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Abstract

Objective

Slow walking speed paired with increased energy cost is a strong predictor for mortality and disability in older adults but has yet to be examined in a heterogeneous sample (ie, age, sex, disease status). The aim of this study was to examine energy cost of slow and normal walking speeds among low- and normal-functioning adults.

Design

Adults aged 20–90 yrs were recruited for this study. Participants completed a 10-m functional walk test at a self-selected normal walking speed and were categorized as low functioning or normal functioning based on expected age- and sex-adjusted average gait speed. Participants completed two successive 3-min walking stages, at slower than normal and normal walking speeds, respectively. Gas exchange was measured and energy cost per meter (milliliter per kilogram per meter) was calculated for both walking speeds.

Results

Energy cost per meter was higher ($P < 0.0001$) in the low-functioning group ($n = 76$; female = 59.21%; mean ± SD age = 61.13 ± 14.68 yrs) during the slower than normal and normal ($P < 0.0001$) walking speed bouts compared with the normal-functioning group ($n = 42$; female = 54.76%; mean ± SD age = 51.55 ± 19.51 yrs).

Conclusions

Low-functioning adults rely on greater energy cost per meter of walking at slower and normal speeds. This has implications for total daily energy expenditure in low-functioning, adult populations.

Keywords:

Mobility, Energy Expenditure, Walking Speed, Usual Gait Speed

Low physical function can impede successful ambulation or engagement in activities of daily living.[1] A common measure of ambulation, or physical mobility, is preferred (self-selected) gait speed.[2] Slower preferred gait speed has been linked to poor health, increased chronic disease risk, increased mortality risk in older adults,[3] and is a strong predictor of disability,[4] consequently being dubbed the “sixth vital sign.”[5] It has been shown that energy cost of walking tends to increase with decreased gait speed and with increased age.[1,6–9] It is purported that individuals with functional limitations select slower walking speeds to conserve energy and reduce fatigue because of the increased effort of ambulation.[1,7,10] For the sake of this article, “low functioning” (LF) will refer to a self-selected, usual walking speed less than a designated threshold. Typically, a gait-speed less than 1.0 m sec^{-1} is considered a clinical threshold for increased risk of mortality.[11]

Several studies have investigated differences in energy cost of treadmill walking at an assigned speed, between young and old populations, as well as fit and unfit individuals.[1,2,7,9] Schrack et al.[7] (2013) found that energy cost of walking in unfit individuals was significantly higher than fit individuals across a wide age range and that older adults exhibited a more dramatic, inverse relationship between gait speed, and energy cost. Similarly, Richardson et al.[1] (2014) reported that among older adults (70–89 yrs), fast walkers exhibited a lower energy cost when walking at a standardized and self-selected speed on a treadmill compared with slow walkers. These findings suggest that slower self-selected gait speed is associated with increased age and decreased function, which can affect physical fitness.

This phenomenon also occurs within clinical populations. A study by Motl et al.[10] (2012) reported lower self-selected gait speed associated with higher energy cost within individuals with multiple sclerosis. Similarly, stroke patients exhibited higher energy cost per meter at a self-selected walking speed compared with a healthy control.[12] Research suggests that individuals with lower body impairments, such as stroke patients, will experience increased energy expenditure per unit of distance because of altered gait mechanics.[13] However, the degree of disability varies for every disease condition and not every individual will display an altered gait. Therefore, the aim of this study was to extend scientific understanding in this area by examining the energy cost of slow and normal overground walking speeds among a broad group of LF and normal-functioning (NF) adults. It was hypothesized that LF adults would display a higher energy cost at slow and normal overground walking speeds compared with NF adults, despite slower self-selected speeds.

