Energetics of Walking in Elderly People: Factors Related to Gait Speed

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Background. Slow walking speed in elderly people predicts increased morbidity and mortality. We examined factors that may be associated with decreased habitual walking speed in older men and women.

Methods. Older (range: 60–88 years, mean = 72.5 years) men (n = 25) and women (n = 24) were recruited. The Short Physical Performance Battery, body composition, VO2peak on a treadmill, VO2 and rated perceived exertion during 10 minutes of walking at habitual gait speed and at a walking speed of 0.9 m/s, muscle strength, and level of physical activity were measured.

Results. VO2peak was strongly related to habitual gait speed (r = .744, p < .001) and remained significant even after controlling for age, muscle strength, and gender. Compared with the tertile of fastest walkers (mean gait speed, 1.37 ± 0.04 m/s), the tertile of slowest walkers (0.87 ± 0.02 m/s) were older (p < .001), shorter (p = .026), had lower lean body mass (p = .011), lower strength (p < .001), less self-reported daily physical activity (p = .012), and higher relative (to VO2peak) intensity during walking at their habitual speed (65.3% ± 3.9% vs 54.3% ± 2.1% of VO2peak; p = .013).

Conclusions. VO2peak was strongly associated with habitual walking speed, suggesting that as aerobic capacity declines with age, the exertion associated with habitual gait speed increases. A slowing of walking speed may be a response to increased perception of exertion. The extent to which exercise training affects habitual gait speed and fatigue is not clear.

Key Words: Aerobic capacity—Gait speed—Walking speed—Perceived exertion—Fatigue.

Received March 17, 2010; Accepted July 6, 2010

Decision Editor: Luigi Ferrucci, MD, PhD

Changes in body composition and functional capacity are normal components of advancing age. The causes of declining functional capacity in older people have been attributed to a number of factors, including sarcopenia (1), muscle weakness, deconditioning, mitochondrial dysfunction (2), joint pain, poor balance, and incipient cognitive impairment (3,4). The functional capacity of an older person is highly predictive of mortality and many other important outcomes, such as loss of independence and nursing home admission, onset of dementia, and falls (5,6). Additionally, decline in functional status is the final common pathway of many chronic conditions that capture the overall impact of multiple, co-occurring conditions and is an important indicator of quality of life. Among a large number of different measures of functional capacity in older people, gait speed is most closely related to distal outcomes (6,7). However, the mechanism by which older people slow their gait speed is not well investigated and remains poorly understood.

Components of walking that may be associated with mobility in elderly people include muscle size, strength, body composition, and maximal aerobic capacity (VO2peak). These components change with age and are likely to be predictors of slow gait speed. Specifically, maximal aerobic capacity has been demonstrated to be a strong predictor of mobility. VO2peak declines with advancing age at the rate of 3%–6% per decade before the age of 70 years and accelerates to greater than 20% per decade in those older than the age of 70 years (8). As VO2peak declines with advancing age, walking at habitual speed increases in relative intensity. Relative exercise intensity is the percentage of maximal capacity of any activity. For example, a young healthy individual walking at a speed of 2 m/s may be close to 40% of maximum, whereas a deconditioned older person may be at 90% of maximum aerobic capacity at the same speed. This increased intensity of normal walking may result in decreased amount of walking or the slowing of walking speed to decrease the perceived exertion of the activity. Therefore, we examined the relationship of VO2peak and habitual gait speed in older men and women. In addition, we examined other components of functional capacity that may be related to mobility.
Methods

Participants
Community-dwelling older (60–88 years) men and women (n = 56) were recruited from the Little Rock metropolitan area. After providing written informed consent and meeting eligibility criteria, participants (n = 49) participated in two separate days of testing. Eligible participants were required to be mobile (Short Physical Performance Battery [SPPB] score ≥4) with no impaired cognitive function (Saint Louis University Mental Status Examination [9] score ≥22). Participants were ineligible if they reported a history of disease or injury that could interfere with study procedures or measurements. Safety screening included resting electrocardiogram and blood pressure before treadmill testing. The first day of testing included measurements of functional capacity, body composition, VO$_2$ while walking at habitual walking speed, and during a standard walking speed of 0.9 m/s (2 mph). A second testing day included measurements of VO$_2$peak, muscle strength, and physical activity as described later. Study procedures were approved by the Institutional Review Board of the University of Arkansas for Medical Sciences.

Measures
SPPB (10) was assessed during the initial screening period for each volunteer. Participants with an SPPB score of <4 were excluded from participation.

