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Speed training with body weight unloading improves walking energy cost and maximal speed in 75- to 85-year-old healthy women

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Thomas EE, De Vito G, Macaluso A. Speed training with body weight unloading improves walking energy cost and maximal speed in 75- to 85-year-old healthy women. *J Appl Physiol* 103: 1598–1603, 2007. First published September 6, 2007; doi:10.1152/japplphysiol.00399.2007.—This randomized controlled study was designed to prove the hypothesis that a novel approach to high-speed interval training, based on walking on a treadmill with the use of body weight unloading (BWU), would have improved energy cost and speed of overground walking in healthy older women. Participants were randomly assigned to either the exercise group (n = 11, 79.6 ± 3.7 yr, mean ± SD) or the nonintervention control group (n = 11, 77.6 ± 2.3 yr). During the first 6 wk, the exercise group performed walking interval training on the treadmill with 40% BWU at the maximal walking speed corresponding to an intensity close to heart rate at ventilatory threshold (T_{vent} walking speed). Each session consisted of four sets of 5 min of walking (three 1-min periods at T_{vent} walking speed, with two 1-min intervals at comfortable walking speed in between each period at T_{vent} walking speed) with 1-min interval between each set. Speed was increased session by session until the end of *week 6*. BWU was then progressively reduced to 10% during the last 6 wk of intervention. After 12 wk, the walking energy cost per unit of distance at all self-selected overground walking speeds (slow, comfortable, and fast) was significantly reduced in the range from 18 to 21%. The exercise group showed a 13% increase in maximal walking speed and a 67% increase in mechanical power output at T_{vent} after the training program. The novel "overspeed" training approach has been demonstrated to be effective in improving energy cost and speed of overground walking in healthy older women.

randomized controlled trial; walking speed; walking economy; ventilatory threshold; aging

A CRITICAL LEVEL OF WALKING speed is an important component to maintain functional independence in older people (20). A decline in self-selected walking speed with aging has been consistently reported (17, 36), which is accompanied by a higher energy cost of walking (25, 27, 29, 33) and a reduction in stride length (SL) rather than stride frequency (SF) (21, 43). Although the beneficial effects of exercise on various physiological parameters in the older population have been well established, limited literature exists on the effects of exercise aimed specifically at improving walking (5). To increase walking performance of older people, it may be necessary to adopt specific training programs with special attention to the improvement of speed and walking economy.

The use of a treadmill in conjunction with an apparatus for body weight unloading (BWU) has been shown to be effective in the rehabilitation of both neurological (8, 14) and orthopedic patients (13, 26) with locomotor impairment. The combined use of a treadmill and BWU could be adopted also in older individuals who have not been affected by neurological or orthopedic diseases, but only by the aging process itself, to carry out "overspeed training," since BWU enables older participants to walk at very fast speed, but without increasing their energy cost (39). BWU is traditionally used in the clinical practice to allow patients who cannot stand or maintain their balance during walking; however, in this study, BWU is proposed as a novel device to carry out "overspeed training" in healthy older people, thus transferring and adapting lessons learned from the athletic field (32) to the aging population.

The present investigation was therefore designed to assess the effects of a novel approach to carry out high-speed interval training, based on walking on a treadmill with the use of BWU, on the overground walking performance of healthy older women. It was hypothesized that improvements in overground walking speed and energy cost of walking in older women who were trained by walking on a treadmill at high speed with progressively reduced BWU would be significantly higher than changes shown in the nonintervention control group. Women were chosen because they are more vulnerable to disability, which is more marked with advancing age (1), than men (16), thus suggesting that older women should be the first target group in intervention and rehabilitation studies.