METHODS

Participants

This cross-sectional study was part of a larger study, which spanned two visits. The primary aim for the larger study was to create a series of tests to fit people into functional categories to better monitor their physical activity behaviors based on upper and lower body functional limitations. Participants were recruited based on the following inclusion criteria: (*a*) 20–90 yrs old, (*b*) able to walk 10 f. unassisted, (*c*) no chronic hip/low back pain that precludes activity or lying supine for 40 mins, (*d*) ability to consent, (*e*) no previous head trauma, (*f*) free of uncontrolled medical conditions (ie, hypertension), (*g*) free of any metabolic diseases (ie, diabetes or thyroid disease), (*h*) free of any contraindications to contracting the hip, knee, or ankle (ie, torn tendons or stress fractures), and (*i*) a resting blood pressure below 160/100 mm Hg. Participants were also recruited if they had any conditions (based on self-report) that could affect upper or lower body function. This included stroke, a diagnosis of Parkinson disease, a diagnosis of multiple sclerosis, arthritis, and any other movement limitations in the arms or legs (self-identified as LF). Individuals who were considered otherwise healthy and had no physical limitations were also recruited for comparison purposes. Participants were recruited from the community via telephone inquiry, flyers, and word of mouth. Upon providing written consent to the procedures approved by the internal review board at a large, urban university, participants completed the study protocol. All measurements took place in a laboratory and surrounding area on the university campus.

Measures

Participant Characteristics

Participants completed demographic and health history questionnaires. Anthropometric measures were collected at the beginning of the first visit, before which participants were asked to remove any outer layers, empty pockets, and remove shoes. Height was recorded to the nearest quarter of an inch using a manual stadiometer (Detecto, Webb City, MO) and weight to the nearest quarter of a pound using a standard physician's scale (Detecto). Height and weight were converted to kilogram and centimeter, respectively, and body mass index (BMI, kilogram per square meter) was calculated.

Resting Metabolic Rate

Resting metabolism was measured using standard procedures.[14] Participants did not consume food or calorie-containing beverages for 8–12 hrs, engage in exercise for 12 hrs, or ingest caffeine, stimulants, or drugs for 4 hrs before the test. Participants rested quietly on their backs for 10 mins on an examination table. Once rested, the hood was placed over the participant and gas exchange was measured for 20–30 mins (Parvo Medics TrueOne

2400; Parvo Medics, Sandy, UT). A minimum of 10 min of steady state values were required before ending the test.

Functional Testing

A 10-m functional walk test determined usual gait speed. Upon the command "go," participants walked 10-m at their usual walking pace. The test was administered on a flat, noncarpeted surface. Time to completion was recorded in seconds, and gait speed was calculated as meter per second. To account for acceleration and deceleration, only the middle 6 m were timed. Participants repeated the test two more times for a total of three trials. Three trials were then completed at a maximal walking speed. The average speed was calculated for each condition, usual and maximal walking speed, respectively.

Measurement of Energy Cost of Walking

Energy cost assessment took place during two consecutive 3-min walking bouts on a flat surface (overground walking test). Participants walked at a self-selected slower than normal walking speed (ie, slower than usual walking speed) for the first stage and a self-selected normal speed for the second stage. Distance in meters was recorded using a distance wheel (Pittsburgh 10,000 Ft./Meter Digital Measuring Wheel). To avoid influencing the participant's walking speed, researchers trailed the participant.

During the overground walking test, participants wore a portable metabolic unit ($K4b^2$; Cosmed, Rome, Italy) that analyzed oxygen consumption. Participants were fitted with a mask and harness to hold the unit. This metabolic unit has previously been validated against the traditional Douglas bag method and has been shown to be an acceptable method of measuring gas exchange.[15]

Data Reduction

The result of the 10-m walk test was dichotomized to whether a participant's performance was classified as "NF" or "LF." Linear regression, using the 10-m walk test results from the self-identified healthy individuals, and adjusted for age and sex, determined the expected mean value of the 10-m walk test. With the expected mean value and the root mean square error from the linear regression model, and each participant's 10-m walk result, a z-score was calculated for each participant. If the z-score for a participant was greater than one standard deviation worse than the age- and sex-adjusted expected value for either 10-m walking condition, they were categorized into the LF group (Fig. 1). Before analyzing walking energy expenditure, relative resting oxygen consumption was accounted for.

