Effects of Combined Strength and Endurance Training on Treadmill Load Carrying Walking Performance in Aging Men

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Abstract

Holviala, J, Häkkinen, A, Karavirta, L, Nyman, K, Izquierdo, M, Gorostiaga, EM, Avela, J, Korhonen, J, Knuutila, V-P, Kraemer, WJ, and Häkkinen, K. Effects of combined strength and endurance training on treadmill load carrying walking performance in aging men. *J Strength Cond Res* 24(6): 1584–1595, 2010—The present study examined the effects of twice weekly total body strength training (ST), endurance cycling (ET), and combined ST and ET (2 + 2 times a week) (SET) training on the load carrying walking test performance on the treadmill (TM) and changes in neuromuscular and endurance performance during a 21-week training period in aging men. Forty healthy men (54.8 ± 8.0 years) were divided into 3 training groups (ET $n = 9$, ST $n = 11$, SET $n = 11$) and a control group (C, $n = 9$). Peak oxygen uptake ($\dot{V}O_2$peak), heart rate, and blood lactate concentration were measured before and after a 21-week training program using a graded TM and maximal incremental bicycle ergometer (BE) tests. Isometric forces, vertical jump, and electromyographic activity of leg extensor and/or forearm flexor (F) muscles were measured before and after training and the TM tests. Increases of 20–21% in strength and of 7–12% in cycling BE $\dot{V}O_2$peak occurred in the training groups, whereas the changes of C remained minor. $\dot{V}O_2$peak was associated, both before and after training, with TM exercise time in all groups (from $r = 0.65$, $p = 0.030$ to $r = 0.93$, $p < 0.001$). Only SET showed a significant training-induced increase ($p = 0.011$) in exercise time of the TM walking with no significant increase in TM $\dot{V}O_2$peak. The present data suggest that in older men ET and SET induced specific increases in BE $\dot{V}O_2$peak and ST and SET in strength. However, only SET increased walking exercise time indicating improved load carrying walking performance because of large individual differences in the magnitude of the development of either strength or endurance capacities.

Key Words graded exercise test, walking

Introduction

Aging is known to decrease maximal oxygen uptake ($\dot{V}O_2$max) of men between the age of 30–70 years by as much as 60% (3,12,16) and maximal strength by 30–50% (18,25,35). Decreases in $\dot{V}O_2$max and maximal strength have also an effect on aging workers' ability to cope with their work especially in physically demanding occupations that involve also load carrying tasks (21). However, many studies have shown that these age-related decreases in aerobic and neuromuscular function can possibly be slowed down because of proper training (18,20,27,45). Simultaneous strength and aerobic training may negatively interfere with muscle strength and endurance improvements, if the volume and frequency of training are too high (6,10,15,17,32). In contrast, several studies have observed no interference in young or older subjects when the volume and frequency are low or moderate (9,19,22,23,26,40,47,48).

Several studies have shown that maximal oxygen uptake is most often the reason for limitations to endurance capacity of prolonged load carrying performance. Many graded walking and running loading protocols have been studied with or without backpacks as external load, even during anaerobic actions (5,36,37). When the external load is carried with the hands, rapid overall exhaustion occurs including also a local decrease in grip force (28,38,39) or in force of the legs (29,36). However, several physiological actions such as strength and endurance capacities, especially maximal oxygen uptake, may explain the outcome of these tests performed with long-distance running and walking protocols (24,30,44). In addition, it has been suggested that maximal oxygen uptake alone might

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24(6)/1584–1595

Journal of Strength and Conditioning Research

not the best way to describe overall physical capacity in aging humans (42). Therefore, not only running or bicycle ergometer (BE) testing but especially load carrying walking protocols on the treadmill (TM) may describe functional load carrying performance in a more detailed way in aging humans.

The purpose of this study was to examine effects of strength, endurance, and combined strength training (ST) and endurance training (ET) on TM load carrying walking performance and its associations to neuromuscular and endurance performance and their changes during a 21-week training period in aging men. We hypothesized that the combination of ST and ET might result in a better performance in the TM walking until exhaustion compared to either ST or ET alone.

Methods

Experimental Approach to the Problem

Strength and endurance training protocols in aging men have been separately investigated in several studies. Although typical resistance and ET protocols are important for aging men, one could suggest that either type of training alone might not be beneficial enough in the long term with regard to demands of many occupational tasks. Several occupational tasks of aging men require carrying of the loads with the hands and a combination of strength and endurance capabilities. No study has investigated the effects of combined ST and ET on the load carrying performance. The possible change in exhaustion time on the TM load carrying walking test was selected as a dependent variable, because it should increase especially during combined training compared to those increases taking place in maximal oxygen uptake and strength production, which are independent variables of the present study. The goal of the present study was to examine the effects of strength, endurance, and combined ST and ET on the load carrying walking test performance on the TM and its associations to neuromuscular and endurance performance and their changes during a prolonged training period in aging men.

Subjects

All subjects (men) were recruited from the city of Jyväskylä and the surrounding area through newspaper advertisements and sending flyers by post and email. Telephone interviews were conducted by the examiner, which included questions regarding medical history, occupational commitments, and current physical activity level in 60 men. The selection for attending the physician examination was based on the filled entry forms and interviews by the examiner. Subjects with no contraindications to exercise (2), for example, known cardiovascular, pulmonary or musculoskeletal diseases and medications, known to influence cardiovascular performance or muscle functions were invited to clinical examination ($n = 50$). The resting electrocardiogram (ECG) was recorded, and the results were analyzed by the cardiologist who also examined all study participants to screen for any medical conditions that would compromise the subject's successful participation to the study (e.g., orthopedic, endocrine, neurological medical disorders). The subjects who passed the medical examination ($n = 45$) performed a maximal BE exercise test with ECG monitoring to voluntary exhaustion under supervision of a physician. Men without evidence of cardiovascular diseases or musculoskeletal problems or other severe diseases proceeded to the maximal TM walking test ($n = 41$). These subjects were considered healthy. They were physically active, but none of the subjects had any background in systematic ST or ET.