METHODS

Participants. With Ethics Committee approval from the University of Strathclyde, 25 participants between 75 and 84 yr old were selected according to the exclusion criteria to define "medically stable" older participants for exercise studies, as proposed by Greig et al. (15). Participants were randomly assigned to either an exercise group or a nonintervention control group. Of the 25 participants, only 22 (91.7%) completed the study: in the exercise group, n = 11, age = 79.6 ± 3.7 yr, stature = 1.56 ± 0.05 m, and body mass = 65.6 ± 12.2 kg; in the control group, n = 11, age 77.6 ± 2.3 yr, stature = 1.54 ± 0.05 m, and body mass = 63.5 ± 8.1 kg (mean ± SD). Two participants from the control group withdrew because of health reasons not related to the program, and one participant from the exercise group withdrew because of lack of time due to other commitments. The study was carried out in accordance with the Declaration of Helsinki, and informed consent was obtained from all volunteers for participation in the study.

Instrumentation and measurements. BWU during treadmill walking was achieved by the use of a pneumatic apparatus (Pneu-Lift, Pneumex) positioned directly above a standard treadmill (Powerjog). The pneumatic apparatus provided BWU up to 640 N by a nearly constant and controlled upward force on the participant's body via a modified harness that consisted of a metal frame supporting the

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Fig. 1. A healthy older participant walking on a treadmill (Powerjog) with the pneumatic apparatus of body weight unloading (BWU) (Pneu-Lift, Pneumex) attached.

participants under their armpits through adaptable pads (Fig. 1). The percentage of BWU was defined as the percentage of participant's body weight unloaded by the pneumatic apparatus.

Gait was assessed by means of a three-dimensional motion analysis system (VICON 612, Oxford, UK), with six infrared cameras sampling at 250 Hz, while participants walked on an oval-shaped 20-m walkway circuit (rectilinear for 8 m on each side) for 10 laps at their self-selected walking speeds [slow walking speed (SWS), comfortable walking speed (CWS), and fast walking speed (FWS)]. Three of the 10 laps were randomly selected for further analysis. Gait was also assessed during a 6-m maximal walking speed test. Maximal walking speed was carried out on a 9-m course with visible markers at the beginning and at 6 m. The participants started from a standing position and were instructed to walk as fast as possible from the beginning of the 9-m course. The time from the beginning to the 6-m marker was timed with a stop watch. The test was repeated three times and used for further analyses. Reflective markers were placed on the heel, lateral malleolus, and great toe of both feet. Stride time was computed as the elapsed time between sequential heel strikes of the same leg. SF was calculated as 1/stride time, and SL was computed as the antero-posterior displacement between sequential heel strikes of the same leg. Speed was computed as the product of SL and SF.

The steady-state oxygen uptake ($\dot{V}O_2$), pulmonary ventilation ($\dot{V}E$), and carbon dioxide production ($\dot{V}CO_2$) were measured by means of a telemetric, portable system (K4b^2, COSMED), in which validity, accuracy, and reproducibility were assessed during rest and exercise at various intensities (10, 30). Heart rate (HR) was recorded by means of a portable HR monitor (Polar); monitor output was telemetrically transmitted and recorded in the K4 system. $\dot{V}O_2$ and HR were first measured while participants stood on the walkway circuit and while participants stood on the treadmill with minimal BWU for 5 min to reach a steady-state condition. Participants were then requested to walk on the 20-m curvilinear circuit described above at three self-selected speeds and on the treadmill at two different conditions (CWS at 0% of BWU, FWS at 40% of BWU). Each condition lasted 5 min to reach a steady state, and 5 min were given for adequate recovery between each condition. The sequence of measurement conditions was randomized for each participant. The data obtained during the final 2 min were used for further analyses. Table 1 shows $\dot{V}O_2$ during standing and overground walking (SWS, CWS, and FWS) at the baseline tests (i.e., before training). In accordance with Zamparo et al. (44) and Bernardi et al. (4), the walking energy cost per unit of time (WEC*t*) was calculated as the amount of $\dot{V}O_2$ per unit of body mass and per unit of time (expressed in $J \cdot kg^{-1} \cdot min^{-1}$). It was calculated as WEC*t* = *k*($\dot{V}O_2$), where $\dot{V}O_2$ is the energy cost (expressed in $ml \cdot kg^{-1} \cdot min^{-1}$) and *k* is the energy (in J) equivalent of oxygen. The net walking energy cost per unit distance (WEC*d*) was then calculated as the net energy cost per unit of body mass and per unit of distance (expressed in $J \cdot kg^{-1} \cdot m^{-1}$). The following formula was used: WEC*d* = (WEC*t* − SEC*t*)/*S*, where SEC*t* is the energy cost during standing (in $J \cdot kg^{-1} \cdot min^{-1}$) and *S* is walking speed (in m/min). HR was expressed in beats per minute. The net HR per unit of distance (HR*d*) was calculated as the number of heart beats per unit of distance (beats/m) according to the formula: HR*d* = (WHR − SHR)/S, where WHR is HR during walking (in beats/min) and SHR is HR during standing (in beats/min).

