Walking Speed at Self-Selected Exercise Pace Is Lower but Energy Cost Higher in Older Versus Younger Women

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Running head: Energy Costs of Walking

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Abstract

**Background:** Walking is usually undertaken at a speed that coincides with the lowest metabolic cost. Aging however, alters the speed-cost relationship, as preferred walking speeds decrease and energy costs increase. It is unclear to what extent this relationship is affected when older women undertake walking as an exercise modality. The aim of this study was to compare the energetic cost of walking at a self-selected exercise pace for a 30 minute period in older and younger women. **Methods:** The energetic cost of walking was assessed using the energy equivalent of oxygen consumption measured in 18 young (age 25-49 years) and 20 older (age 50-79 years) women who were asked to walk at their ‘normal’ exercise pace on a motorised treadmill for 30 minutes duration. **Results:** The mass-specific net cost of walking (Cw) was 15% higher and self-selected walking speed was 23% lower in the older women than in the younger group. When speed was held constant, the Cw was 0.30 (J.kg\(^{-1}.m^{-1}\)) higher in the older women. **Conclusions:** Preferred exercise pace incurs a higher metabolic cost in older women and needs be taken into consideration when recommending walking as an exercise modality.
Introduction

Walking is a convenient and popular form of aerobic activity and is widely recommended for health and fitness for individuals of all ages.\textsuperscript{1, 11, 12, 18, 23} The associated energy costs of this activity are the result of the need to convert chemical energy to the mechanical work of walking. Measurement of oxygen consumption during physical activity allows an assessment of the associated metabolic costs to be made. The mass-specific net cost of walking (Cw), defined as the energy cost of moving 1 kg of body mass 1 metre,\textsuperscript{2, 22} and speed is U-shaped, with an individual’s walking speed selected to coincide with the lowest metabolic cost.\textsuperscript{2, 21, 31} This relationship can be altered by changes in gait patterns as a result of amputation,\textsuperscript{17} disease,\textsuperscript{3} loading,\textsuperscript{2} obesity,\textsuperscript{6, 7} gender,\textsuperscript{6} and aging.\textsuperscript{8, 15, 16, 19-21, 29}

Self-selected walking speeds decrease with age, while the associated energy costs increase, resulting in an upward shift in the Cw-speed relationship during aging.\textsuperscript{8, 15, 16, 19-21, 29} The reason for this upward shift in older adults is multifactorial. Determinants of walking speed and metabolic cost in older individuals that have been proposed include the effects of age,\textsuperscript{16, 21} alterations in muscle efficiency,\textsuperscript{22} step length,\textsuperscript{27} height,\textsuperscript{16, 20} body composition,\textsuperscript{15, 26} and increased cardiorespiratory demands.\textsuperscript{20, 21}

Many studies undertaken to evaluate the metabolic cost of walking at self-selected or pre-determined walking speeds in older individuals have been undertaken for relatively short periods of time or over relatively short distances.\textsuperscript{15, 19-22, 25, 26} Furthermore, no studies to date have focused on the metabolic costs of walking at a self-selected exercise pace. American College of Sports Medicine (ACSM) physical activity recommendations for adults suggest moderate intensity exercise be
undertaken five days per week for 30 minutes per session for adults aged 18-65 years, although in adults >65 years this recommendation can be obtained by shorter duration exercise repeated several times per day. It is more difficult to extrapolate Cw over short periods of time to a continuous ‘exercise-focused’ protocol. Therefore the aim of this study was to compare the energetic cost of walking at a self-selected speed for a 30 minute period in older and younger women.

**Methods**

Forty Caucasian women were recruited by advertisement to participate in this cross-sectional comparative study, which was approved by the University of Otago Human Ethics Committee. All women were regular recreational exercisers, ie physical activity was normally undertaken less than four days or 150 minutes per week. Participants in the younger (YOU) group comprised women between 25-49 years of age (n=20), while women aged between 50-79 years comprised the older (OLD) group (n=20).

