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Brief Report

Walking Smoothness Is Associated With Self-Reported Function After Accounting for Gait Speed

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Background. Gait speed has shown to be an indicator of functional status in older adults; however, there may be aspects of physical function not represented by speed but by the quality of movement. The purpose of this study was to determine the relations between walking smoothness, an indicator of the quality of movement based on trunk accelerations, and physical function.

Methods. Thirty older adults (mean age, 77.7 ± 5.1 years) participated. Usual gait speed was measured using an instrumented walkway. Walking smoothness was quantified by harmonic ratios derived from anteroposterior, vertical, and mediolateral trunk accelerations recorded during overground walking. Self-reported physical function was recorded using the function subscales of the Late-Life Function and Disability Instrument.

Results. Anteroposterior smoothness was positively associated with all function components of the Late-Life Function and Disability Instrument, whereas mediolateral smoothness exhibited negative associations. Adjusting for gait speed, anteroposterior smoothness remained associated with the overall and lower extremity function subscales, whereas mediolateral smoothness remained associated with only the advanced lower extremity subscale.

Conclusion. These findings indicate that walking smoothness, particularly the smoothness of forward progression, represents aspects of the motor control of walking important for physical function not represented by gait speed alone.

Key Words: Gait—Motor control—Physical function.

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GAIT speed has shown to be an indicator of functional status and survival in older adults (1). Although informative, gait speed alone offers limited insight into the quality of whole body motion. Smoothness of walking, quantified by harmonic ratios (HRs), measures the symmetry and repeatability of trunk accelerations in anteroposterior (AP), vertical, (VT) and mediolateral (ML) directions, and has been proposed as a quality indicator of the motor control of walking (2). According to studies that have simultaneously examined gait speed and smoothness, these measures provide different information about walking ability (2–5). Together, the findings illustrate that some older adults may walk slower with "good" control or control similar to young adults; and some may walk at normal speeds with altered control.

Gait is a major component of many daily physical function activities and an important factor in independence in older adults. Although faster gait speeds have been associated with better function (6–8), there may be aspects of physical function not represented by speed but by the quality of control. The purpose of this study was to determine the relations between smoothness and function. If smoothness is related to function, and more importantly, if smoothness is related to function independent of gait speed, this would suggest smoothness represents aspects of the motor control of walking important for physical function not represented by gait speed alone.

Methods

Participants

Thirty older adults (>65 years old), identified from a longitudinal study of mobility, were included in this observational study. Participants were independent in ambulation without an assistive device. The exclusion criteria for participation in the longitudinal study included the presence of (i) neuromuscular disorders that impair movement, (ii) cancer with active treatment, (iii) a life-threatening illness or major surgical procedure in the past

6 months, (iv) need of supplemental oxygen, and (v) chest pain with activity. The goal of this observational study was to enroll older adults with a range of mobility: 10 individuals with poor to fair mobility (defined as gait speed <0.80 m/s), 10 individuals with good mobility (defined as gait speed 0.80–1.0 m/s), and 10 individuals with very good mobility (defined as gait speed >1.0 m/s). We included the first 10 individuals by order of enrollment in the parent study to meet the group criteria for poor to fair mobility, the first 10 to meet the good mobility criteria, and the first 10 to meet the very good mobility group criteria. The Institutional Review Board at the University of Pittsburgh approved this study, and all participants provided written informed consent prior to their participation.

Demographics and Comorbidity

Baseline demographics and health status were collected by questionnaire. The Comorbidity index (9) was used to quantify health status; higher numbers indicate a greater number of comorbidities.

Gait Measures

Usual gait speed and spatiotemporal characteristics.—Participants walked at their preferred speed on the GaitMat II 4-m instrumented walkway, with 2-m noninstrumented sections at either end to allow for acceleration and deceleration. Each participant completed two walks and all spatiotemporal characteristics were averaged. Gait speed has demonstrated test–retest reliability (Intraclass correlation coefficient [ICC] = .98) (10) and predictive validity for mobility disability (11).

Smoothness.—Smoothness of walking was quantified by HRs derived from AP, VT, and ML trunk accelerations using a triaxial accelerometer (BIOPAC Systems, Inc., Santa Barbara, CA) secured over the third lumbar spine vertebra. Trunk accelerations were sampled at 100 Hz and were recorded using wireless technology during a single trial of overground, straight-path walking (12.2 m) at usual speed. A footswitch system was used to determine heel contact events for stride segmentation. HRs were determined per stride and averaged across strides resulting in a mean HR for each direction of motion. HR theory and calculation has been previously described (12–14). HRs are used to characterize the complex acceleration trajectories for each direction of motion as a single value for a given stride by quantifying the deviation from an ideally symmetrical acceleration pattern; higher HRs are interpreted as greater walking smoothness. Trunk accelerometric gait analysis has shown high test–retest reliability, with $ICC_{3,1}$ values ranging from .77 to .96 (15,16) and high stride-to-stride reliability for trunk acceleration signals across a range of walking speeds (17).

