly subjects, does not lead to muscle hypertrophy in the legs (Sipilä and Suominen 1995).

The present 21-week strength training program led to smaller increases (9–12%) in leg extension strength than reported earlier in older women (24–29%) (Häkkinen et al. 2000; Sallinen et al. 2006) and to larger increases (20%) in isometric bench press that have been observed with men (13–14%) of the same age (Sillanpää et al. 2008). Combining 2 times endurance and 2 times strength training in a week did not cause interference in muscle strength development in our previously untrained healthy 39- to 64-year-old women, which is consistent with training studies with similar or lower training intensity in men (Izquierdo et al. 2004; Sillanpää et al. 2008). The relatively large increases in muscle strength were most likely related to neural adaptations to strength training, because the changes in lean mass of the legs and arms were rather minor. These neural mechanisms include motor unit recruitment and synchronization, firing frequency and changes in agonist-antagonist activation (Häkkinen et al. 1998a).

The increases in maximal oxygen consumption during endurance and combined training were consistent with other studies in older men and women (Ferketich et al. 1998; Hagberg et al. 1989; Sillanpää et al. 2008). The magnitude of the increase in VO_2max was slightly greater in E (23%) than in SE (16%), but the difference was not statistically significant. This is consistent with studies comparing combined training versus endurance training only in older men (Izquierdo et al. 2004, 2005). Overall, no interference occurred in physical fitness development during this moderate frequency (2 + 2 times in a week) training in previously untrained women, which is supported by a similar study in men of the same age (Sillanpää et al. 2008).

Metabolic health factors were related to fat% and waist circumference at baseline, which is supported by the large number of cross-sectional studies. In addition, during training the change in triglyceride level was related to the change in body weight and fat%, which also emphasizes the importance of concomitant training-induced changes in body composition in the prevention and treatment of metabolic risk factors.

Overall, training-induced changes in glucose and lipid metabolism and blood pressure were small and did not differ between the training or control groups. Moreover, the combined training with higher training volume and frequency (2 times endurance and 2 times strength) did not produce synergistic benefits over 2 times a week endurance training alone, even though total workload and energy output were much higher during combined training than E or S only. Total cholesterol and LDL-C decreased and HDL-C increased during training only in E, which may be related to concomitant aerobic training and changes in body composition (loss of body weight and total and abdominal fat) in this group. Many studies in middle-aged and older women have found positive changes in blood lipids after aerobic training (Seip et al. 1993; Stefanick et al. 1998; Vasankari et al. 1998). In some studies, also resistance training has been shown to improve lipid metabolism in older women (Fahlman et al. 2002), but most studies (Elliott et al. 2002; Vincent et al. 2003; Boardley et al. 2007) have not. Therefore, an aerobic component of exercise or a concomitant decrease in abdominal fat may be needed to augment positive changes in blood lipids or lipoproteins by exercise training in older adults.

Significant within group decreases in serum fasting insulin concentrations were found in S ($-11.0 \pm 24.9\%$) and SE ($-9.3 \pm 24.8\%$). The mean decrease was even higher in group E ($-12.2 \pm 35.0\%$), but the change was nonsignificant, because of the high variation in the insulin response of the subjects. Blood pressure did not change with training, which may be in part because blood pressure was normal at baseline.

Strengths of this study included the randomized controlled trial with the comparison of strength and endurance training alone and together. The amount and intensity of training during the 21-week training period were carefully defined and completely supervised. On the other hand, our observations are limited to middle-aged and older healthy women, and the results cannot be generalized for obese or high-risk populations. The effects of seasonal and behavioral confounding factors are difficult to control during such a long training period. Nutritional factors may also have an influence on some of the metabolic variables. However, these confounding factors are unlikely to differ between the experimental and control groups.

Combined endurance and strength training 2 + 2 times in a week markedly enhanced both neuromuscular and cardiorespiratory fitness in 39- to 64-year-old non-obese women without interference in physical fitness of muscle mass development. Both endurance and strength training and especially their combination seem to be effective in modifying body composition by increasing lean mass. However, decreases in total and regional fat and modest beneficial changes in lipid metabolism seem to be more related to aerobic type of training than strength training. Prolonged combined training and endurance training alone may be of benefit in preventing the adverse changes in body composition and metabolic risk factors that occur with ageing.

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