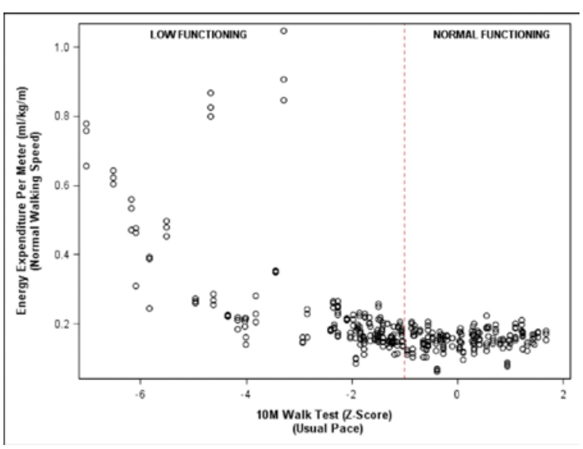

FIGURE 1: Sample distribution of the dichotomization based on the usual speed 10-m z-score. Individuals who fell to the left of −1 standard deviation were classified as LF. For all walking conditions, individuals in the LF group exhibited a higher energy cost per meter compared with the NF group.

Energy expenditure was assessed by using the final minute of each walking stage to account for physiological steady state. Energy cost per meter (milliliter per kilogram per meter) was determined for both self-selected speeds during the overground walking test by dividing the average energy cost for each minute divided by the number of meters covered.

Statistical Analysis

Statistical analysis was performed using SAS 9.4 (Cary, NC). Continuous variables were summarized as mean ± standard deviation, and categorical variables were summarized as frequencies and percentages. The χ^2 test of association compared discrete characteristics with regard to the normal paced 10-m walk test. Comparison of continuous characteristics for the normal 10-m test was completed using the independent sample *t* test. Energy cost was tested for normality using the Kolmogorov-Smirnov test and was found to deviate significantly from normality. Thus, a Box-Cox transformation was used to normalize the energy cost variable. Hierarchal regression determined whether the energy cost was significantly different between the two groups after controlling for age, sex, and BMI. Finally, residual analysis was performed and no significant model violation was identified.

RESULTS

Participant Characteristics

The final sample size consisted of 118 men and women (age = 57 ± 17.1 yrs; height = 168.1 ± 9.4 cm; weight = 78.1 ± 18.0 kg; BMI = 27.6 ± 5.9 kg/m^2; female = 57.6%). The 10-m prediction equation was as follows: 10-m (m/sec) = 1.64598–0.00099994Age − 0.03664Male. This resulted in 42 participants falling under the NF classification and 76 participants falling under the LF classification. Of note, some individuals who had self-identified as "healthy" were categorized as "LF," and conversely, there were some individuals who self-identified as having a pre-existing health condition that fell into the "NF" category. Participant characteristics are found in Table 1. The LF group tended to be older (LF = 61.1 ± 14.7 yrs *vs.* NF = 51.6 ± 19.5 yrs; $P = 0.006$) and were more likely to be from the stroke (LF = 100% *vs.* NF = 0%; $P < 0.001$) or arthritis (LF = 84.2% *vs.* NF = 15.8%; $P = 0.049$) groups, respectively.

TABLE 1: Participant characteristics

	Overall (*N* = 118)	LF Group (*n* = 76; Female = 45)	NF Group (*n* = 42; Female = 23)	*P*
Age, yr	57.72 ± 17.11	61.13 ± 14.68	51.55 ± 19.51	0.0057*
Height, cm	168.17 ± 9.37	167.61 ± 9.40	169.19 ± 9.34	0.4344
Weight, kg	78.08 ± 17.96	79.65 ± 18.72	75.23 ± 16.34	0.2512
BMI, kg/m^2	27.56 ± 5.89	28.35 ± 6.20	26.13 ± 5.06	0.0547
Condition breakdown:				
Stroke	*n* = 19	*n* = 19 (100.0%)	*n* = 0 (0.0%)	<0.001*
MS	*n* = 18	*n* = 14 (77.8%)	*n* = 4 (22.2%)	0.1981
PD	*n* = 17	*n* = 13 (76.5%)	*n* = 4 (23.5%)	0.2615
Arthritis	*n* = 34	*n* = 26 (84.2%)	*n* = 8 (15.8%)	0.0490*
Low function	*n* = 2	*n* = 2 (100.0%)	*n* = 0 (0.0%)	0.2890
Energy cost, ml/kg/m				
Slower than normal walking speed	0.25 ± 0.16	0.28 ± 0.19	0.18 ± 0.03	<0.0001*
Normal walking speed	0.21 ± 0.13	0.24 ± 0.16	0.16 ± 0.03	<0.0001*
10-m walk test, m/sec				
Usual pace	1.33 ± 0.36	1.16 ± 0.32	1.65 ± 0.14	<0.0001*
Fast pace	1.94 ± 0.66	1.63 ± 0.57	2.50 ± 0.40	<0.0001*

Data presented as mean ± SD.