The participants were informed about the design of the study and possible risks and discomforts related to the measurements after which they signed an informed consent. All study participants were informed of the independent possibility to quit from the measurements whenever they felt it was necessary. The Ethics Committee of the University of Jyväskylä, Jyväskylä, Finland, approved the procedures of the present study.

Forty-one men were randomized into 4 groups: ST ($n = 10$), ET ($n = 11$), combined strength and endurance training (SET, $n = 11$), and control (C, $n = 9$). Dropout during the training period consisted of only one subject from the ST group because of health reasons and, therefore, the final number of subjects was 40. Subject characteristics are presented in Table 1.

Procedures

Experimental Design. The subjects were tested with the similar test protocols and at the same time of day at weeks 0 and 21 during the 6-month training study. Dynamic and isometric strength was measured during the first measurement day independently 5–7 days before the BE test to ensure a complete recovery. Maximal aerobic capacity was measured using the progressive BE test until exhaustion. During the separate third measurement day, maximal TM test with extra load carried with the hands was conducted until exhaustion. Static jumps, isometric grip strength, and electromyographic (EMG) activity of selected muscles were measured before and immediately after the TM test. There were also 3–4 days after the BE test to ensure a complete recovery before the load carrying test (Figure 1). During the 21-week training period, both strength and endurance groups trained 2 times a week, and the combined strength and endurance group trained 2 times a week for strength and 2 times a week for endurance. All training sessions were supervised by M.Sc. students specialized in the science of sport coaching and fitness testing. The subjects in the C group were instructed to continue their habitual physical activities as before.

Training Programs. Strength training. The present 21-week training program was a total body program for the lower and upper extremities and trunk. However, each training session included 2 exercises for the leg extensor muscles (bilateral leg

TABLE 1. Mean ($\pm SD$) values of age, height, weight, and BMI of subjects at 0 weeks.*

Group (*n*)	Age (y)	Height (cm)	Weight (kg)	BMI ($kg \cdot m^{-2}$)
Strength training (9)	56 ± 2	177 ± 8	82.3 ± 8.5	26.3 ± 1.8
Endurance training (11)	53 ± 9	179 ± 6	79.9 ± 8.0	24.9 ± 2.2
Combined SET training (11)	54 ± 8	180 ± 8	84.3 ± 10.7	25.9 ± 2.3
Control (9)	54 ± 9	178 ± 7	80.5 ± 10.8	25.2 ± 2.5

*SET = combined strength and endurance training; BMI = body mass index.

press and knee extension), one exercise for the knee flexors (bilateral or unilateral knee flexion), and 4–5 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; bilateral or unilateral elbow extension exercise and leg adduction or abduction exercise). The training period consisted of 3 training cycles of 7 weeks in duration: (a) to improve muscle strength endurance, (b) to produce muscle hypertrophy to increase overall muscle mass, and (c) to optimize gains in maximal strength of trained muscles (20). The individual loads of ST were determined on the basis of the initial strength tests. Muscle strength exercises used during the first cycle of the training were carried out with light loads (40–60% of the 1 repetition maximum [1RM]) but with a high number of repetitions with multiple sets. To optimize muscle mass development during the second cycle, the loads increased progressively up to 60–80% of the 1RM with a relatively short recovery time to produce muscle growth (31). The third cycle included somewhat higher loads (70–85% of the 1RM) to optimize strength gains. Both overall intensity and volume of training increased progressively throughout the training period after a periodized training program. The supervised training sessions averaged from 60 to 90 minutes in length (Table 2).

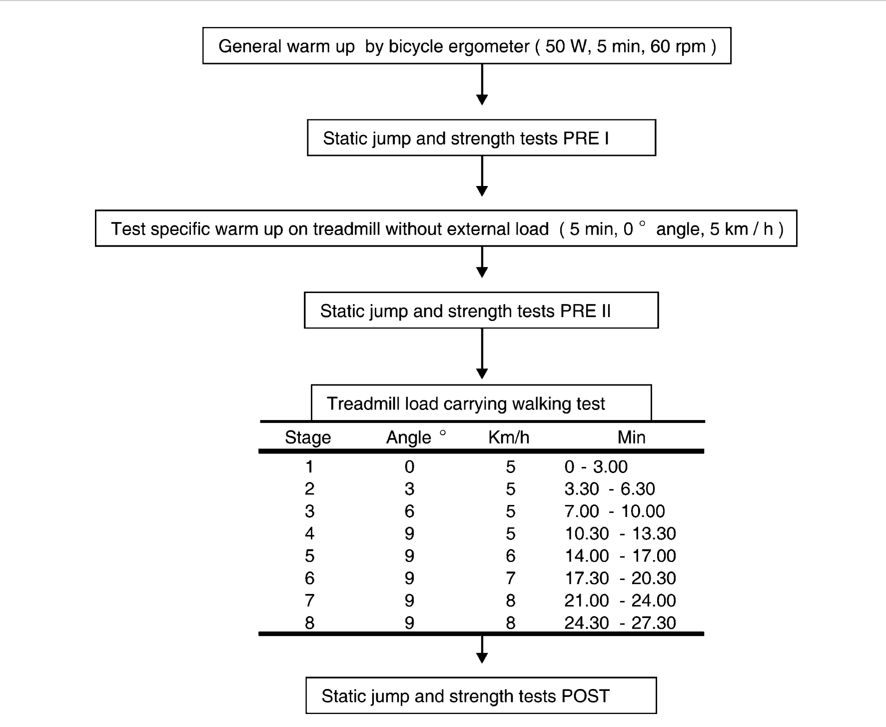

Figure 1. Treadmill load carrying walking test protocol at 0 and 21 weeks. The stage time was 3 minutes, and the break between the stages was 30 seconds. Jump and strength tests were done twice (PRE I and PRE II) before the treadmill tests and once after (POST).

Endurance training. The intensity of ET performed by BE was progressively increased and based on the aerobic performance tests (aerobic and anaerobic thresholds) (19). The thresholds for ET were determined based on respiratory parameters and blood lactate concentrations, as described in detail previously (4). Heart rate (HR) monitoring was used during the training period, which was divided into 3 cycles of 7 week in duration. During the first training cycle, the subjects trained in both weekly sessions 30 minutes under the level of their aerobic threshold. In weeks 5–7, every other training session included 10 minutes under the level of their aerobic threshold, 10 minutes between aerobic and anaerobic thresholds, and 10 minutes under the level of their aerobic threshold to

Table 2. Strength training protocol during the 21-week training period.