Ventilatory threshold (T_{vent}) was estimated with the use of an incremental test on the treadmill (7). The test started with 2 min of walking on the treadmill at the CWS of the participant (measured overground) with minimal BWU. Treadmill gradient was then increased every minute by 2.5% until T_{vent} was reached, which was monitored online. T_{vent} was determined by using the ventilatory equivalent (Veq) method, i.e., a systematic increase in the Veq of O_2 ($\dot{V}E/\dot{V}O_2$), with no concomitant rise in the Veq of CO_2 ($\dot{V}E/\dot{V}CO_2$) (41) and by using the V-slope method of Beaver et al. (3). The V-slope method involves the analysis of the behavior of $\dot{V}CO_2$ as a function of $\dot{V}O_2$ and assumes that the threshold corresponds to the break in the linear $\dot{V}CO_2$-$\dot{V}O_2$ relationship. The final value of T_{vent} was calculated as the average of the two values obtained with the two methods.

Mechanical power output (expressed in W) during T_{vent} at a certain percent grade (amount of vertical rise of the treadmill per 100 units of belt traveled) was calculated as power = work done/time, where work done (expressed in J) is the product of distance (m) traveled vertically per unit of body weight (expressed in N).

Before the first assessment session, each participant visited the laboratory on 3 separate days for familiarization with treadmill walking, BWU system, measuring equipment, and study protocol. Both groups were assessed before, in the middle, and after the training intervention on 3 different days (1 day to investigate gait assessment during overground walking, 1 day to measure the metabolic cost during overground walking, and 1 day to measure metabolic cost during treadmill walking and T_{vent}).

Intervention. The walking program consisted of interval training on the treadmill with BWU three times per week. During the first 6 wk, the exercise group performed interval training on the treadmill with 40% of BWU at the speed referred in the text to as "T_{vent} walking speed," which was the maximal walking speed tolerated by each

Table 1. *$\dot{V}O_2$ during standing and over ground walking (slow, comfortable, and fast walking speed) at the baseline tests (i.e., before training)*

Condition	Exercise Group	Control Group
Standing $\dot{V}O_2$, $ml \cdot kg^{-1} \cdot min^{-1}$	4.09±0.38	3.89±0.72
$\dot{V}O_2$ at slow walking speed, $ml \cdot kg^{-1} \cdot min^{-1}$	12.28±1.92	12.69±2.16
$\dot{V}O_2$ at comfortable walking speed, $ml \cdot kg^{-1} \cdot min^{-1}$	15.25±2.07	14.90±1.59
$\dot{V}O_2$ at fast walking speed, $ml \cdot kg^{-1} \cdot min^{-1}$	18.86±2.90	19.65±3.14

Values are means ± SD. $\dot{V}O_2$, Oxygen uptake.