*Significant difference between LF and NF groups.
MS, multiple sclerosis; PD, Parkinson disease.

Gait Speed and Energy Cost

Self-selected usual gait speed for the 10-m walk test was 1.16 ± 0.32 m/sec and 1.65 ± 0.14 m/sec for the LF and NF groups, respectively. Energy cost per meter (milliliter per kilogram per meter) during the overground walking test was greater in the LF group. During the slower than normal walking condition, the NF group had a lower energy cost per meter (0.18 ± 0.03 ml/kg/m) than the LF group (0.28 ± 0.19 ml/kg/m; $P < 0.001$). Similarly, during the normal walking condition the NF group had a lower energy cost per meter (0.16 ± 0.03 ml/kg/m) than the LF group (0.24 ± 0.16 ml/kg/m; $P < 0.001$) (Fig. 2). Both groups exhibited a higher energy cost at a slower walking speed *vs.* the normal walking speed stage. Significant determinants of energy cost for both walking conditions were 10-m test performance, age, sex, and BMI. These results (transformed) are presented in Table 2 and a correlation table of the full sample is presented in Table 3.

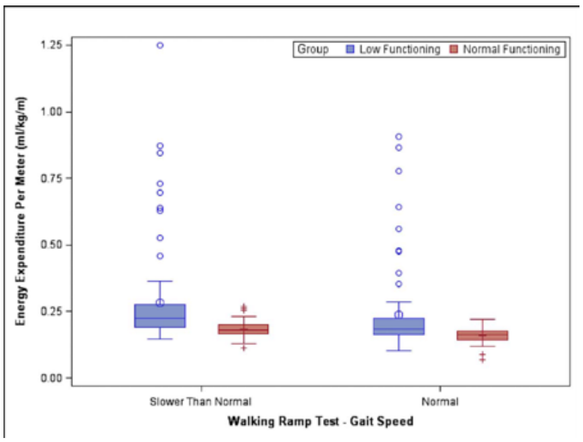

FIGURE 2: Energy cost per meter (milliliter per kilogram per meter) during the slower than normal and normal self-selected walking speeds, compared between groups. Energy cost is higher in the LF group during both walking conditions, compared with the NF group ($P < 0.0001$).

TABLE 2: Results from multiple regression models

	Energy Cost: Slower Than Normal Walking Speed			Energy Cost: Normal Walking Speed		
Parameters	EST	SE	*P*	EST	SE	*P*
Model 1						
Intercept	−3.9708	0.4993	<0.0001	−4.5991	0.6851	<0.0001
Age	0.0153	0.0054	0.0056	0.0079	0.0075	0.2947
Female	0.0908	0.1844	0.6236	0.1632	0.2526	0.5197
BMI	0.0058	0.0158	0.7151	0.0106	0.0218	0.6244
		R^2 = 0.0798			R^2 = 0.0195	
Model 2						
Intercept	−3.9382	0.4665	<0.0001	−4.5621	0.6417	<0.0001
10-m walk test*	0.7687	0.1860	<0.0001	1.0282	0.2549	0.0001
Age	0.0101	0.0052	0.0542	0.0010	0.0072	0.8860
Female	0.0587	0.1725	0.7342	0.1221	0.2368	0.6071
BMI	−0.0020	0.0149 R^2 = 0.2044	0.8926	0.0002	0.0204 R^2 = 0.1478	0.9916

*Reference: 10-m performance in the NF group.
EST, unstandardized β.

TABLE 3: Full correlation table

	Overall		LF Group		NF Group	
	Energy Cost		Energy Cost		Energy Cost	
Variables	Slower Than Normal Speed	Normal Speed	Slower Than Normal Speed	Normal Speed	Slower Than Normal Speed	Normal Speed
10-m walk test (Ref: normal function)	**0.43**	**0.39**	NA	NA	NA	NA
Age	**0.27**	0.11	0.19	0.08	0.18	-0.07
Female	0.07	0.07	0.14	0.09	-0.21	0.01
BMI	0.08	0.07	0.11	0.12	**-0.34**	-0.28

Bolded values are significant, $P < 0.05$.
NA, not available.