Weeks	Main exercises: 1 and 2*				Accessory exercises†‡		Exercises/training sessions
	Sets × reps 1	Load 1§	Sets × reps 2	Load 2§	Sets × reps	Load	
1–4	3 × 12–20	40–60% of 1RM	3 × 10–15	50–60% of 1RM	3 × 12–15	40–60% of 1RM	7–8
5–7	4 × 8–12	50–70% of 1RM	2–3 × 8–15	50–70% of 1RM	2–4 × 8–15	40–70% of 1RM	8–9
8–11	4 × 8–12	40–70% of 1RM	2–3 × 8–12	50–70% of 1RM	2–4 × 8–5	40–70% of 1RM	9–12
12–14	4 × 5–12	40–80% of 1RM	2–3 × 8–12	40–80% of 1RM	2–4 × 5–5	40–80% of 1RM	12–13
15–18	5 × 5–12	50–80% of 1RM	2–3 × 8–12	50–75% of 1RM	2–4 × 5–5	50–80% of 1RM	11–12
19–21	5 × 5–12	50–85% of 1RM	2–3 × 8–12	60–75% of 1RM	2–4 × 5–5	50–70% of 1RM	9–12

*Exercise 1 = leg press and bench press machine; exercise 2 = knee flexion and extension.
†Muscle groups that were trained along main exercises.
‡Accessory exercises: elbow extensors and flexors; abdominals, upper and lower back; hip adductors and abductors; triceps surae.
§40–50% loads of 1RM and reps 9–12 were used for explosive training in leg press, knee extension, and bench press exercises from weeks 8–21.

accustom to higher intensity. During the second training cycle, the 45-minute session was divided into 4 loading intervals: 15 minutes under the level of aerobic threshold, 10 minutes between the aerobic–anaerobic thresholds, 5 minutes above the anaerobic threshold, and 15 minutes again under the aerobic threshold. The other of the 2 weekly training sessions was 60 minutes under the aerobic threshold. The focus of training during the third 7-week cycle was to improve cycling speed and maximal endurance in a 60-minute session: 30 minutes under the aerobic threshold during the whole session altogether, 2 × 10 minutes between the aerobic and anaerobic thresholds, and 2 × 5 minutes above the anaerobic threshold. Every other training session included 90 minutes of cycling at a steady pace under the aerobic threshold (19) (Table 3).

Combined strength and endurance training. The combined training group performed both 2 strength sessions and 2 endurance sessions a week. The strength and endurance sessions followed the protocols described above (19).

Measurements

Maximal Isometric and Dynamic Strength and Electromyographic Measurements. Dynamic muscle strength was measured by the bilateral 1RM leg press (1RMleg) dynamometer (a modified David 210 horizontal leg press) (20). The subjects were in a seated position so that the hip angle was 110° and the starting knee angle was set to 70° with manual goniometer. On verbal command, the subject performed a concentric leg extension starting from the flexed position of 70° to the full extension of 180° against the resistance determined by the loads (kg) chosen on the weight stack. After each repetition, the load was increased (precision of 2.5 kg) 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 as used earlier by Häkkinen et al. (20).

Isometric maximal voluntary unilateral knee extension force (N) was measured by a David 200 electromechanical dynamometer with a subject in a seated position so that the hip and knee angles were 110° and 90°. For maximal isometric force, the subjects were instructed to produce their maximal force as rapidly as possible during a time period of 2–4 seconds. Three to 5 maximal testing trials were recorded. The time period of rest between the maximal trials was about 1 minute. A minimum of 3 trials was completed for each subject, and the best performance trial with regard to maximal peak force was used for the subsequent statistical analysis (20). The analysis of isometric knee extension was performed using a customized script (Signal 2.16, CED) and filtered using low-pass 20 Hz–3 dB-1 filter.

During dynamic 1RM leg extension and isometric unilateral knee extension, EMG was measured from quadriceps muscles (a) vastus lateralis (VL), (b) vastus medialis (VM), and (c) rectus femoris (RF). Bipolar (20-mm inter-electrode distance) surface EMG recording (miniature-sized skin electrodes ECG-MedOla, Oriola Inc., Espoo, Finland)

TABLE 3. Endurance training protocol during the 21-week training period.

Week	Training session 1	Loading protocol	Training session 2	Loading protocol
1–4	30 min	Under the level of aerobic threshold	30 min	Under the level of aerobic threshold
5–7	10 + 10 + 10 min, total 30 min	10 min under the level of aerobic threshold 10 min between aerobic and anaerobic thresholds 10 min under the level of aerobic threshold	30 min	Under the level of aerobic threshold
8–14	15 + 10 + 5 + 15 min, total 45 min	15 min under the level of aerobic threshold 10 min between aerobic and anaerobic thresholds 5 min above the anaerobic threshold	60 min	Under the level of aerobic threshold
15–21	30 + 2 × 10 + 2 × 5 min, total 60 min	30 min under the level of aerobic threshold 2 × 10 min between aerobic and anaerobic thresholds 2 × 5 min above the anaerobic threshold	90 min	Steady pace under the level of aerobic threshold

was employed. Seniam (46) guidelines were followed for skin preparation, electrode placement, and orientation (interelectrode distance 20 mm, input impedance <10 kΩ, rejection rate 80 dB, 1,000 gain), and placing of the electrodes was tattooed on the skin using ink to ensure the same electrode placement at both 0 and 21 week time points. Raw EMG signals passed from the transportable pack, around subjects' waist, to the receiving box (Telemyo 2400R, Noraxon, Scottsdale, AZ, USA), and then relayed to the computer via an AD converter (Micro 1401, CED, Cambridge, United Kingdom). Electromyographic signals were filtered using a band-pass filter (20–350 Hz) before the analysis. During dynamic 1RM leg press, EMG signals were averaged for the concentric contraction. Maximum integrated EMG (iEMG) during the isometric action was determined from the time period of 500–1500 milliseconds. The best attempts during the measurements with regard to maximal peak force and highest EMG were used for the subsequent statistical analysis.