participant corresponding to an intensity close to HR at T_{vent} and within a rate of perceived exertion (RPE) (22) of 15. Each session consisted of four sets of 5 min of walking [three 1-min periods at T_{vent} walking speed, with two 1-min intervals at the CWS (measured overground) in between each period at T_{vent} walking speed] with 1-min interval between each set. T_{vent} walking speed, which was 1.69 ± 0.13 m/s at the end of the first week of training, was increased session by session as tolerated by each participant within the safety limits defined by HR corresponding to T_{vent} and RPE ≤15. During the last 6 wk, the training speed corresponded to the maximal speed achieved at the end of the first 6 wk (1.82 ± 0.17 m/s), which was then kept constant while BWU was progressively reduced to 10% (the minimal BWU enabling the participants to sustain the maximal training speed, always within the safety limits defined by HR corresponding to T_{vent} and RPE ≤15). All of the participants met the goal in the second 6 wk of reducing the extent of BWU to 10%. A gradual decrease of BWU was equivalent to overloading the muscle with the participant still walking at a faster speed. In practice, the participants were gradually induced to maintain the same high speed, but with less support and with the same perception of effort, which is a sign of improvement in walking performance. HR and RPE, which were monitored during each session, did not change during the exercise program, since it was the target of the intervention to have the participants exercising at their maximal walking speed within the intensity defined by these two parameters (for example, during the first session of *week 2* HR was 109.8 ± 11.7 beats/min and RPE was 12.7 ± 2.5; during the first session of *week 7* HR was 107.0 ± 9.2 beats/min and RPE was 10.9 ± 1.8; during the first session of *week 12* HR was 109.1 ± 14.2 beats/min and RPE was 11.1 ± 1.5). All sessions were preceded by a warm-up period of 5 min and ended by a cool-down period of 5 min by walking on the treadmill at CWS with minimal BWU.

Compliance with the training program was assessed by the number of exercise sessions attended divided by the number of exercise sessions held.

Data analyses. All data were normally distributed in terms of skewness and kurtosis (all values <2). Statistical comparisons of the parameters (WEC*d*, HR*d*, walking speeds, SL, SF, T_{vent}) between groups (exercise and control) at three stages (before, in the middle, and after training) were carried out with ANOVA for repeated measures, followed by Student's *t*-tests with Bonferroni adjustment where appropriate. Statistical significance was set at $P = 0.05$. Unless otherwise specified, data are presented as means ± SE.

RESULTS

There were no significant differences in any of the variables measured between the two groups at *week 0* ($P > 0.05$). No significant changes were observed in any of the anthropometric measurements at any time point ($P > 0.017$). Compliance of the exercise group with the exercise protocol was 97%, and no injuries related to training occurred.

Walking speed and temporospatial parameters. The ANOVA for walking speed showed a significant group-by-time interaction for maximal walking speed ($F = 4.31$, $P = 0.02$), but not for FWS ($F = 1.78$, $P = 0.18$), CWS ($F = 0.71$, $P = 0.50$), and SWS ($F = 2.36$, $P = 0.11$). The post hoc analysis showed that maximal walking speed significantly increased across time in the exercise group by 12.6% (from 1.66 ± 0.19 m/s before training to 1.87 ± 0.23 m/s at the end of training), compared with a 2.7% increase in the control group.

The ANOVA for SL showed significant group-by-time interaction at maximal walking speed ($F = 4.10$, $P = 0.02$); however, there was no significance for SF ($F = 2.77$, $P = 0.08$). The post hoc analysis showed that SL at maximal walking speed significantly increased across time in the exercise group by 4.1% (from 1.37 ± 0.07 m before training to 1.43 ± 0.11 m at the end of training), compared with a 0.2% decrease in the control group. The SF increased across time in the exercise group by 8.1% (from 1.21 ± 0.13 Hz before training to 1.31 ± 0.15 Hz at the end of training), compared with a 2.9% increase in the control group, which explains the lack of statistical significance in the group-by-time interaction.