Peak O$_2$ consumption during exercise.—VO$_2$peak was measured on each participant during graded treadmill walking as previously described (11). As a safety measure, participants were allowed to hold on to a handrail to maintain their balance during the test. The test was terminated when the participant indicated volitional fatigue. Strong verbal encouragement was used to motivate participants to exercise to a maximal effort during each test. Rated perceived exertion using the Borg scale (12) was assessed every 2 minutes until completion of the test. VO$_2$ and VCO$_2$ were calculated from analysis of gas concentration (models S-3A/I and CD-3A, respectively; AEI Technologies, Pittsburgh, PA) and gas volume (Rayfield Equipment, Watsfield, VT) using a computerized system. VO$_2$ was also measured prior to the test for VO$_2$peak while each participant stood motionless on the treadmill for 5 minutes. We define “reserve VO$_2$” as the difference between VO$_2$peak and VO$_2$ during standing. Reserve VO$_2$ is a reflection of capacity of increased oxygen consumption available for ambulation for an individual.

Skeletal muscle strength.—The strength of the hip extensor muscles was measured as previously described (13,14). Maximal dynamic force production was measured as the one repetition maximum (1-RM) using a Keiser pneumatic device (Keiser Sports Equipment, Inc., Fresno, CA).

Physical activity.—Overall level of daily physical activity was estimated using the Yale Physical Activity Survey (15).

Body composition.—Body weight and standing height without shoes were measured to determine body mass index. Body composition was measured using dual energy x-ray absorptiometry (Hologic, Inc., Waltham, MA).

O$_2$ cost of walking.—Energy expenditure was assessed during each participant’s self-selected habitual walking speed as well as during a standardized walking speed. Participants walked for 10 consecutive minutes on the treadmill at (a) the habitual gait speed measured during the SPPB and (b) a standard speed of 0.9 m/s. VO$_2$ was measured as described previously.

Statistics
Data are presented as mean ± SEM. Independent sample t tests were used to compare the data by sex and by highest and lowest tertile of walking speed. Multiple linear regression was used to examine associations between habitual walking speed and participant demographics, body composition, muscle strength, and related variables. A variety of regression models were developed in order to identify a model that explained the largest proportion of the variance in habitual walking speed. Standard plots of residuals, leverage, and other diagnostics were used to identify potential violations of the regression assumptions or the presence of unusual data points. No problems or issues were identified using these diagnostic techniques. Statistical analyses and graphs were completed using SPSS 12.0.0 (SPSS Inc., Chicago, IL).

Results
Participant characteristics are shown in Table 1. We recruited participants stratified by gender in order to achieve approximately equal representation of men and women, allowing us to examine whether any parameter related to habitual walking speed was also gender related. As expected, women had less lean mass (36.5 ± 0.9 vs 55.0 ± 1.2 kg, p < .001), less strength (719 ± 31 vs 1311 ± 69 N, p < .001), lower VO$_2$peak (17.3 ± 0.7 vs 22.7 ± 1.1 mL/kg/min, p < .001), and slower habitual walking speed (1.04 ± 0.04 vs 1.21 ± 0.04 m/s, p = .006) compared with men. However, habitual walking speed was strongly associated with VO$_2$peak even when controlling for gender (partial r = .69, p < .001).

Reserve VO$_2$ represents the metabolic capacity available for locomotion after accounting for the metabolic cost associated with standing and was calculated by subtracting the oxygen cost of standing on the treadmill (measured immediately prior to beginning the VO$_2$peak test) from VO$_2$peak. As shown in Figure 1, reserve VO$_2$ was strongly related to habitual walking speed (overall sample r = .744, p < .001). Habitual walking speed was also less strongly related to age (r = −.586, p < .001), strength (r = .561, p < .001), and lean
regression model included reserve VO\textsubscript{2}, age, total lean body mass, and 1-RM, with all other variables excluded from the model, as shown in Table 2. This final model explained approximately 57% of the variance in habitual gait speed in this population. Although the final model explained the greatest proportion of the variance in habitual gait speed, a simpler model containing even fewer variables (reserve VO\textsubscript{2} and age) was nearly identical, with a model adjusted R\textsuperscript{2} value of .566 (data not shown).