Maximal Bicycle Ergometer Test. Bicycle ergometer test (Ergoline Ergoselect, Ergoline GmbH, Bitz, Germany) was started with a 5-minute warm-up period at the intensity of 50 W. For the first 2-minute stage of the test, the same intensity of 50 W was used, and it was increased by 20 W every second minute until exhaustion. The subjects were asked to maintain a pedaling rate of 60 rpm that was monitored continuously. Electrocardiogram was monitored (Cardiosoft V.5.0, GE Medical System Corina, Ge Medical Inc., United Kingdom, HP computer) continuously during the test by a physician, who also supervised the test. The subjects were verbally encouraged to continue cycling until volitional exhaustion. The exact time of exercise was described in minutes and seconds. Peak $\dot{V}O_2$ (BE $\dot{V}O_2$peak) was measured breath by breath and averaged in 60-second intervals (Sensor Medics Vmax 229; Viasys Healthcare Inc., Washington, DC, USA). The spiroergometer was calibrated before each test, and the calibration was checked after each test. Blood samples were taken from the fingertip (Minilancet CCS Clean Chemical Sweden AB, Borlange, Sweden) before the test, every second minute during the test just before changing the workload, and immediately and 3 and 5 minutes after exhaustion for the determination of blood lactate concentrations. Blood samples were analyzed with Lactate Pro LT-1710 analyzer (Arkray Lactate Pro, Arkray Factory Inc., Shiga, Japan), and the highest value after the test was used as maximal posttest lactate value (Lamax). Heart rate was measured using Polar S810i HR monitors (Polar Electro Oy, Kempele, Finland). Bicycle ergometer $\dot{V}O_2$peak was the highest minute average of $\dot{V}O_2$ presented in $ml \cdot kg^{-1} \cdot min^{-1}$, and HRmax was the highest HR at the end of the test. Maximal aerobic cycling power in watts (BE *W*max) was calculated as: BE $W\text{max} = W\text{com} + t/120\ Q$, in which *W*com is the last cycling load completed, *t* is the time in seconds the noncompleted load was maintained, and Q is the increment in watts (34).

Treadmill Walking Test. Maximal TM walking load-carrying test was conducted until exhaustion (Treadmill OJK-1, Telineyhtyma, Kotka, Finland). In addition, isometric strength measurements were done twice before (PRE I and II) and once (POST) immediately after the TM test (Figure 1). A 5-minute general warm-up with the BE at the intensity of 50 W preceded the first strength measurements. After these strength measurements, a test specific 5-minute warm-up period was performed with the TM at 5 km·h^{-1} walking speed and 0° angle. Thereafter, the strength measurements were repeated. During the first 3-minute stage of the actual TM walking test, an inclination of 0° and a speed of 5 km·h^{-1} were used. Both inclination and speed were increased until voluntary exhaustion was reached. The exact time of exercise was described in minutes and seconds. Normal bags (30 × 25 × 3 cm) with handles 5.0 cm below the top edge of the bag were used to carry the load during TM walking. The subjects carried the load of 10.1 kg with each hand (20.2-kg total load) including 100 g of foam padding.

Peak oxygen uptake ml·kg^{-1}·min^{-1} was calculated by subjects' body weight without external load (TM $\dot{V}O_2$peak) and peak respiratory exchange ratio (TM RER_{peak}) were measured breath by breath and averaged in 30-second intervals. Oxygen uptake, blood lactate, HR, and ECG were measured similarly with the same equipments as described in the BE test, with the exception the blood samples were taken during 30-second breaks, and immediately and 3 and 5 minutes after exhaustion. Electrocardiogram was monitored continuously during the test by a physician, and the subjects were verbally encouraged to continue walking until volitional exhaustion. Maximal aerobic power during load carrying walking in watts (TM Wmax) was calculated as TM Wmax: $M = 1.5K + 2.0\ (K + L)\ (L/K)\ 2 + \eta\ (K + L)\ [1.5V2 + 0.35VG]$ in which M = metabolic rate (watts, W), K = subject weight (kg), L = external load (kg), V = speed of walking (m·s·$^{-}$1), G = angle (slope, %), and η = terrain coefficient (η = 1.0 for TM) (43). The Pandolf equation (43) has been validated using wide range of external loads and body masses by Duggan and Haisman (11).

Dynamic Power and Isometric Force Tests during Treadmill Walking Test. Two different power and force tests were performed before and after the TM walking test. Static vertical jump power (W) (SJW) was measured using a standard force plate. In static vertical jumps subjects were instructed to jump as explosively as possible starting from the 90° knee angle while keeping their hands on the hips during the jump. Two maximal testing attempts were recorded, with 10–15 seconds of rest between the attempts. In addition, isometric right hand grip force (N) (GFmaxF) was measured using the grip handle dynamometer in a standing position so that the elbow angle was set to 90°. In maximal isometric grip force test, the subjects were instructed to produce their maximal force as

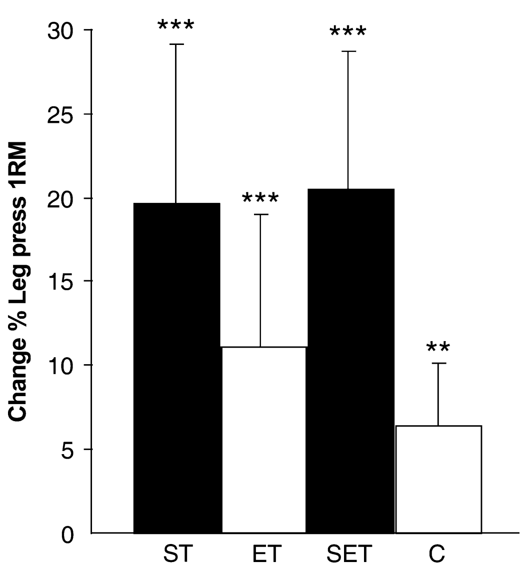

Figure 2. Mean ± *SD* changes of dynamic bilateral 1 repetition maximum (1RM) leg press strength after the 21-week training period; ET = endurance training; SET = combined strength and endurance training; C = control group; **$p \le 0.01$; ***$p \le 0.001$.

