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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, VO_{2peak} on a treadmill, VO_2 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. VO_{2peak} 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 = .102), and higher relative (to VO_{2peak}) intensity during walking at their habitual speed (65.3% ± 3.9% vs 54.3% ± 2.1% of VO_{2peak}, p = .013).

Conclusions. VO_{2peak} 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.

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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 (VO_{2peak}). 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. VO_{2peak} 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 VO_{2peak} 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 VO_{2peak} 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_{2peak}, 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_{2peak} 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 at 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, Waitsfield, VT) using a computerized system. VO_2 was also measured prior to the test for VO_{2peak} while each participant stood motionless on the treadmill for 5 minutes. We define "reserve VO_2" as the difference between VO_{2peak} 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_{2peak} (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_{2peak} 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_{2peak} test) from VO_{2peak}. 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

Table 1. Participant Characteristics for the Total Sample and by Sex

	All Participants (n = 49)	Women (n = 24)	Men (n = 25)	p Value
Age (y)	72.5 ± 1.2 (60–88)	74.5 ± 1.6	70.6 ± 1.8	.105
Body composition variables				
BMI (kg/m^2)	25.9 ± 0.5 (17.3–33.8)	24.7 ± 0.8	27.0 ± 0.6	.035
Body fat (%)	34.3 ± 1.0 (18.1–49.4)	39.2 ± 0.9	29.6 ± 0.9	<.001
Fat-free mass (kg)	45.9 ± 1.5 (29.1–66.5)	36.5 ± 0.9	55.0 ± 1.2	<.001
Physical function variables				
SPPB score	10.4 ± 0.2 (7–12)	10.0 ± 0.3	10.8 ± 0.3	.056
1-RM (N)	1021 ± 57 (451–2039)	719 ± 31	1311 ± 69	<.001
Habitual gait speed (m/s)	1.13 ± 0.03 (0.6–1.7)	1.04 ± 0.04	1.2 ± 0.04	.006
YPAS index score	47.6 ± 2.7 (21–99)	43.7 ± 3.0	51.3 ± 4.2	.155
VO_2 variables				
VO_2 standing (mL/kg/min)	3.5 ± 0.1 (2.4–4.5)	3.4 ± 0.1	3.5 ± 0.1	.529
VO_2 at 2 mph* (mL/kg/min)	9.2 ± 0.2 (6.6–12.6)	9.5 ± 0.3	9.0 ± 0.3	.209
VO_2 at habitual gait* (mL/kg/min)	11.2 ± 0.3 (6.8–16.0)	10.7 ± 0.4	11.6 ± 0.5	.194
VO_{2peak} (mL/kg/min)	20.1 ± 0.8 (11.3–36.5)	17.3 ± 0.7	22.7 ± 1.1	<.001

Notes: Data are mean ± *SEM* (range). 1-RM = one repetition maximum; BMI = body mass index; SPPB = Short Physical Performance Battery; YPAS = Yale Physical Activity Survey; VO_2 = oxygen uptake.

*Value measured at 10 minutes of exercise time.

body mass (r = .407, p = .004) but not significantly related to walking efficiency (VO_2 while walking at 0.9 m/s; r = −.167, p = .252).

A variable selection process was used to develop a multiple linear regression model that explained the relationship between habitual walking speed and measured study parameters. The initial model included the independent variables reserve VO_2 (milliliters per kilogram per minute), age (years), gender, total body fat mass (kilogram), total lean body mass (kilogram), 1-RM (Newton), and physical activity score. Nonsignificant independent variables were removed individually until the maximum proportion of the variance in habitual walking speed was explained. The final regression model included reserve VO_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_2 and age) was nearly identical, with a model adjusted R^2 value of .566 (data not shown).