In an effort to further examine physiologic factors that may contribute to habitual walking speed, participants with the fastest and slowest tertiles of walking speed were compared. Characteristics of fastest and slowest walkers are shown in Table 3 along with independent analysis of male and female cohorts within these tertiles. Compared with the fastest walkers (n = 14), the slowest walkers (n = 25) were older (79.0 ± 1.9 vs 68.4 ± 1.6 years, p < .001) and shorter (164.8 ± 2.3 vs 171.8 ± 1.9 cm, p = .026) with less lean body mass (40.2 ± 2.8 vs 50.6 ± 2.6 kg, p = .011) and less strength (754 ± 71 vs 1277 ± 108 N, p < .001) but without a significant difference in body mass index (24.6 ± 1.2 vs 27.1 ± 0.9 kg/m\textsuperscript{2}, p = .094). Slower walkers also reported less physical activity during their daily routines than faster walkers (Yale Physical Activity Survey index score: 43.9 ± 5.1 vs 55.6 ± 4.7, p = .102). Slowest participants also tended to be female (11 females and 3 males) compared with the fastest participants (6 females and 12 males). Importantly, compared with faster participants, slower participants demonstrated reduced reserve VO\textsubscript{2} (12.1 ± 0.9 vs 20.1 ± 1.2 mL/kg/min, p < .001) and VO\textsubscript{2peak} (15.8 ± 0.9 vs 23.7 ± 1.2 mL/kg/min, p < .001) and therefore had a greater relative oxygen cost of walking at habitual pace (87.1% ± 6.5% vs 64.5% ± 2.9% of reserve VO\textsubscript{2}, p = .005), despite their significantly slower pace (0.87 ± 0.02 vs 1.37 ± 0.04 m/s, p < .001).
sustainably related to VO$_{2\text{peak}}$ people aged 68–85 years, habitual gait speed was significantly associated with VO$_{2\text{peak}}$. In a group of community-dwelling older adults aged 19–66 years (22). In a group of community-dwelling older men and women (21). As maximal aerobic capacity demonstrated to be predictive of 10-year mortality in elderly people (20). Fatigue has also been shown to be closely associated with VO$_{2\text{peak}}$. The principal finding of this study was the strong relationship between self-selected (habitual) walking speed and peak metabolic capacity (VO$_{2\text{peak}}$). The consequence of this relationship is that the intensity of walking among the slowest walkers was extremely high. On average, the slowest walkers utilized 87% of reserve VO$_2$ in order to maintain their habitual gait speed (compared with a relative intensity of 64% among those with the most rapid gait speed), similar to the intensity of well-trained aerobic athletes during competition (16). In addition, compared with the fast walkers, the rated perceived exertion of the slowest walkers at a relative intensity of 55% of VO$_{2\text{peak}}$, irrespective of fitness level (17), an intensity well below that of habitual walking speed seen in our participants. The data from the present study suggest that as aerobic capacity declines with age, walking at habitual speed becomes increasingly more intense and, therefore, difficult, resulting in a slowing of walking speed in an effort to reduce fatigue.

In nondisabled community-dwelling older people (age 74–80 years), fatigue measured as a feeling of “tiredness” was predictive of mobility disability (18,19) and an overall decline in functional capacity (20). Fatigue has also been demonstrated to be predictive of 10-year mortality in elderly men and women (21). As maximal aerobic capacity declines with advancing age, the relative oxygen cost of habitual gait increases. Habitual walking speed is significantly associated with VO$_{2\text{peak}}$ (and unrelated to age) in men aged 19–66 years (22). In a group of community-dwelling older people aged 68–85 years, habitual gait speed was significantly related to VO$_{2\text{peak}}$, leg strength, and body weight (23). In the present study, we found that the perception of exertion and feeling of fatigue during this walking test were closely associated with VO$_{2\text{peak}}$. That is, for many of these participants, the oxygen cost of walking at their habitual speed was a relatively large percentage of their reserve metabolic capacity (31% were more than 80% of reserve VO$_2$ and eight individuals were more than 90%), and for these individuals, 10 minutes of walking at their self-selected speed was exhausting. It is, therefore, likely that fatigue during walking is strongly linked to aerobic capacity, and reduced aerobic capacity results in a slowing of habitual walking speed to reduce the feeling of fatigue.

There are a number of factors associated with decreased VO$_{2\text{peak}}$ with advancing age. Skeletal muscle mass explains much of the variability in maximal aerobic capacity (24) among older people. The fact that VO$_{2\text{peak}}$ declines with advancing age at a greater rate than the decline in maximal heart rate (8) strongly suggests that factors related to skeletal muscle metabolism and function cause this loss. Short and coworkers (2) examined components of maximal aerobic capacity in 146 people between 18 and 89 years of age. They reported an average 8% reduction in VO$_{2\text{peak}}$ per decade along with a reduction in skeletal muscle mass with advancing age. Muscle mass was significantly associated with this reduction in VO$_{2\text{peak}}$. Reduced mitochondrial amount (measured by mitochondrial density) and function (measured by mitochondrial protein and oxidative capacity) were even more strongly associated with this age-associated decrease. Together, leg lean mass and mitochondrial function explained 86% of the decrease in VO$_{2\text{peak}}$. Changes in mitochondrial DNA that may result in reduced oxidative capacity have been linked to sarcopenia (25,26). Taken together, these data strongly support the hypothesis that reduced muscle oxidative capacity in elderly people results in fatigue during normal activities, particularly walking. Interestingly, there was a strong trend for greater levels of self-reported physical activity for the faster tertile of walkers, with no differences seen between faster and slower women, but an almost double the level of physical activity in faster compared with the slower men ($p = .035$). Therefore, declining aerobic capacity and muscle function act to