Walking energy cost and HRd during overground walking. The ANOVA for WEC*d* during overground walking showed significant group-by-time interaction at FWS ($F = 4.18$, $P = 0.02$), CWS ($F = 8.24$, $P = 0.00$), and SWS ($F = 3.56$, $P = 0.04$), whereas that for HR*d* showed no significant main ef-

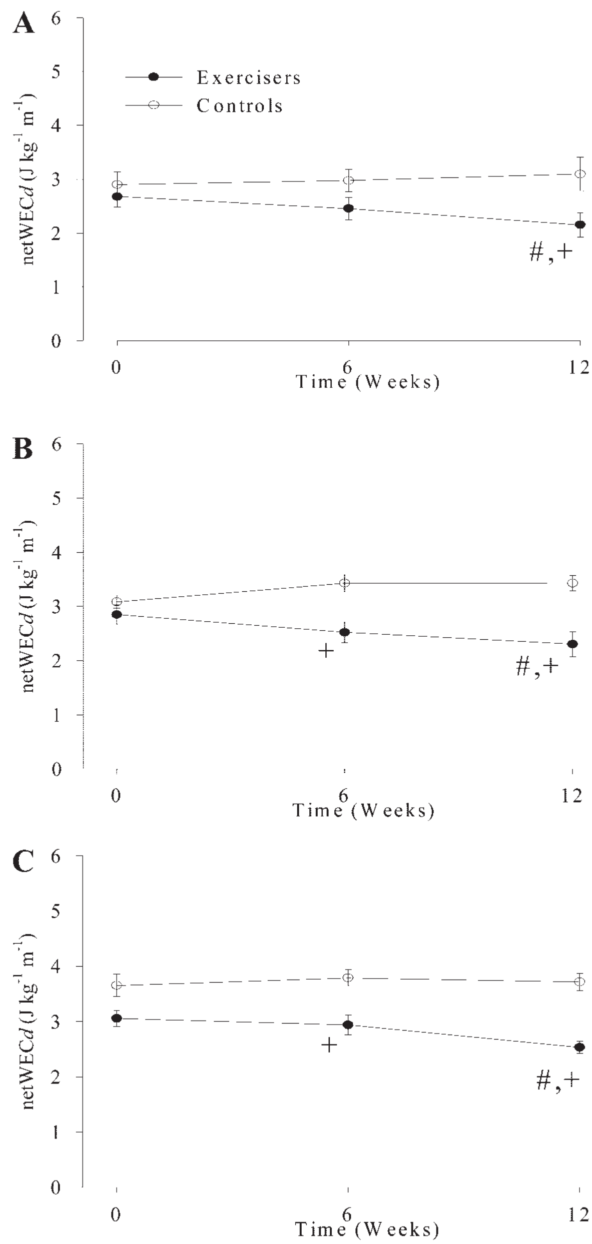

Fig. 2. Mean (±SE) net walking energy cost per unit of distance (WEC*d*) at slow walking speed (SWS; *A*), comfortable walking speed (CWS; *B*), and fast walking speed (FWS; *C*) of the 2 groups at *weeks 0*, *6*, and *12* of the intervention. #Significantly different from *week 0*, and +significantly different from the control group ($P = 0.05$).

fects. The post hoc analysis (Fig. 2) showed that there were no significant differences in the WEC*d* of the control group at any given speed at any time point ($P > 0.017$). Although no significant changes in WEC*d* at any speeds were observed in the exercise group at *week 6* ($P > 0.017$), the exercise group showed a significant reduction of the WEC*d* at SWS by 21% ($P = 0.006$; Fig. 2*A*), CWS by 20% ($P = 0.007$; Fig. 2*B*), and FWS by 18% ($P = 0.001$; Fig. 2*C*) after 12 wk of intervention.

Walking energy cost during treadmill walking. The ANOVA for walking energy cost during treadmill walking showed significant main effects of group and time, although there was no significant group-by-time interaction. The post hoc analysis showed (Fig. 3) that there were no significant changes at any self-selected speeds of the control group at any time point ($P > 0.017$). At *week 6*, the exercise group showed a significant reduction of WEC*d* at CWS at 0% of BWU ($P = 0.015$) (Fig. 3*A*) and FWS at 40% of BWU ($P = 0.017$) (Fig. 3*B*). After the 12 wk of intervention, the exercise group showed a further significant reduction of WEC*d* at CWS at 0% of BWU ($P = 0.008$; Fig. 3*A*) and FWS at 40% of BWU ($P = 0.016$; Fig. 3*B*).