Informed written consent was obtained and a medical and exercise screening questionnaire was completed prior to the first exercise testing session. Exclusion criteria included a history of heart disease, Type 2 diabetes, orthopaedic problems, current hormone replacement therapy use, regular use of any medications known to affect metabolism (eg thyroid drugs), significant weight fluctuations within the six months (± 5kg) prior to participation in this study, any health problem which may have interfered with exercise, or an inability to walk continuously for 30 minutes. Participants were also excluded if they demonstrated a high level of current physical activity, ie exercised more than four days or 150 minutes per week.
Anthropometry

Height, weight, waist and hip circumferences were recorded prior to the treadmill walk. Height was determined without shoes using a free standing stadiometer, while weight was taken with participants wearing their walking attire, also without shoes, using electronic scales (Digi, D1-10, Teraoka Ltd, Tokyo, Japan). A standard fibreglass anthropometric tape was used to measure waist circumference, defined as the narrowest part between the last rib and the anterior superior iliac spine (ASIS), and hip circumference, defined as the widest part between the ASIS and the greater trochanter. Body mass index (BMI = weight (kg)/height (m$^2$)) was used to estimate adiposity, while waist hip ratios (WHR) were calculated to describe body fat distribution.

Exercise Protocol

All exercise sessions and maximal exercise testing took place at the School of Physical Education, University of Otago. The study protocol required the participants to complete 30 continuous minutes of treadmill walking. Participants were tested individually and were asked to undertake the exercise sessions at their ‘normal’ exercise pace, ie self-paced exercise. Participants were asked to maintain their normal diet and activity patterns between the exercise session and the maximal exercise test. The maximal exercise test was undertaken 48 hours after the exercise session had been completed to ensure the women chose their own exercise pace during the walk. Prior experience or perception of higher intensity exercise on the treadmill could have influenced the choice of exercise pace made by each woman.
Treadmill walking was undertaken in an exercise physiology laboratory, ambient temperature 26°C, using a Quinton motorised treadmill (Quinton Instrument Company, Series 90 Q65, WA, USA) set at 0% gradient. Breath sampling occurred at rest, for three minutes immediately prior to beginning the treadmill walk, the average of the final two minutes was used in the analyses. Thereafter the 30-minute exercise session was divided into five six-minute blocks for sampling purposes. Breath samples were collected for the final 80 seconds of each block. The Sensormedics metabolic cart samples every 20 seconds, therefore the initial 20 seconds of data were discarded and the remaining 60 seconds averaged for analytical purposes. Rating of perceived exertion (RPE), Borg scale 6-20, and HR values (Polar heart rate monitor, Polar etc) were collected at the end of each six minute block. All women were given the opportunity to increase or decrease treadmill speed at the end of each six-minute interval to ensure replication of a self-selected exercise pace. Speed was increased or decreased by a technician when requested and any change in speed noted. All women were familiarised with the exercise environment, equipment and the measurement scales to be used, following the rest period, and before sampling began for their exercise session. Throughout the exercise session, participants were verbally reminded to continue exercising at their normal pace.

Energy expenditure (EE) was calculated using the energetic equivalent of 20.1 J.mL⁻¹O₂ from the indirect calorimetry values collected at rest and at the end of each six minute block. Resting EE was calculated from the mean oxygen consumption (\(\dot{V}O_2\)) over the two minute sampling period immediately prior to the exercise session, while the 60 seconds of breath analysis was averaged and used to estimate EE per minute during the exercise session at minutes 6, 12, 18, 24 and 30. The average EE for the
treadmill session does not include resting values, thus these data represent EE associated with activity only.