DISCUSSION

The aim of this study was to investigate the differences in energy cost for two different, self-selected walking speeds, between NF and LF adults. The primary finding was that when controlling for age, sex, and BMI, individuals categorized as LF had a significantly higher energy cost per meter at both a slower than normal and normal self-selected, overground walking speed compared with the NF group.

This finding has important implications for understanding total daily energy demands in LF groups compared with NF groups and adds to previous findings by Schrack et al.,[7] (2013) who reported higher energy cost of walking at a set speed with increased age. Research suggests that adults from special populations acquire an estimated 3500–5500 steps per day (approximately 1.5–2.75 mile/d).[16] By extrapolating energy cost per meter walked data from the current study, we can estimate that adults in the LF group will burn an estimated 180.0 kcals and 152.1 kcals/mile at a self-selected slower than normal and normal walking speed, respectively. Over a day (approximately 1.5–2.75 mile/d), this equates to 270–495 kcals (slower than normal pace) to 228–418 kcals (normal pace) because of ambulation alone. The NF group, by extrapolated comparison, uses about half the energy (approximately 166–304 [slower than normal pace] to 145.2–266 kcals [normal pace]) to cover the same distance at the same self-selected speeds. This represents a substantial difference in energy expenditure, up to 162% higher for a slower than normal pace and 175% higher for the normal pace in the LF group compared with the NF group. This could potentially contribute to the lower daily step count seen in LF adults. The potential consequence to this difference in energy cost data is reducing self-selected gait speed to minimize perceived effort and conserve energy,[1,7,10] which actually requires more energy.

The relationship between reduced gait speed and increased energy expenditure is not fully understood. It is established that slower gait speed is associated with older age[2,7,8] and certain clinical populations.[9,12] This is likely due to several factors, including altered gait, which will influence the energy cost of walking.[17] Although there is a significant difference in age between the LF and NF groups in the present study, age was controlled for in the analysis, and energy cost was significantly higher at both walking speeds for the LF group. Further comparison of the two groups shows that most individuals who self-reported a condition fell into the LF group (~82%). It is plausible that many of these individuals walk with an altered gait, thus increasing energy cost at the two self-selected walking speeds. Individuals in the stroke, multiple sclerosis, and Parkinson groups (~62% of individuals in LF group with a self-reported condition) are likely experiencing some metabolic abnormalities, resulting in increased energy cost. For example, individuals with multiple sclerosis have been shown to have impaired skeletal muscle oxidative capacity.[18] It is likely that the combination of altered gait biomechanics and inefficient oxidative metabolism result in the increased energy cost per meter in some LF adults.

One limitation of this study is the lack of maximal oxygen consumption data on the sample. Maximal oxygen consumption data would allow for a comparison of relative intensity for both walking speeds between the LF and NF groups. At this time, we can only speculate that the LF groups were using a higher percentage of their maximal oxygen consumption at both walking speeds as reflected by the higher energy cost of the walking activities based on previous research.[1] A second limitation is that the cutoff to be characterized as LF is based on normative data within this small sample. Future studies should consider larger sample sizes to allow for greater generalization of results. Finally, slower gait speeds are typically selected as a strategy to preserve energy,[6,9] but in some cases, energy cost is higher despite the attempt to preserve energy cost. Evidence suggests that exercise interventions can have a positive impact on gait speed in healthy, older adults,[19,20] as well as frail, older adults,[21] but future investigations should focus on how exercise affects gait speed in adults exhibiting neurological or metabolic conditions.

In conclusion, this study supports an intersection between functionality and energy cost, in that LF adults rely on greater energy cost per meter of walking at both slower and normal self-selected walking speeds. This finding highlights the potential for a downward spiral between function and health in individuals displaying increased energy cost with a slower self-selected gait speed. Specifically, increased cost of usual activities, such as walking, could dissuade individuals from engaging in regular physical activity. Less movement throughout the day can negatively impact mobility; thus, the spiral continues. This phenomenon has major implications for independence, health care, and mortality risk. Future studies should seek to clarify this phenomenon of increased energy cost despite a slower self-selected walking speed and look at targeted interventions to improve energy cost efficiency in such populations.

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