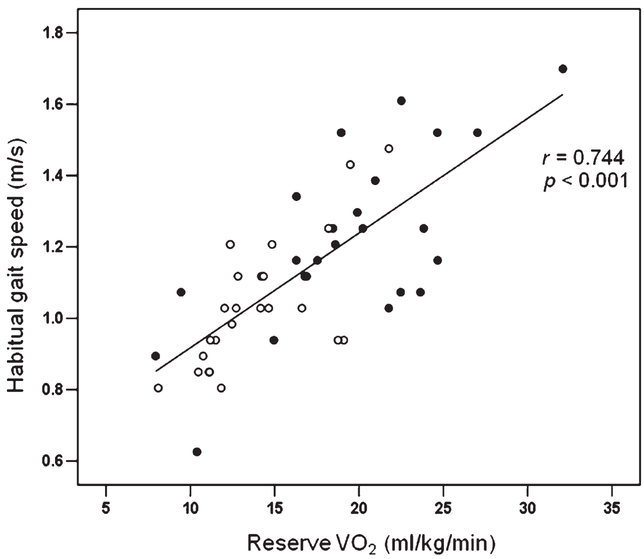

Figure 1. Association between habitual gait speed and reserve VO_2 in men (closed circles) and women (open circles). Reserve VO_2 was calculated by subtracting the rate of oxygen uptake while standing from VO_{2peak}.

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 = 18), the slowest walkers (n = 14) 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^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_2 (12.1 ± 0.9 vs 20.1 ± 1.2 mL/kg/min, p < .001) and VO_{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_2, p = .005), despite their significantly slower pace (0.87 ± 0.02 vs 1.37 ± 0.04 m/s, p < .001).

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

Variable	β	*SE*	Partial *r*	*p* Value	Adjusted R^2
Original model					
Constant	1.300	0.459	—	.007	
Reserve VO_2 (mL/kg/min)	0.023	0.007	0.475	.001	
Age (y)	−0.006	0.003	−0.247	.111	
Gender	−0.075	0.113	−0.103	.512	
Total fat (kg)	0.002	0.004	0.090	.568	
Total lean (kg)	−0.008	0.007	−0.175	.263	
1-RM (N)	0.0002	0.0001	0.202	.194	
YPAS index score	0.0003	0.001	0.039	.805	.540
Final model					
Constant	2.615	0.692	—	<.001	
Reserve VO_2 (mL/kg/min)	0.052	0.014	0.496	<.001	
Age (y)	−0.012	0.007	−0.251	.092	
Total lean (kg)	−0.009	0.009	−0.153	.309	
1-RM (N)	0.0004	0.0003	0.204	.174	.565

Notes: Gender was coded as 0 = male and 1 = female. 1-RM = one repetition maximum; β = unstandardized beta coefficient; VO_2 = oxygen uptake; reserve VO_2 = difference between the rate of oxygen uptake while standing and VO_{2peak}; YPAS = Yale Physical Activity Survey.

Discussion

The principal finding of this study was the strong relationship between self-selected (habitual) walking speed and peak metabolic capacity (VO_{2peak}). 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 relatively slow gait speed of 0.9 m/s was significantly greater. When asked to walk at a rapid pace, young men and women pace themselves at close to 55% of VO_{2peak}, 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_{2peak} (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_{2peak}, 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_{2peak}. 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_{2peak} with advancing age. Skeletal muscle mass explains much of the variability in maximal aerobic capacity (24) among older people. The fact that VO_{2peak} 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_{2peak} per decade along with a reduction in skeletal muscle mass with advancing age. Muscle mass was significantly associated with this reduction in VO_{2peak}. 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_{2peak}. 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 3. Comparison of Participants With Measured Habitual Gait Speeds in the Slowest and Fastest Tertiles of the Sample Plus Subgroup Analysis of Male and Female Participants Within These Tertiles