T_{vent}. The ANOVA for $\dot{V}O_2$ (Fig. 4*A*) and HR (Fig. 4*B*) showed no significant main effects, whereas mechanical power output at T_{vent} (Fig. 4*C*) showed a significant group-by-time interaction ($F = 7.23$, $P = 0.00$). Mechanical power output at T_{vent} of the exercise group increased at *weeks 6* and *12* by 23% and 67% ($P < 0.017$), respectively, with no significant changes in the control group (Fig. 4*C*).

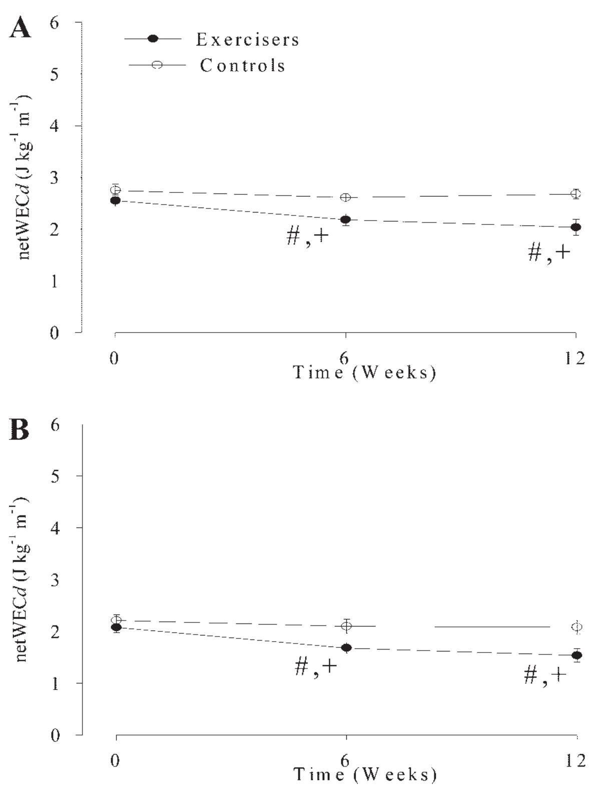

Fig. 3. Mean (±SE) net WEC*d* at CWS at 0% of BWU (*A*) and FWS at 40% of BWU (*B*) of the 2 groups on the treadmill at *weeks 0*, *6*, and *12* of the intervention. #Significantly different from *week 0*, and +significantly different from the control group ($P = 0.05$).