To find the mass-specific net cost of walking (Cw), i.e., the energy cost of moving 1 kg of body mass 1 metre, the energetic equivalent of the average rate of oxygen consumption at rest and over the 30 minute treadmill walk was calculated using the energetic equivalent of O$_2$ and expressed in J.sec$^{-1}$. Only participants with a respiratory exchange ratio (RER) < 1.0 were used in these analyses to ensure aerobic metabolism was the primary metabolic pathway. Two women in the YOU group had RER values > 1.0 and were excluded from further analyses; thus, the final participant number for the YOU group was eighteen. The mass-specific net metabolic rate was calculated by subtracting the resting EE from the average EE over the 30 minute TM walk, and dividing by body mass (W.kg$^{-1}$). Mass specific net metabolic rate was then divided by the average treadmill speed (metres.sec$^{-1}$) to give the net metabolic cost of walking (Cw, in J.kg$^{-1}$m$^{-1}$)$^2$. Metabolic equivalents were calculated to facilitate direct comparisons of exercise intensity between the self-selected walking pace of our groups and the recent ACSM recommendations defining moderate intensity as activities using 3.0-6.0 METs. For the purposes of this estimation, resting metabolic rate was assumed to be 3.5 ml.kg$^{-1}$.min$^{-1}$.

**Maximal oxygen consumption (VO$_{2\text{max}}$) test**

Following the completion of the walk, a maximal oxygen consumption exercise (VO$_{2\text{max}}$) test was undertaken on a treadmill using individualised ramp protocols, with
predicted $\dot{V}O_{2\text{max}}$ and grade increments calculated from established equations. Treadmill speed was determined from the average of velocities chosen during the 30 minute walking exercise session and was held constant throughout the test. Following a two minute warm up, grade was increased every minute until volitional fatigue. Grade increments were calculated using predicted $\dot{V}O_{2\text{max}}$ estimated from equations of Cooper and Storer (2001).

Continuous breath analysis (Sensormedics 2900 metabolic cart, Sensormedics, California, USA) and heart rate (HR) were undertaken throughout the exercise test and values were recorded at 20 second intervals.

**Statistical Analysis**

Group mean ± standard error of the mean (SEM) was used to describe the data. Shapiro-Wilk testing of all variables was undertaken to ensure normal distribution of data; all data were found to be normally distributed. Independent t-tests were performed to determine differences in physiological parameters between the YOU and OLD groups. To control for self-selected treadmill speed, analysis of covariance (ANCOVA) was used to examine the influence of group (YOU or OLD) on the net energetic cost of walking (J.kg$^{-1}$.m$^{-1}$). A stepwise multiple regression analysis was undertaken using combined group data (n=38) to determine the predictor(s) of treadmill speed selection (m.sec$^{-1}$). Independent variables entered into the model were age, height, weight, and $\dot{V}O_{2\text{max}}$ (expressed as ml.kg$^{-1}$.min$^{-1}$). Pearson product-moment correlation coefficient testing was undertaken to investigate the relationships between the independent variables and walking speed. Statistical Package for the
Social Sciences (SPSS) was used for all statistical analyses (SPSS Inc, v14.0, Chicago, IL). Significance was set at p<0.05.

**Results**

Demographic and baseline physiological data (mean ± SEM) are presented in (Table 1). Maximum HR and $\bar{VO}_2$ measured from the treadmill exercise test were significantly higher (p<0.05) in the YOU group than the OLD group (Table 1).

The self-selected treadmill speed was significantly greater for the younger women compared with the older group (5.3 ± 0.19 vs 4.1 ± 0.24 km.hr$^{-1}$, respectively p<0.001). Net $C_w$ was also significantly higher in the OLD group compared with the YOU group (p<0.05, Table 2). Mean $\bar{VO}_2$, HR, MET values, and RPE were not significantly different between the groups (p<0.05, Table 2).

A one-way ANCOVA was conducted to investigate the cost of walking at similar speeds between the two groups. Correlations between the cost of walking and self-selected treadmill speed were small and non significant ($r^2=0.10$, p=0.16 vs $r^2=0.01$, p=0.59) for the YOU and OLD groups, respectively. There was no significant difference found in the slopes of the regression lines (p=0.53), thereby demonstrating homogeneity, but a significant difference in the net cost of walking was observed at the y-intercept by 0.30 J.kg$^{-1}$.m$^{-1}$, p=0.006 (Figure 1).

