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 trial 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 (Tvent walking speed). Each session consisted of four sets of 5 min of walking (three 1-min intervals at Tvent walking speed, with two 1-min intervals at comfortable walking speed in between each period at Tvent 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 Tvent 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.

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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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 \( \text{VO}_2 \) during standing and overground walking (SW, 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\( \text{t} \)) was calculated as the amount of \( \text{VO}_2 \) per unit of body mass and per unit of time (expressed in J kg\(^{-1}\) min\(^{-1}\)). It was calculated as 
\[
\text{WEC}_{\text{t}} = \frac{\text{WEC}_{\text{d}}}{\text{SHR} / \text{S}},
\]
where \( \text{WEC}_{\text{d}} \) is the energy cost during walking (in J kg\(^{-1}\)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: 
\[
\text{HR}_{d} = (\text{WHR} - \text{SHR}) / \text{S},
\]
where WHR is HR during walking (in beats/min) and SHR is HR during standing (in beats/min).

### Ventilatory threshold (T\( \text{vent} \))

The ventilatory threshold (T\( \text{vent} \)) 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\( \text{vent} \) was reached, which was monitored online. T\( \text{vent} \) was determined by using the ventilatory equivalent (Ve) method, i.e., a systematic increase in the Ve of \( \text{O}_2 \) (VE/\( \text{VO}_2 \)) with no concomitant rise in the Ve of CO\( _2 \) (VE/\( \text{CO}_2 \)) (41) and by using the V-slope method of Beaver et al. (3). The V-slope method involves the analysis of the behavior of \( \text{VO}_2 \) as a function of \( \text{VO}_2 \) and assumes that the threshold corresponds to the break in the linear Ve\( \text{CO}_2 \)-\( \text{VO}_2 \) relationship. The final value of T\( \text{vent} \) was calculated as the average of the two values obtained with the two methods.

### Mechanical power output (expressed in W)

Mechanical power output (expressed in W) during T\( \text{vent} \) 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

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\( \text{vent} \)).

### 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 BWU three times per week. During the first 6 wk, the exercise group performed interval training on the treadmill with BWU three times per week. For each condition, 10 laps were randomly selected for further analysis. Gait was also assessed during a 6-m maximal walking speed test. Maximal walking speed 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).

### Table 1. \( \text{VO}_2 \) during standing and overground walking (slow, comfortable, and fast walking speed) at the baseline tests (i.e., before training)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Exercise Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing ( \text{VO}_2 ), ml kg(^{-1})min(^{-1})</td>
<td>4.09 ± 0.38</td>
<td>3.89 ± 0.72</td>
</tr>
<tr>
<td>( \text{VO}_2 ) at slow walking speed, ml kg(^{-1})min(^{-1})</td>
<td>12.28 ± 1.92</td>
<td>12.69 ± 2.16</td>
</tr>
<tr>
<td>( \text{VO}_2 ) at comfortable walking speed, ml kg(^{-1})min(^{-1})</td>
<td>15.25 ± 2.07</td>
<td>14.90 ± 1.59</td>
</tr>
<tr>
<td>( \text{VO}_2 ) at fast walking speed, ml kg(^{-1})min(^{-1})</td>
<td>18.86 ± 2.90</td>
<td>19.65 ± 3.14</td>
</tr>
</tbody>
</table>

Note: Values are means ± SD. \( \text{VO}_2 \) was calculated as the net energy cost per unit of body mass and per unit of distance (expressed in J kg\(^{-1}\) m\(^{-1}\)). The net walking energy cost per unit distance (WEC\( \text{d} \)) was calculated as the amount of \( \text{VO}_2 \) per unit of body mass (expressed in ml kg\(^{-1}\) min\(^{-1}\)). The final value of T\( \text{vent} \) was determined by the equivalent (Ve) method, i.e., a systematic increase in the Ve of \( \text{O}_2 \) (VE/\( \text{VO}_2 \)) with no concomitant rise in the Ve of CO\( _2 \) (VE/\( \text{CO}_2 \)) (41) and by using the V-slope method of Beaver et al. (3). The V-slope method involves the analysis of the behavior of \( \text{VO}_2 \) as a function of \( \text{VO}_2 \) and assumes that the threshold corresponds to the break in the linear Ve\( \text{CO}_2 \)-\( \text{VO}_2 \) relationship. The final value of T\( \text{vent} \) was calculated as the average of the two values obtained with the two methods.
SPEED TRAINING WITH BWU IN HEALTHY OLDER WOMEN

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 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 WECd 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 HRd showed no significant main ef-
fects. The post hoc analysis (Fig. 2) showed that there were no significant differences in the WECd of the control group at any given speed at any time point ($P > 0.017$). Although no significant changes in WECd at any speeds were observed in the exercise group at week 6 ($P > 0.017$), the exercise group showed a significant reduction of the WECd at SWS by 21% ($P = 0.066$; Fig. 2A), CWS by 20% ($P = 0.007$; Fig. 2B), and FWS by 18% ($P = 0.001$; Fig. 2C) 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 WECd at 0% of BWU ($P = 0.015$) (Fig. 3A) and FWS at 40% of BWU ($P = 0.017$) (Fig. 3B). After the 12 wk of intervention, the exercise group showed a further significant reduction of WECd at 0% of BWU ($P = 0.008$; Fig. 3A) and FWS at 40% of BWU ($P = 0.016$; Fig. 3B).

$T_{vent}$ The ANOVA for $\dot{V}O_2$ (Fig. 4A) and HR (Fig. 4B) showed no significant main effects, whereas mechanical power output at $T_{vent}$ (Fig. 4C) 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. 4C).

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 WECd 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, WECd 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 of the exercise group during treadmill walking, which was accompanied also by a significant decrease of 20%, 19%, and 18% of the WEC 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 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 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 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 Tvent. 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). VO2 and HR of the exercise group at Tvent, 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 VO2 and HR after the intervention. The reason for the discrepancy might be because the VO2 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. 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 Tvent 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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