Table 4. Mean (±*SD*) EMG values of leg extensor muscles in bilateral 1RM leg press at 0 and 21 weeks.*

Group (*n*)	1RM leg press EMG 0 wk	1RM leg press EMG 21 wk	*p* Value
Vastus lateralis (μV)			
ST (9)	273 ± 94	299 ± 97	1.00
ET (11)	246 ± 86	237 ± 82	0.74
SET (11)	320 ± 100	365 ± 118	0.13
C (9)	276 ± 70	277 ± 80	0.48
Rectus femoris (μV)			
ST (9)	175 ± 48	177 ± 49	0.71
ET (11)	162 ± 54	157 ± 48	1.00
SET (11)	170 ± 44	185 ± 55	0.13
C (9)	191 ± 63	181 ± 53	0.48
Vastus medialis (μV)			
ST (9)	257 ± 109	297 ± 57	0.059
ET (11)	251 ± 116	232 ± 62	1.00
SET (11)	274 ± 116	359 ± 178	0.035
C (9)	250 ± 49	269 ± 55	1.00

*ST = strength training; ET = endurance training; SET = combined strength and endurance training; C = control group; 1RM = 1 repetition maximum; EMG = electromyography.

rapidly as possible. Two maximal testing attempts were recorded, with 10–15 seconds of rest between the attempts. Isometric force and dynamic power were recorded on a computer (486 DX-100) and on magnetic tape (RACAL 16) and analyzed thereafter with the Codas TM computer system (Data Instruments). Maximal force was expressed in Newtons (N), and maximal power was expressed in watts (W) as used earlier by Häkkinen et al. (20).

Electromyographic activities were recorded during (a) the concentric phase of the dynamic vertical jump from the right VL (Jump EMG VL) and VM muscles (Jump EMG VM), (b) maximal isometric unilateral grip force as sum EMG from the right forearm flexor muscles (Grip EMG FL). The same electrode placement and orientation procedures were employed as previously mentioned for 1RM leg extension and isometric knee extension actions. EMG signals were recorded telemetrically (2000 Glonner, Biomes Martinsried n. Munich Fraunhoferstr. Germany). The EMG signal was amplified (by a multiplication factor of 200; low-pass cut-off frequency of 360 Hz/3 dB^{-1}) and digitized at the sampling frequency of 1,000 Hz by an online computer system. The EMG was full-wave rectified, integrated (iEMG in $\mu V \cdot s^{-1}$), and time normalized for 1 second for the maximal peak force of the unilateral isometric grip force action between 500 and 1,500 milliseconds to calculate maximal iEMG as used earlier by Häkkinen et al. (20). The best attempts of PRE I and II and POST measurements conducted before and after the TM walking test (described below) with regard to maximal peak force and highest EMG was used for the subsequent statistical analysis (see also Figure 1).

Table 5. Mean ($\pm SD$) values of isometric unilateral knee extension force and EMG of leg extensor muscles at 0 and 21 weeks.*

	Isometric knee extension		
Group (*n*)	0 wk	21 wk	*p* Value
Force (N)			
ST (9)	688 ± 122	747 ± 101	0.020
ET (11)	684 ± 122	711 ± 133	0.058
SET (11)	707 ± 132	792 ± 116	0.035
C (9)	682 ± 130	732 ± 119	0.16
EMG vastus lateralis (μV)			
ST (9)	185.9 ± 67.0	176.5 ± 58.5	0.41
ET (11)	209.0 ± 84.2	200.1 ± 83.5	0.74
SET (11)	260.6 ± 82.9	307.5 ± 127.0	0.020
C (9)	227.9 ± 32.5	251.2 ± 38.7	0.16
EMG rectus femoris (μV)			
ST (9)	190.5 ± 84.1	177.7 ± 58.5	0.41
ET (11)	165.1 ± 61.4	158.5 ± 60.0	0.53
SET (11)	181.9 ± 54.0	207.8 ± 52.2	0.011
C (9)	185.8 ± 59.3	194.4 ± 62.4	0.16
EMG vastus medialis (μV)			
ST (9)	140.2 ± 62.8	185.6 ± 86.4	0.025
ET (11)	205.4 ± 80.4	192.4 ± 99.6	0.21
SET (11)	229.3 ± 109.7	242.1 ± 78.1	0.53
C (9)	211.2 ± 57.8	215.8 ± 66.5	1.00

*ST = strength training; ET = endurance training; SET = combined strength and endurance training; C = control group; EMG = electromyography.

Statistical Analyses

Normal distribution and homogeneity of the parameters were checked with Shapiro–Wilk, Levene and box's tests, respectively. Standard statistical methods were used to calculate means, *SD*, and percentages (%). Differences between the groups in normally distributed parameters were analyzed by one-way analysis of variance using Post Hoc Bonferroni test. General linear model multivariate test was used to calculate the difference between before and after the TM walking test values and also before and after training period (0–21 week) values. The correlations were calculated by Pearson's product moment correlation coefficients (*r*). In nonnormally distributed parameters the difference between the groups were analyzed by Kruskal–Wallis test using Mann–Whitney tests. Friedman test was used to calculate the difference between before and after the TM walking test values and also before and after training period (0–21 week) values. The correlations were calculated by Spearman's rho (*r*). Both linear and

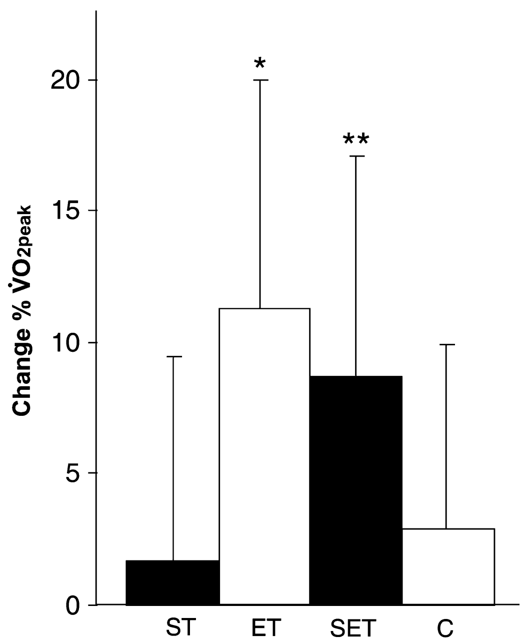

Figure 3. Mean ± *SD* changes of peak oxygen uptake in the graded bicycle ergometer test after the 21-week training period. ET = endurance training; SET = combined strength and endurance training; C = control group; *$p \leq 0.05$; **$p \leq 0.01$.

nonlinear tests statistical significances were expressed as *$p \leq 0.05$, **$p \leq 0.01$, and ***$p \leq 0.001$.