When the independent variables of age, height, weight, and relative $\bar{VO}_2$ were entered into the regression model, only $\bar{VO}_2$, expressed relative to body mass, remained a significant predictor of self-selected walking pace in this group of women. This
variable accounted for 61% of the variance in walking speed (β coefficient = 0.78; p=0.0005). Age was significantly (p<0.05) inversely associated with walking speed, while height and relative maximal oxygen consumption were positively related with walking speed (Table 3).

**Discussion**

We investigated the net energetic cost of walking at a self-selected pace over exercise duration of 30 minutes in two groups of women. The main findings in this study were that older women incurred a higher metabolic cost while walking at a slower pace than younger women and that their level of fitness was the greatest predictor of self-selected speed. Furthermore, when walking speed is held constant, the net energetic cost of walking remains higher in the older group than the younger group of women.

It has been suggested that all individuals have an ideal, or habitual, walking speed and it is at this speed that EE is lowest. However, walking speed decreases with age and the metabolic costs increase. Walking speeds and the associated energy costs have been evaluated using subjective instruction of ‘slow, normal, or fast’ walking pace, or by using pre-determined speed on a treadmill. To our knowledge, this is the first paper to address the metabolic costs of self-selected walking pace as an exercise modality.

Haveman-Nies et al. (1996) reported a 27% lower self-selected walking speed in older women when compared with their younger counterparts, with total energy expenditure 22% higher when walking at either a self-selected or fixed speed. Malatesta et al. (2003) found preferred walking speed to be approximately 15%
slower in the oldest group of adults (80 years), with oxygen cost per distance walked approximately 22% higher than those aged 25 years. Waters et al (1983)\textsuperscript{29} reported that normal walking speed was approximately 10% slower in older (60-80 years) versus younger (20-59 years) adults, although gross oxygen cost at this speed was similar. However, when expressed per distance walked, oxygen costs were 8% higher in the older group. Similarly, when treadmill speeds are fixed, energy costs are also higher for older individuals. Walking at speeds over a range of 0.7-1.8 m/s, average metabolic costs of walking have been reported as 31\%\textsuperscript{22} and 20\%\textsuperscript{25} higher in older adults when compared with younger adults. In the present study, self-selected walking speed at exercise pace was approximately 23% lower in our OLD group than in the YOU group, while the average net $C_w$ was 15% higher. Our results are similar to those found by Haveman-Nies et al. (1996)\textsuperscript{15} and Malatesta et al. (2003)\textsuperscript{19} for ‘normal’ walking pace, while our finding of a similar gross rate of oxygen consumption between the two groups, despite significantly slower walking speeds selected by the older women, concur with those of Waters et al. (1983).\textsuperscript{29} Furthermore, the rate of energy consumption-speed relationship in our women falls within the range of normative data for adults aged 20-80 years produced by Waters et al. (1988).\textsuperscript{29} The discrepancies amongst studies investigating speed and metabolic costs of walking are likely to be attributable to methodological differences. Participant age groups vary, which may distort speed-related results as the most rapid decline in walking speed occurs at age 62 years.\textsuperscript{16} Gender may also have an effect, as gait speed and stride length and frequency have been shown to differ between males and females.\textsuperscript{29} The modality used to assess gait speed may also explain part of the differences. Some studies used subjective instruction to assess walking over a range of speeds on level ground or treadmill,\textsuperscript{15,26} while others used fixed speeds while
participants walk on a treadmill. Furthermore, oxygen consumption values that have not been corrected for resting oxygen consumption may underestimate the metabolic costs attributable to locomotion.