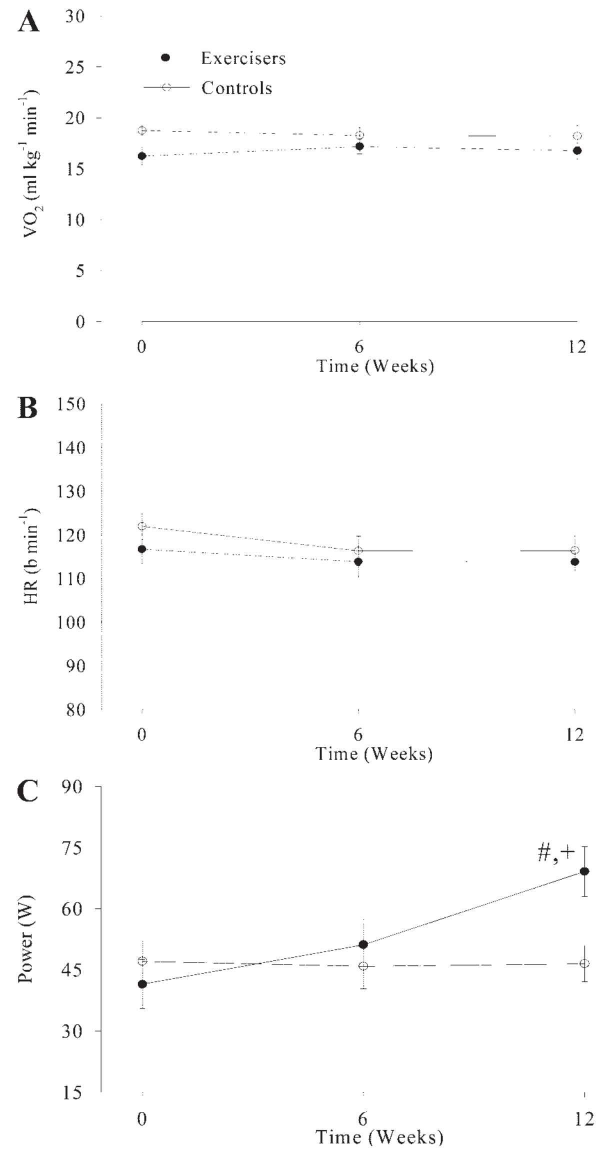

Fig. 4. Mean (±SE) oxygen uptake ($\dot{V}O_2$; *A*), heart rate (HR; *B*), and power (*C*) at ventilatory threshold of the 2 groups at *weeks 0*, *6*, and *12* of the intervention. #Significantly different from week 0, and +significantly different from the control group ($P = 0.05$).

DISCUSSION

The main finding of this controlled randomized study is that the novel approach to performing "overspeed" interval training, based on walking on a treadmill with progressively reduced BWU, has been shown to be effective in improving the energy cost and speed of overground walking in a group of healthy older women. The WEC*d* decreased at self-selected fast, comfortable, and slow speeds. Maximal walking speed increased, which was accompanied by a significant increase in SL, which is the temporospatial parameter most compromised by aging (21, 43), and a tendency toward an increase in SF.

After the first 6 wk of intervention, WEC*d* of the exercise group decreased during treadmill walking with BWU (Fig. 3, *A* and *B*) but not overground (Fig. 2). This early adaptation might be attributed to the specificity of the training program (28) with the testing procedure closely mimicking the training maneuver.

In the last 6 wk of the intervention, however, there was a further decrease of WEC*d* of the exercise group during treadmill walking, which was accompanied also by a significant decrease of 20%, 19%, and 18% of the WEC*d* during overground walking at SWS, CWS, and FWS, respectively. To the authors' knowledge, this is the first study to show a significant reduction in the energy cost per unit of distance during walking at self-selected speeds after a training program in healthy elderly people. In fact, the energy cost of the exercise group was reduced to levels that are similar to those of younger individuals (33). The finding is particularly relevant because it has been demonstrated that the WEC*d* at a comparable speed is significantly higher in healthy elderly populations than their younger counterparts (25, 29), which is a contributory factor for the mobility impairment.

The WEC*d* of the exercise group was improved independently of walking speeds, indicating that the improvement was probably due to altered walking mechanics or other neuromuscular adaptations. In older individuals, the higher WEC*d* has been associated with an impaired exchange of potential and kinetic energy leading to increased mechanical work (25). The gait stability offered by the harness system during speed walking on the treadmill might have helped the older participants to "relearn" to walk with improved gross motor efficiency (14) and thereby reduce the walking energy cost. Improved walking energy cost might also be due to improvements in skeletal muscle function and muscle morphology. Muscle biopsies taken before and after submaximal training programs in older participants have shown increased oxidative capacity of muscles (31). After submaximal training, mitochondria size, number, and enzymes in older people have been reported to increase significantly, thus increasing the mitochondrial respiration capacity (18). Changes in the expression of myosin heavy-chain isoforms toward a slower phenotype could also be a contributing factor, as suggested by observations in stroke patients showing that skeletal muscle in the hemiparetic leg shifts to a fast myosin-heavy chain isoform phenotype with associated metabolic changes and that the magnitude of the shift, which is reversible, is related to the degree of neurological gait deficit severity, indexed by the self-selected floor walking speed (6).