Results

No significant changes were observed in any of the groups in body weight or body mass index after the 21-week training period.

Bilateral leg press 1RM strength increased significantly after the 21-week training period in all groups (Figure 2); however, the changes in the C group 6% ($p = 0.003$) and in ET 11% ($p < 0.001$) was significantly smaller compared to the those of 20% in the ST ($p < 0.001$) and 21% in SET ($p < 0.001$) groups. A significant change in 1RM EMG of VM occurred in SET ($p = 0.035$) (Table 4). The change of 1RM EMG VM in ET was significantly smaller compared to those of ST ($p = 0.040$) and SET ($p = 0.007$).

Isometric knee extension force increased significantly after the 21-week training period in ST (10%, $p = 0.020$) and SET (13%, $p = 0.035$). The respective EMG parameters changed significantly in VL (15%, $p = 0.020$) and RF (17%, $p = 0.011$) of SET and in VM of ST (31%, $p = 0.025$) (Table 5). The changes of VL ($p = 0.019$) and RF ($p = 0.021$) were significantly smaller in ET compared to SET, and the changes of VM ($p = 0.020$) were smaller in ET compared to ST.

In the graded BE test, BE $\dot{V}O_2$peak increased significantly after the 21-week training period in ET ($p = 0.011$) and SET ($p = 0.021$) (Figure 3). The change of BE $\dot{V}O_2$peak in ET was significantly larger ($p = 0.041$) compared to C, whereas ST showed a smaller change than SET ($p = 0.042$). Cycling exercise time increased significantly after the 21-week

Table 6. Mean ($\pm SD$) values of the graded bicycle ergometer test at 0 and 21 weeks.*

Group (*n*)	Bicycle test 0 wk	Bicycle test 21 wk	*p* Value
Exercise time (min:s)			
ST (9)	17:18 ± 3:40	18:07 ± 3:19	0.26
ET (11)	18:57 ± 4:00	21:17 ± 3:49	0.011
SET (11)	19:08 ± 3:08	22:03 ± 3:43	0.13
C (9)	18:49 ± 4:34	18:19 ± 4:16	0.48
W_{max} (W)			
ST (9)	203 ± 37	210 ± 37	0.26
ET (11)	210 ± 40	243 ± 38	0.002
SET (11)	222 ± 31	249 ± 38	0.001
C (9)	218 ± 46	213 ± 43	0.48
HRmax ($b \cdot min^{-1}$)			
ST (9)	168 ± 11	166 ± 11	0.64
ET (11)	177 ± 9	173 ± 12	0.15
SET (11)	176 ± 10	175 ± 11	0.37
C (9)	169 ± 8	166 ± 10	0.19
La_{max} ($Mmol \cdot mL^{-1}$)			
ST (9)	9.4 ± 1.5	11.3 ± 1.9	0.018
ET (11)	10.8 ± 1.8	12.2 ± 2.3	0.061
SET (11)	11.4 ± 2.1	13.1 ± 1.6	0.021
C (9)	10.1 ± 1.6	10.1 ± 2.1	0.99
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)			
ST (9)	33.7 ± 8.7	34.1 ± 8.2	0.71
ET (11)	34.4 ± 5.8	38.2 ± 6.4	0.011
SET (11)	32.9 ± 4.2	35.7 ± 4.3	0.007
C (9)	33.5 ± 4.2	34.7 ± 6.4	0.48

*ST = strength training; ET = endurance training; SET = combined strength and endurance training; C = control group; W_{max} = maximal aerobic work; HRmax = maximal heart rate; La_{max} = maximal lactate level; $\dot{V}O_2$peak = peak oxygen uptake.

Table 7. Mean ($\pm SD$) values of the treadmill walking test at 0 and 21 weeks.*

Group (*n*)	Treadmill test 0 wk	Treadmill test 21 wk	*p* Value
Exercise time (min:s)			
ST (9)	13:56 ± 2:49	14:10 ± 2:35	0.74
ET (11)	14:18 ± 2:22	14:25 ± 1:57	0.76
SET (11)	14:09 ± 2:14	14:42 ± 1:49	0.035
C (9)	13:55 ± 2:25	12:42 ± 2:12	0.020
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)			
ST (9)	36.0 ± 7.5	35.4 ± 6.0	0.56
ET (11)	37.3 ± 7.9	37.7 ± 5.9	0.69
SET (11)	35.6 ± 4.6	35.3 ± 5.3	0.81
C (9)	37.4 ± 7.3	35.2 ± 6.6	0.18
W_{max} (W)			
ST (9)	1,202 ± 277	1,218 ± 242	0.32
ET (11)	1240 ± 217	1,235 ± 200	0.37
SET (11)	1,282 ± 210	1,315 ± 232	0.13
C (9)	1,209 ± 243	1,153 ± 264	0.020
HRmax ($b \cdot min^{-1}$)			
ST (9)	173 ± 9	179 ± 8	0.73
ET (11)	178 ± 11	179 ± 8	0.68
SET (11)	177 ± 10	177 ± 10	0.92
C (9)	171 ± 12	170 ± 5	0.85
La_{max} ($Mmol \cdot mL^{-1}$)			
ST (9)	11.3 ± 1.9	11.4 ± 2.9	0.74
ET (11)	12.7 ± 2.5	12.2 ± 2.2	0.058
SET (11)	12.3 ± 2.6	12.9 ± 2.3	0.76
CO (9)	10.9 ± 2.2	10.6 ± 2.2	0.74
RER_{peak}			
ST (9)	1.18 ± 0.07	1.17 ± 0.05	0.67
ET (11)	1.24 ± 0.06	1.21 ± 0.04	0.18
SET (11)	1.22 ± 0.04	1.21 ± 0.07	0.70
C (9)	1.22 ± 0.06	1.19 ± 0.07	0.35

*ST = strength training; ET = endurance training; SET = combined strength and endurance training; C = control group; $\dot{V}O_2$peak = peak oxygen uptake; W_{max} = maximal aerobic work; HRmax = maximal heart rate; La_{max} = maximal blood lactate level; RER_{peak} = peak respiratory exchange ratio.