Function Measure

Late-Life Function and Disability Instrument, function component.—The function component of the Late-Life Function and Disability Instrument is an instrument used to record self-reported physical functioning of older adults and includes 32 activities categorized as upper extremity, basic lower extremity, or advanced lower extremity activities. The basic lower extremity subscale involves standing and fundamental walking activities (eg, washing dishes while standing, walk around one floor of home), whereas the advanced lower extremity subscale includes activities that require a higher level of physical ability and endurance (going up and down a flight of stairs without a handrail, walking several blocks). All subscales have a 0–100 range, with higher scores indicating better function (ICC = .91–.98) (18).

Data Analyses

We used descriptive statistics to summarize participant characteristics and variables of interest. First, we used unadjusted Pearson correlations (r) and linear regression models with each measure of function as the dependent variable and each measure of smoothness as the only independent variable to examine associations between smoothness and function. Next, we repeated the analyses using partial correlations (r_p) controlling for gait speed and linear regression models with gait speed as an additional independent variable to examine associations of smoothness with function independent of gait speed. We interpreted level of statistical significance of correlations (r, r_p) and regression coefficients (β) for smoothness as strength of evidence of associations between smoothness and functional outcomes in this initial investigation. We examined, on a post hoc exploratory basis, associations of smoothness and gait speed with individual ordinal items of interest from the function scales using Spearman's rank correlation coefficients (r_s), and associations of smoothness and spatiotemporal gait variables using Pearson's correlation coefficients.

Results

Participant Characteristics

The mean age was 77.7 years (*SD* = 5.1), 77% were women (Table 1). Mean usual gait speed was 1.00 m/s (range: 0.47–1.53), which is slower than usual adult speed of 1.2–1.4 m/s (19) but comparable with average walking speeds reported for community-dwelling older adults, which range from 0.60 to 1.45 m/s (20). Mean Late-Life Function and Disability Instrument function scores were similar to previous values reported for a sample of nonmobility limited community-dwelling older adults (8); however, there was a wide range of scores (Table 1).

Associations Between Smoothness and Function

As expected, gait speed was positively associated with overall function (r = .78, p < .001), basic lower extremity function (r = .73, p < .001), advanced lower extremity function (r = .81, p < .001), and upper extremity function (r = .43, p = .015). AP smoothness was positively associated with overall function, basic lower extremity function, advanced lower extremity function (all p < .001), and upper extremity function (p = .045; Table 2). Controlling for usual gait speed attenuated the relationship between the AP smoothness and function; however, AP smoothness remained related to all subscales of function independent of gait speed except the upper extremity subscale. For example, a unit increase in smoothness was associated with an 8.8 point improvement (r = .68, β = 8.82, p < .001) in overall function; controlling for gait speed, a unit increase in smoothness was associated with a 4.4 point improvement (r_p = .45, β = 4.43, p = .029) in function. Vertical smoothness was positively associated only with basic lower extremity function (p = .034) and the relationship persisted independent of usual gait speed (p = .039). ML smoothness was negatively associated with overall function (p = .011), basic lower extremity function (p = .046), advanced lower extremity function (p = .002), and upper extremity function (p = .043). ML smoothness remained negatively associated with advanced lower extremity function independent of gait speed (p = .012).

From the exploratory post hoc analyses, AP smoothness was associated with a majority of individual function items; the highest correlations were for the following activities: negotiating a flight of stairs without a handrail (r_s = .78), running to catch a bus (r_s = .73), getting in/out of a car (r_s = .71), getting on and off a bus (r_s = .68), stepping up and down from a curb (r_s = .64), and on and off a step stool (r_s = .60).

The patterns of associations for AP and ML smoothness with spatiotemporal variables differed. AP smoothness was positively associated with gait speed (r = .59 p = .001) and step length (r = .55, p = .003). Conversely, ML smoothness was negatively associated with both speed (r = −.40, p = .043) and step length (r = −.39, p = .049). Although not statistically significant, AP and ML smoothness were negatively associated with each other (r = −.21, p = .285).