After the 12-wk training intervention, maximal walking speed of the exercise group improved by 13%, although there was a tendency for a 7% increase in FWS, with no changes observed in the control group. This is in line with other studies showing a similar magnitude of improvement in maximal and FWS after different exercise protocols (12, 37, 38). The results of the present study further indicate that the improvement in maximal walking speed of the exercise group resulted from a combined increase in SL and SF (although SF showed only a tendency toward an increase, due to the greater variability in the control group), which might have been mediated by improved hip extension and ankle power (21). There were no significant differences between the control group and the exercise group during self-selected SWS and CWS at any time point. The lack of difference in walking speed is not in agreement with the majority of studies, which show an improvement in SWS and CWS of older people after different exercise programs (2, 11, 23). The discrepancy might be because the participants in the present study were high-functioning older women and because the initial self-selected SWS of both groups were considerably higher than those in the above-mentioned studies and therefore may have limited potential for any improvement. Moreover, Lord et al. (23) pointed out that only exercising subjects with initial lower SWS showed greater improvements in walking speed after the exercise program. On the other hand, the CWS of both groups in the present study remained unchanged at 1.25–1.3 m/s, the most economical speed identified by several studies (27, 34, 35). An increase above the most economical speed would have increased the walking energy cost (9), which might explain why the exercise group did not increase their CWS.

The present study also showed that the training program produced a significant improvement in mechanical power output at T_{vent}. The higher mechanical output is shown to be the characteristic of a successful training program at submaximal levels (42), which would allow the older individuals to sustain physical activities or exercise at higher power output without accumulation of blood lactate (19). $\dot{V}O_2$ and HR of the exercise group at T_{vent}, however, remained unchanged after the training intervention. This finding is in contrast to other submaximal training studies in older individuals (11) and patients with chronic obstructive pulmonary disease (40), which showed increased $\dot{V}O_2$ and HR after the intervention. The reason for the discrepancy might be because the $\dot{V}O_2$ and HR values of the participants in the present study during baseline were at the higher end of the spectrum in their age group and therefore may have limited potential for any improvement.

Although there was a trend in the reduction of HR per unit of distance in the exercise group after the training intervention during overground walking speeds, it was not significant as observed in the WEC*d*. This is in contrast to a study by Gazzani et al. (14) in which the authors found a significant reduction in HR per unit of distance of stroke patients after treadmill training with BWU. This might be attributed to differences in participant groups, as the potential to improve was higher in stroke patients. HR at quiet standing did not change significantly. A similar observation was reported by Fabre et al. (11) who found no differences in HR at rest after an individualized training program at HR corresponding to T_{vent} in older people.

The high adherence rate in the present study is encouraging, and it might be due in part to a motivated group and the fact that the exercise training was within the group's submaximal levels; these results may offer an effective health promotion strategy for improving mobility in older persons. Furthermore, the individualization of training intensity might have maximized compliance to the training program (11) because it is easier to perform and to increase overall improvement in aerobic capacity.

It is acknowledged that the participants were not blinded to the intervention, and part of the improvement in gait performance of the exercise group may have been due to the increased motivation and effort (24). Although individualized training programs seem to be very effective for elderly individuals, there are practical difficulties in prescribing them on a large scale because of the present difficulties in conducting exercise tests for every applicant.

In conclusion, the individualized interval speed training on a treadmill with progressively reduced BWU induced substantial carryover improvement in the net walking energy cost of healthy older individuals at self-selected overground walking speeds. This was accompanied by an improvement in maximal walking speed. This method could be implemented at numerous fitness and health clubs, which are growing in number and popularity nowadays (also for older people), by the addition of the apparatus for BWU to existing treadmills.

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GRANTS

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