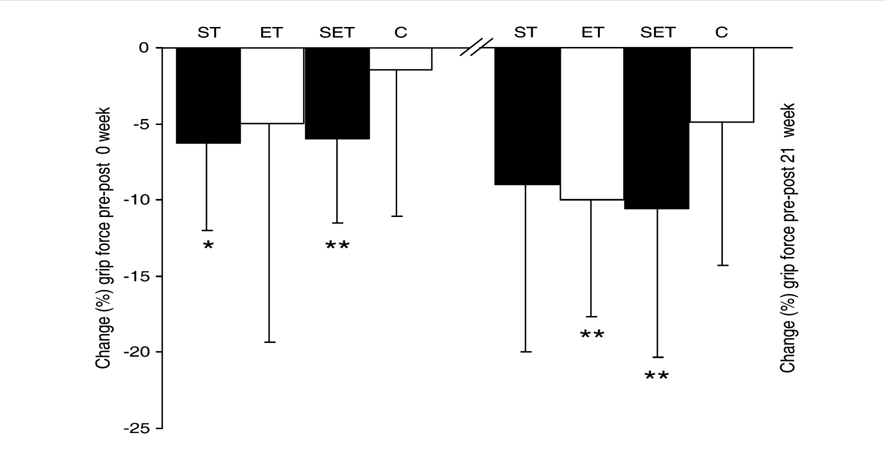

Figure 4. Mean ± *SD* changes of isometric grip force after the treadmill walking test at the 0- and 21-week measurement points. ET = endurance training; SET = combined strength and endurance training; C = control group; $^*p \leq 0.05$; $^{**}p \leq 0.01$.

training period in ET ($p = 0.011$). Correspondingly, maximal aerobic cycling power increased in ET ($p = 0.002$) and SET ($p = 0.001$) and maximal blood lactate levels in ST ($p = 0.018$) and SET ($p = 0.021$) (Table 6). The change of maximal aerobic cycling power in both C and ST was significantly lower compared to in ET ($p = 0.006$ and 0.041) and in SET ($p = 0.002$ and 0.040).

The change of cycling exercise time was significantly smaller in C compared to in the ET ($p = 0.009$) and SET groups ($p = 0.001$). Also, ST showed a smaller change than SET ($p = 0.014$).

Table 8. Mean (±*SD*) values of vertical jump power before (pre) and after (post) the treadmill walking test at the 0 and 21-week measurement points.*

Group (*n*)	Static jump pre	Static jump post	*p* Value
Power 0w (W)			
ST (9)	1,608 ± 461	1,460 ± 380	0.16
ET (11)	1,440 ± 284	1,449 ± 372	0.74
SET (11)	1,601 ± 434	1,456 ± 382	0.034
C (9)	1,392 ± 258	1,222 ± 241	0.41
Power 21w (W)			
ST (9)	1,739 ± 436	1,664 ± 253	0.48
ET (11)	1,520 ± 407	1,439 ± 370	0.32
SET (11)	1,611 ± 428	1,660 ± 528	1.00
C (9)	1,463 ± 442	1,520 ± 403	1.00

*ST = strength training; ET = endurance training; SET = combined strength and endurance training; C = control group.

After the 21-week training period exercise time of the TM walking test increased significantly in SET (4.5 ± 5.9%, $p = 0.035$) (Table 7). The change of exercise time in C (−8.5%, $p = 0.020$) was significantly different compared to that of ST, ET, and SET ($p = 0.009$, $p = 0.003$, $p = 0.001$), respectively. The change of maximal aerobic walking power in C was significantly different compared to that in the ET and SET groups ($p = 0.025$, $p = 0.006$), respectively.

Exercise time of the TM walking test correlated significantly with TM $\dot{V}O_2$peak in ST, ET, SET, and C both at week 0 (from $r = 0.65$, $p = 0.030$ to $r = 0.91$, $p = 0.001$) and at week 21 (from $r = 0.78$, $p = 0.014$ to $r = 0.93$, $p < 0.001$).

Isometric grip force decreased significantly after the TM walking test in ST ($p = 0.024$) and SET ($p = 0.005$) at 0 weeks and at 21 weeks in ET ($p = 0.004$) and SET ($p = 0.004$) (Figure 4). There were no differences between the groups in any of the isometric grip force variables before or after training. The only significant change in isometric grip force EMG parameters between PRE and POST values was the decrease in sum EMG of the right forearm flexor muscles of ST ($p = 0.020$) at 0 weeks.

Vertical jump power decreased significantly after the TM walking test only in SET (−8.1 ± 11.4%, $p = 0.034$) at 0 week (Table 8). The only significant change in vertical jump EMG parameters of the muscles examined between before and after the TM loading was VL of ET ($p = 0.034$) at 0 week. No significant decreases occurred at week 21 in any of the vertical jump variables examined.

Discussion

The present results showed substantial training-induced increases in maximal strength of the leg extensors after the 21-week training period in both ST and SET groups, whereas the increases of the peak oxygen uptake in the BE test occurred in both ET and SET groups. However, the major finding of the present study was that the peak oxygen uptake in the TM load carrying walking test did not increase significantly in any of the training groups after the 21-week training period, but the SET group showed a significant increase in exercise time in this test. Furthermore, the changes of peak oxygen uptake in the TM load carrying walking test and strength values showed no significant correlations to the changes in exercise time of the TM load carrying walking test. Therefore, the increase of walking exercise time in SET might result from large individual differences in the magnitude of the development of either strength or endurance capacities.