We also demonstrated that when walking speed is held constant, the cost of walking was increased by was 0.30 J.kg$^{-1}$.m$^{-1}$ in the older women. This would equate to the expenditure of an additional 111.3 kJ in one hour of walking at the same pace as the YOU group. While this level of energy expenditure appears small, in older individuals who may be under-nourished, the increased energy requirements for exercise may further deplete existing limited energy reserves.

Older individuals are being encouraged to undertake regular physical activity; however, the impact of increased daily exercise energy expenditure on activities of daily living (ADL) has not been fully appreciated. In a free-living situation, Harris et al.,(2007) using a telemetry-based system, calculated that older individuals walk approximately 6.5 miles (10.4 km) per day, three miles (5 km) per day less than younger individuals and, in agreement with the results of the present study, energy expenditure per mile walked at the same speed was higher in the older group. In addition to a reduction in total distance walked at a higher energy cost, Harris et al. (2007) observed a decline in daily nonexercise movement, standing time and movement accelerations in the older individuals, although total energy expenditure did not differ between the young and old individuals. Thus, it could be proposed that some compensatory behaviours are undertaken by older individuals to limit energy expenditure of ADL throughout the day. Careful attention to nutritional intake and recovery strategies should be incorporated when programming exercise for older
individuals. Failure to do so may result in an even greater reduction in movement associated with ADL.

Cardiorespiratory demands are increased in older adults walking at their preferred speed, evidenced by the higher relative fractions of $\dot{V}O_2_{\text{max}}$ and ventilatory threshold used compared with younger individuals.\textsuperscript{20} In the present study, while differences were not significant, the older women were walking at a slightly higher percentage of their maximum aerobic capacity than the younger group, 47% vs 44%, respectively. This compares well with a study by Malatesta et al. (2004)\textsuperscript{20} who found preferred walking speed in a group of 65-year old adults to be undertaken at 43% $\dot{V}O_2_{\text{max}}$, however; the women in our study were asked to walk at their ‘normal exercise pace’ and thus the working fraction might have been expected to be somewhat higher. Despite this, the self-selected exercise pace in both groups satisfied the recent ACSM physical activity definition of ‘moderate intensity’ (3.0-6.0 METs), which is recommended for cardiovascular maintenance in healthy adults aged 18-65 years.\textsuperscript{14}

A consistent finding in previous studies is that walking speed declines with age.\textsuperscript{8, 10, 15, 16, 19-21, 29} Reasons proposed for this have been attributed to age-related changes in physiological function and biomechanical efficiency.\textsuperscript{10, 15, 16, 20-22, 26, 27} We found associations between self-selected exercise pace and age, height, and maximal $\dot{V}O_2$; which concur with those previously reported.\textsuperscript{16, 20, 27} In agreement with studies by others,\textsuperscript{10, 20} we found maximal oxygen consumption, expressed relative to bodyweight, to be the primary determinant of walking speed when our groups were combined, accounting for 61% of the variance. Malatesta et al. (2004)\textsuperscript{20} reported 48% of the variance in walking speed in adults aged 65-80 years to be explained by the
fraction of VO₂ corresponding to the ventilatory threshold at preferred walking speed. Given the numerous studies which have reported a decrease in walking speed with advancing age, it is somewhat surprising that, as with our study, Malatesta et al. (2004)²⁰ and Cunningham et al. (1982)¹⁰ also did not find age to be an independent factor in determining preferred walking speed. In both studies, and with ours, the lack of an independent age effect on walking speed may be explained by the strength of association with the use of more stringent statistical procedures. Simple correlational analyses in all studies reveal significant negative associations between age and aerobic fitness and walking speed; however, age effects are lost in multiple regression analysis.¹⁰,²⁰ It is also notable that the self-selected speed of walking for exercise in our two groups of women coincided with the normal, or preferred, walking speed of individuals in similar age categories reported elsewhere.¹⁰,¹⁶,¹⁹,²⁶,²⁷,²⁹