Table 2. Multiple Linear Regression Analysis of Factors Associated With Habitual Gait Speed (m/s) in Healthy Older Men and Women ($n = 49$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$</th>
<th>SE</th>
<th>Partial $r$</th>
<th>$p$ Value</th>
<th>Adjusted $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original model</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.300</td>
<td>0.459</td>
<td></td>
<td>.007</td>
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<tr>
<td>Reserve VO$_2$ (mL/kg/min)</td>
<td>0.023</td>
<td>0.007</td>
<td>0.475</td>
<td>.001</td>
<td></td>
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<tr>
<td>Age (y)</td>
<td>-0.006</td>
<td>0.003</td>
<td>-0.247</td>
<td>.111</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>-0.075</td>
<td>0.113</td>
<td>-0.103</td>
<td>.512</td>
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</tr>
<tr>
<td>Total fat (kg)</td>
<td>0.002</td>
<td>0.004</td>
<td>0.090</td>
<td>.568</td>
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<tr>
<td>Total lean (kg)</td>
<td>-0.008</td>
<td>0.007</td>
<td>-0.175</td>
<td>.263</td>
<td></td>
</tr>
<tr>
<td>1-RM (N)</td>
<td>0.0002</td>
<td>0.0001</td>
<td>0.202</td>
<td>.194</td>
<td></td>
</tr>
<tr>
<td>YPAS index score</td>
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<td>0.001</td>
<td>0.039</td>
<td>.805</td>
<td></td>
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<tr>
<td><strong>Final model</strong></td>
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<tr>
<td>Constant</td>
<td>2.615</td>
<td>0.692</td>
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<td>&lt;.001</td>
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<tr>
<td>Reserve VO$_2$ (mL/kg/min)</td>
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<td>0.014</td>
<td>0.496</td>
<td>&lt;.001</td>
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<tr>
<td>Age (y)</td>
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<td>-0.251</td>
<td>.092</td>
<td></td>
</tr>
<tr>
<td>Total lean (kg)</td>
<td>-0.009</td>
<td>0.009</td>
<td>-0.153</td>
<td>.309</td>
<td></td>
</tr>
<tr>
<td>1-RM (N)</td>
<td>0.0004</td>
<td>0.0003</td>
<td>0.204</td>
<td>.174</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Gender was coded as 0 = male and 1 = female. 1-RM = one repetition maximum; $\beta$ = unstandardized beta coefficient; VO$_2$ = oxygen uptake; reserve VO$_2$ = difference between the rate of oxygen uptake while standing and VO$_{2\text{peak}}$. YPAS = Yale Physical Activity Survey.
increase exertional fatigue in the elderly participants, which translates clinically into limited physical activities of daily living, a central component to independence and quality of life. It is also important to note that the majority of the slowest walkers were women and the majority of fast walkers were men. This is a reflection of the generally lower fitness and strength of older women versus older men and not a true gender-associated difference.

Poor functional capacity is a powerful predictor of a number of important outcomes in older people, including risk of mortality, hospitalization, nursing home admission, and dementia. Of all the components of mobility, gait speed...
is most closely related to these outcomes. Of the three components of the SPPB (habitual gait speed, standing balance, and chair stand speed), walking speed explains almost 80% of the variability in relationship between SPPB and subsequent risk of disability (6). In conclusion, these data suggest that the age-associated decrease in VO\textsubscript{2peak} results in an increased perception of exertion during habitual walking that results in a slowing of gait speed. However, longitudinal trials are needed to demonstrate the causes of loss of maximal aerobic capacity with advancing age and how this decline affects both gait speed and risk of disability. Elderly people are highly responsive to exercise interventions that can increase both VO\textsubscript{2peak} and strength. The extent to which these often observed adaptations to exercise affect walking speed and independence of elderly people has not been conclusively shown and, at the present time, can only be presumed.

ACKNOWLEDGMENT

We thank Patrick Savage and Grant Pahls for assistance with data collection and the study volunteers for their participation.

REFERENCES