As expected, the increases observed in maximal strength characteristics were similar between the 2 groups that performed strength training (SET and ST), without any interference in strength development in SET. These findings are in line with previous studies conducted in younger adults (9,19,40) and in older men (26,47,48) when the frequency of training is low or moderate. These results may suggest that it is possible to obtain substantial strength or cardiovascular gains from a low training frequency (i.e., once weekly or twice weekly for resistance or cardiovascular training, respectively) in previously untrained middle-aged and older subjects (22,23). Statistically significant increases were observed also in the EMG activity of the present subjects in both ST and SET. Several studies have shown that it is likely that early changes in strength characteristics, especially in older subjects, are largely because of neural adaptations (18,20,41). However, these early changes in voluntary muscle activation can be maintained or slightly further increased during longer training periods (18,20).

Endurance training performed by cycling in the present study induced significant increases in peak oxygen uptake of the BE test in both ET and SET. Furthermore, also blood lactate levels and maximal aerobic power showed large increases in both ET and SET. These findings agree with previous studies including endurance or combined ST and ET in both young and older subjects (9,19,23,26).

The combined ET and ST group showed a significant increase in the exercise time of the TM load carrying walking test after 21 weeks of training. This improvement occurred, although no significant change was observed in the peak oxygen uptake or in any other measured variables of the TM load carrying walking test. In addition, no significant correlations were observed between the changes in strength and in exercise time of the TM test in the combined group. Therefore, it is likely that interindividual differences in the magnitude of the development of either endurance or strength capacities in SET may explain the increase in exercise time of the present walking test. On the other hand, this improvement in the exercise time of the TM load carrying walking test in SET could simply be because of higher overall volume compared to the other training groups. The combined ST and ET group may also have possibly shown an increase in the skeletal muscles oxidative capacity, although it was not reflected in the peak oxygen uptake of the TM walking test and it might be just increased physiological tolerance to exercise at such low threshold recruitment levels of motor units by increased efficiency and perceptual toleration. Green and Patla (13) showed in their review a similar phenomenon of increased exercise time without increasing maximal oxygen uptake because of the increase in the amount of mitochondria.

However, our combined ST and ET group increased the peak oxygen uptake significantly in the BE test. Thus, it seems that the cardiovascular adaptation because of cycling training was not transferred to respective adaptations in the present TM load carrying walking test. This suggests a specificity interaction between the training and testing mode. Previous studies in trained subjects have shown a similar training specificity effect in a cross-sectional design on the training modes of BE and TM protocols (8,14). However, previous training studies on load carrying have concentrated on running and walking testing protocols of longer distances mainly using backpacks (30,33) and, therefore may not be directly compared with the present study.

Exercise time of the present TM load carrying walking test was most likely not limited by grip force, because this did not correlate with TM test exercise time. However, grip force reduced significantly after the TM loading both at weeks 0 and 21 in the endurance and combined ST and ET groups. These results are partly in line with cross-sectional studies by Kilbom et al. (28) and Leyk et al. (38), which showed that grip force was not a limiting factor on carrying time until high loads such as 25 kg on each hand was used. Furthermore, no changes were observed in the post loading EMG values of grip force and vertical jump at weeks 0 and 21 suggesting only a minor role of central fatigue during the present TM walking test. Thus, fatigue and a reduction in grip force were probably related to peripheral fatigue factors (such as lactate tolerance and enzymatic activity) at the muscle cell level (1,44).

Exercise time of the TM load carrying walking test correlated with the peak oxygen uptake of the TM walking test at week 0 in all groups of the present study. This is in line with several studies that have shown the same phenomenon in the cross-sectional design (7,37). After the present 21-week training period all of the training groups and also the C group showed strong correlations between walking test exercise time and the peak oxygen uptake of the TM walking test, indicating a strong specificity of TM walking, although the present ET was conducted by cycling.

In conclusion, our aging men showed training-induced specific increases in the peak oxygen uptake of the BE test both in ET and SET groups and strength levels in both ST and SET groups after the 21-week training period. However, on the present maximal TM walking loading test, the peak oxygen uptake was the determining physiological factor of TM walking test exercise time even after the 21-week training period, with no significant contribution of muscle strength because of ST. Interestingly, only the combined strength and endurance group increased load carrying walking exercise time after the 21-week training period with no significant increase in the peak oxygen uptake. Thus, individual differences in the magnitude of the development of either strength or endurance capacities in subjects of the SET group may explain the increase in exercise time of the present walking test. On the other hand, the explanation for improved load carrying capacity in SET could be just the fact that the overall volume of training in this group was twice as much the volume in the training than in the ST and ET groups.

Practical Applications

Several studies have shown that aging is associated with declines in strength and endurance capabilities, although these age-related decreases can possibly be slowed down by proper training. Especially, a combination of ST and ET is beneficial during aging in slowing down the overall decline of physical fitness. Most of the studies that have examined effects of combined training have concentrated on the changes of strength and maximal oxygen uptake or longer distance running or walking protocols with or without backpacks as external load, but none of the studies have examined effects of combined training on the load carrying performance among aging men. The findings of the present study in our working aged and older men demonstrate that total body ST combined with cycling ET (twice a week for each) for 21 weeks is associated not only with increased strength and endurance measured by cycling but also with improvements of the performance in the TM load carrying walking test. These changes may be beneficial in the long term when planning training programs for aging men. Combined training might be especially beneficial for the aging workers in physically demanding occupations. Future studies, and rehabilitation programs, might consider ST and ET protocols using also walking or running training combined with ST. This combined training should enhance the possible further improvements in the load carrying walking performance in every day actions and in occupational tasks. Carefully designed combined training protocols might then become even more applicable to the physical fitness and rehabilitation programs or in preventive exercise protocols in working aged and older men.

Acknowledgments

This study was supported in part by a grant from the Ministry of Education, Finland.

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