In summary, this study demonstrated that the relative energetic costs of walking at a self-selected exercise pace over 30 minutes are significantly higher in older women when compared with younger women. Furthermore, preferred walking speed is determined by the individual’s maximal aerobic fitness level. Some effort should be made to assess initial fitness levels in older women and the higher relative energy costs of walking kept in mind to ensure an exercise plan is developed that will be safe and effective for that individual.
Acknowledgments

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References


Table 1. Demographic and baseline physiological data for younger (YOU) and older (OLD) groups (mean ± SEM)

<table>
<thead>
<tr>
<th></th>
<th>YOU</th>
<th>OLD</th>
<th>Significance (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=18)</td>
<td>(n=20)</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>40 ± 1</td>
<td>59 ± 2</td>
<td>0.001</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165 ± 0.02</td>
<td>161 ± 0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.0 ± 2.9</td>
<td>70.0 ± 2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>BMI (kg.m$^{-2}$)</td>
<td>27.1 ± 1.1</td>
<td>26.8 ± 0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{max}}$ (L.min$^{-1}$)</td>
<td>2.42 ± 0.07</td>
<td>1.82 ± 0.09</td>
<td>0.001</td>
</tr>
<tr>
<td>$\dot{V}O_{2\text{max}}$ (ml.kg$^{-1}$.min$^{-1}$)</td>
<td>33.37 ± 1.25</td>
<td>26.55 ± 1.39</td>
<td>0.001</td>
</tr>
<tr>
<td>HR$_{\text{max}}$ (bpm)</td>
<td>179 ± 2</td>
<td>163 ± 2</td>
<td>0.001</td>
</tr>
</tbody>
</table>

BMI = body mass index; HR = heart rate; bpm = beats per minute
Table 2. Physiological data from the treadmill walking (TM) exercise session for the younger (YOU) and older (OLD) groups (mean ± SEM)

<table>
<thead>
<tr>
<th></th>
<th>YOU (n=18)</th>
<th>OLD (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean TM speed (m.sec(^{-1}))</td>
<td>1.47 ± 0.05</td>
<td>1.14 ± 0.07**</td>
</tr>
<tr>
<td>Net Cw (J.kg(^{-1}).m(^{-1}))</td>
<td>2.39 ± 0.07</td>
<td>2.74 ± 0.10*</td>
</tr>
<tr>
<td>Mean VO(_2) (ml.kg(^{-1}).min(^{-1}))</td>
<td>14.0 ± 0.8</td>
<td>12.2 ± 0.7</td>
</tr>
<tr>
<td>Mean HR (bpm)</td>
<td>110 ± 3</td>
<td>104 ± 3</td>
</tr>
<tr>
<td>METs</td>
<td>4.0 ± 0.2</td>
<td>3.5 ± 0.2</td>
</tr>
<tr>
<td>Mean RPE</td>
<td>11.4 ± 0.2</td>
<td>11.1 ± 0.2</td>
</tr>
</tbody>
</table>

Cw = energetic cost of walking; HR = heart rate; METs = metabolic equivalents; RPE = rating of perceived exertion. * p<0.05; ** p<0.01
Table 3. Pearson correlation coefficients between predictor variables and self-selected walking speed (n=38)

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Walking speed (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.61**</td>
</tr>
<tr>
<td>Height</td>
<td>0.39*</td>
</tr>
<tr>
<td>Weight</td>
<td>-0.96</td>
</tr>
<tr>
<td>VO\textsubscript{2max} (ml.kg\textsuperscript{-1}.min\textsuperscript{-1})</td>
<td>0.78**</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01
FIGURE 1. Cost of walking in relation to self-selected treadmill speed for YOU
\((r^2=0.10, p=0.16; \text{slope coefficient } \pm \text{ standard error, } 0.528 \pm 0.359; \text{solid line, open triangles})\) and OLD \((r^2=0.01, p=0.59; 0.190 \pm 0.350; \text{dashed line, solid squares})\). The slopes of the lines did not differ significantly \((p=0.53)\).