Variable		Slowest Walkers	Fastest Walkers	*p* Value
Habitual gait speed (m/s)		0.87 ± 0.02	1.37 ± 0.04	<.001
	M	0.82 ± 0.10	1.40 ± 0.05	<.001
	F	0.89 ± 0.02	1.30 ± 0.05	<.001
Age (y)		79.0 ± 1.9	68.4 ± 1.6	<.001
	M	83.0 ± 3.5	67.8 ± 2.1	.006
	F	77.9 ± 2.2	69.8 ± 2.2	.032
Body weight (kg)		67.5 ± 4.7	80.4 ± 3.4	.030
	M	89.4 ± 8.3	86.4 ± 3.5	.711
	F	61.5 ± 4.0	68.5 ± 4.9	.304
Height (cm)		164.8 ± 2.3	171.8 ± 1.9	.026
	M	176.3 ± 2.7	175.9 ± 1.8	.906
	F	161.7 ± 1.9	163.8 ± 2.3	.515
Total body fat (kg)		23.5 ± 2.2	25.3 ± 1.5	.486
	M	26.9 ± 4.9	24.3 ± 1.8	.552
	F	22.5 ± 2.5	27.1 ± 2.9	.261
Total lean body mass (kg)		40.2 ± 2.8	50.6 ± 2.6	.011
	M	57.3 ± 3.0	56.9 ± 1.9	.931
	F	35.5 ± 1.5	37.9 ± 2.0	.351
VO_{2peak} (mL/kg/min)		15.8 ± 0.9	23.7 ± 1.2	<.001
	M	15.1 ± 2.0	25.5 ± 1.4	.004
	F	16.0 ± 1.0	20.0 ± 1.6	.041
VO_2 at 0.9 m/s (mL/kg/min)*		9.8 ± 0.4	9.1 ± 0.3	.114
	M	10.0 ± 0.8	9.0 ± 0.4	.242
	F	9.8 ± 0.5	9.1 ± 0.4	.395
RPE at 0.9 m/s*		12.4 ± 0.7	9.3 ± 0.4	<.001
	M	12.3 ± 1.2	9.0 ± 0.5	.009
	F	12.4 ± 0.8	10.0 ± 1.0	.103
VO_2 at habitual gait speed (mL/kg/min)*		10.0 ± 0.5	12.6 ± 0.5	.001
	M	10.1 ± 0.8	12.7 ± 0.6	.065
	F	10.0 ± 0.6	12.4 ± 0.9	.040
RPE at habitual gait speed*		12.1 ± 0.6	11.6 ± 0.4	.472
	M	13.3 ± 1.5	11.1 ± 0.4	.055
	F	11.8 ± 0.7	12.7 ± 1.0	.466
VO_2 at habitual gait speed relative to VO_{2peak} (%)		65.3 ± 3.9	54.3 ± 2.1	.013
	M	68.9 ± 10.3	50.2 ± 1.6	.206
	F	64.3 ± 4.3	62.7 ± 3.6	.808
VO_2 at habitual gait speed relative to reserve VO_2 (%) M		87.1 ± 6.5	64.5 ± 2.9	.005
	M	96.9 ± 19.8	58.3 ± 1.9	.190
	F	84.4 ± 6.7	76.9 ± 5.0	.452
Reserve VO_2 (mL/kg/min)		12.1 ± 0.9	20.1 ± 1.2	<.001
	M	11.1 ± 2.1	22.0 ± 1.3	.002
	F	12.4 ± 1.0	16.5 ± 1.6	.039
1-RM (N)		754 ± 71	1277 ± 108	<.001
	M	1160 ± 75	1528 ± 94	.084
	F	644 ± 47	777 ± 66	.121
YPAS index score		43.9 ± 5.1	55.6 ± 4.7	.102
	M	31.0 ± 7.2	62.7 ± 5.6	.021
	F	47.4 ± 5.8	41.5 ± 4.6	.502

Notes: Data are mean ± *SEM* (range). 1-RM = one repetition maximum; *F* = female cohort; *M* = male cohort; VO_2 = oxygen uptake; RPE = rating of perceived exertion (12); reserve VO_2 = difference between the rate of oxygen uptake while standing and VO_{2peak}; YPAS = Yale Physical Activity Survey. Slowest walkers, *n* = 14 (3 males and 11 females); fastest walkers, *n* = 18 (12 males and 6 females).

*Value measured at 10 minutes of exercise time.

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_{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_{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.

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