Table 1. Participant Characteristics

Variable	Mean (*SD*)	Range
Age, y	77.7 (5.1)	68–86
Women, %	77	
Comorbidity index (0–18)	4.2 (2.0)	0–8
LLFDI, function component (0–100)		
Overall function score	60.2 (10.4)	41–82
Basic lower extremity subscale	71.8 (14.7)	48–100
Advanced lower extremity subscale	50.0 (17.0)	11–82
Upper extremity subscale	76.0 (12.0)	43–100
Usual gait speed, m/s	1.00 (0.27)	47–1.53
Harmonic ratio		
Anteroposterior	2.46 (0.81)	1.09–3.93
Vertical	3.83 (1.27)	2.08–7.19
Mediolateral	2.73 (0.98)	1.39–4.98

Note: LLFDI = Late-Life Function and Disability Instrument.

Discussion

We demonstrated that walking smoothness, particularly AP and ML smoothness, was related to all components of function, and the relation of AP smoothness with function was independent of gait speed. These findings support the premise that smoothness represents aspects of the motor control of walking important for physical function not represented by gait speed alone.

Of the three directions of smoothness, AP smoothness had the highest associations with function; greater smoothness was associated with better function. AP smoothness measures the symmetry and repeatability of trunk accelerations during forward progression of the body. Symmetrical and repeatable forward trunk accelerations emerge from the precise timing and coordination of forces occurring particularly at the

Table 2. Associations Between Smoothness and Function Independent of Gait Speed

	Late-Life Function and Disability Instrument							
	Overall function		Basic lower extremity function		Advanced lower extremity function		Upper extremity function	
Independent Variables	β (*SE*)	r, r_p	β (*SE*)	r, r_p	β (*SE*)	r, r_p	β (*SE*)	r, r_p
Anteroposterior harmonic ratio								
Unadjusted	8.82 (1.96)**	.68	12.48 (2.73)**	.69	14.17 (3.23)**	.68	6.00 (2.84)*	.40
Adjusted for gait speed	4.43 (1.90)*	.45	7.27 (2.89)*	.47	6.44 (2.97)*	.42	3.37 (3.46)	.20
Vertical harmonic ratio								
Unadjusted	2.74 (1.62)	.33	4.93 (2.18)*	.43	3.98 (2.67)	.30	2.25 (1.93)	.24
Adjusted for gait speed	1.56 (1.07)	.30	3.43 (1.57)*	.42	1.96 (1.67)	.24	1.50 (1.83)	.17
Mediolateral harmonic ratio								
Unadjusted	−5.30 (1.93)**	−.50	−6.02 (2.85)*	−.40	−10.32 (2.90)**	−.60	−5.00 (2.34)*	−.41
Adjusted for gait speed	−2.35 (1.46)	−.32	−2.00 (2.35)	−.18	−5.63 (2.06)*	−.50	−3.42 (2.47)	−.28

Notes: β (*SE*) = regression coefficient (standard error); r, r_p = unadjusted/partial correlations.
*p < .05, **p < .02.

lower extremity and hip with every step (21,22). In post hoc analyses, the activities with the highest associations with AP smoothness share similar task requirements. All are whole body coordination tasks that require generation and control of forward momentum, most while simultaneously lifting or lowering the body. These task requirements place greater demands on the precise timing and coordination of forces across body segments for successful completion, possibly explaining their higher associations with AP smoothness.

Although ML smoothness was also related to function, the associations were negative, unlike the positive associations with AP smoothness; greater ML smoothness was associated with worse function. A previous study also found contrasting associations between function and AP versus ML gait control. Moe-Nilssen and Helbostad (23), using a trunk acceleration variability measure, found frail older adults had lower ML but higher AP stride-to-stride trunk acceleration variability, whereas fit older adults exhibited the opposite pattern. Additionally, we found greater ML smoothness was associated with slower gait speeds and shorter step lengths, whereas greater AP smoothness was associated with faster gait speeds and longer step lengths. A potential interpretation of the data may be that this "cautious" walking strategy (ie, slower speed and shorter steps) enhances ML smoothness but at the expense of AP or forward smoothness. This cautious walking strategy was associated with worse function.

Other spatiotemporal measures of gait variability, such as stance time variability and stride time variability have shown to be predictors of incident mobility disability (24) and falls (25) independent of gait speed. Although one study reported moderate negative associations ($r = -.3$ to $-.4$) between stride time variability and smoothness (5), in general, the relations between smoothness and spatiotemporal variability are not well understood. Examination of the independent associations of smoothness, speed, and spatiotemporal variability to function in a larger sample would be an informative future direction of research.

Although our data are preliminary, our findings that walking smoothness is related to function apart from gait speed support smoothness as an informative measure of gait control, and suggest that it may be important to explore interventions that improve both speed and smoothness. Although research has shown that traditional exercise interventions (flexibility, strength, and aerobic training) improve gait speed (26–28), it may be that interventions that include a timing and coordination component that focus on improving motor control processes essential for stepping (29) improve both speed and walking smoothness, and this may ultimately have a greater impact on improving function and disability.

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