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Gait Characteristics Associated with Walking Speed Decline in Older Adults: Results from the Baltimore Longitudinal Study of Aging

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Abstract

Background—Understanding the mechanisms that contribute to walking speed decline can provide needed insight for developing targeted interventions to reduce the rate and likelihood of decline.

Objective—Examine the association between gait characteristics and walking speed decline in older adults.

Methods—Participants in the Baltimore Longitudinal Study of Aging aged 60 to 89 were evaluated in the gait laboratory which used a three dimensional motion capture system and force platforms to assess cadence, stride length, stride width, percent of gait cycle in double stance, anterior-posterior mechanical work expenditure (MWE), and medial-lateral MWE. Usual walking speed was assessed over 6 meters at baseline and follow-up. Gait characteristics associated with meaningful decline (decline ≥ 0.05 m/s/y) in walking speed were evaluated by logistic regression adjusted for age, sex, race, height, weight, initial walking speed and follow-up time.

Results—Among 362 participants, the average age was 72.4 (SD=8.1) years, 51% were female, 27% were black and 23% were identified as having meaningful decline in usual walking speed with an average follow-up time of 3.2 (1.1) years. In the fully adjusted model, faster cadence [OR_{adj}=0.65 95% CI (0.43,0.97)] and longer strides [OR_{adj}=0.87 95% CI (0.83,0.91)] were associated with lower odds of decline. However age [OR_{adj}=1.04 95% CI (0.99,1.10)] was not associated with decline when controlling for gait characteristics and other demographics.

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Conclusion—A sizable proportion of healthy older adults experienced walking speed decline over an average of 3 years. Longer stride and faster cadence were protective against meaningful decline in usual walking speed.

1. Introduction

Walking speed declines with age and slower walking speed has been associated with increased risk of falls, hospitalizations, and subsequent physical and cognitive decline (Mielke et al., 2013; Newman et al., 2006; Peel, Kuys, & Klein, 2013; Watson et al., 2010). Walking speed also predicts five and ten year survival rates over and beyond age (Studenski et al., 2011). In fact, it has been suggested that evaluation of walking speed should become standard clinical measurement for older adults as it is easily evaluated in a clinic settings (Cummings, Studenski, & Ferrucci, 2014; Peel et al., 2013).

Although walking speed is a promising clinical measure, very few studies have tested the hypothesis that increasing walking speed could lead to less disability. Indeed, since the physiological mechanisms that lead to walking speed decline with aging are not completely understood, it is difficult to develop tailored preventive interventions. Age-related differences in biomechanical characteristics of gait may offer some clue on the mechanisms underlying gait speed decline with aging. Older adults have slower walking speeds compared to younger adults and tend to have shorter stride lengths (Judge, Davis, & Ounpuu, 1996; Samson et al., 2001). There are also differences between older and younger participants in stride width and time spent in double support (Gabell & Nayak, 1984). It has been suggested that movements in the sagittal plane, greater lateral movement and even double stance time, are related to compensatory strategies to address progressive balance impairments, and may result in slower gait speeds (Gabell & Nayak, 1984). Interestingly, even among older adults, those who are older have slower walking speed, slower cadence, shorter stride lengths and higher mechanical work expenditures (S. U. Ko, Stenholm, Metter, & Ferrucci, 2012; S. Ko, Ling, Winters, & Ferrucci, 2009). Some studies reported that cadence was associated with age among older adults, while others report no age related differences in cadence (S. U. Ko, Tolea, Hausdorff, & Ferrucci, 2011; Samson et al., 2001).

Remarkably, most work examining gait parameters and walking speed is cross-sectional, and it is mostly unknown whether changes in gait biomechanical parameters emerge before or in parallel to the decline in speed. Thus, there is great need of studies that examine gait characteristics and test the hypothesis that they are predictive of future decline of walking speed in older adults. This includes determining if basic spatio-temporal gait parameters (i.e. stride length) and kinetic parameters (i.e. mechanical work expenditure¹, double stance) known to differ by and vary with age are predictive of walking speed slowing and decline. Attention to spatio-temporal gait parameters in concert with kinetic parameters may be especially important in generally healthy, well-functioning older adults in whom the start of the decline process may be particularly difficult to detect.

¹Note: MWE = mechanical work expenditure.

Important methodological work has identified walking speed declines as small as 0.03 to 0.06 meters per second to be meaningful among older adults (Kwon et al., 2009; Perera, Mody, Woodman, & Studenski, 2006). Meaningful was defined using an anchor based approach to identifying the minimal change perceived as meaningful to the individual (Guyatt et al., 2002). These small detectable changes in walking speed have been identified across demographic groups in healthy older adults and among older adults with clinical conditions (Kwon et al., 2009; Perera et al., 2006; Perera et al., 2014). Identifying early markers of decline among relatively healthy older adults could allow for timely intervention to slow the decline process.

This study examined the association between gait characteristics and decline in walking speed over an average follow-up of three years in generally high functioning older adults participating in the Baltimore Longitudinal Study of Aging (BLSA). Gait characteristics including stride length, stride width and mechanical work expenditure were assessed with a three dimensional motion capture system and force platforms. Usual walking speed was determined during a short corridor walk and change in walking speed was calculated between two study visits.

2. Methods

2.1 Participants

The Baltimore Longitudinal Study of Aging is a continuous enrollment cohort study of normative aging conducted by the National Institute on Aging (NIA), Intramural Research Program (IRP). Eligibility at enrollment is restricted to persons free of cognitive impairment, functional limitations, chronic diseases, and cancer within the past 10 years. Participants receive regularly scheduled comprehensive health, cognitive, and functional evaluations over a 3-day visit to the BLSA clinic facility. Visits occur every two years for persons aged 60-79 and annually for persons aged 80 and older.

Participants in the current analyses were aged 60 to 89 years at the time of their gait laboratory and walking speed assessments. Exclusion criteria for gait evaluation included: hip or knee joint prosthesis; severe joint pain; severe obesity (i.e. body mass index $> 40 \text{ kg/m}^2$); history of Parkinson's disease; inability to walk safely without assistance. In addition, participants in the analytic sample had to have at least one follow-up assessment of walking speed either at the clinic or during a home visit. The BLSA protocol was approved by the standing Institutional Review Board either Medstar Research or the National Institute of Environmental Health Sciences depending on the date of data collection. All participants provided informed consent.

2.2 Demographics and Anthropometrics

Demographic characteristics were self-reported and standardized procedures were used to assess height and weight.

2.3 Gait Characteristics

Detailed procedures for gait evaluation in the NIA IRP Gait Laboratory have been reported previously (S. Ko et al., 2009) and are summarized here. Participants wore non-reflective tight-fitting spandex and reflective markers were placed directly on the skin at 20 anatomical landmarks. A Vicon three dimensional motion capture system with 10 digital cameras (Vicon 612 system, Oxford Metrics Ltd. Oxford, UK) using a 60 Hz sampling frequency recorded the markers during a ten meter walk at usual walking speed. In addition, three staggered force platforms (Advanced Mechanical Technologies, Inc., Watertown, MA, USA) assessed ground reaction forces (1080 HZ sampling frequency). Spatiotemporal (e.g. cadence, stride length, stride width) and kinetic gait characteristics (e.g. mechanical work expenditure) were calculated as previously reported (S. Ko et al., 2009).

2.4 Usual Walking Speed

Usual walking speed in meters per second (m/s) was assessed while participants walked at their “usual, comfortable pace” from a standing start over a six meter course in an uncarpeted corridor. Participants completed the task twice and the faster of the two trials was used for analyses. Follow-up walking speed was obtained from the next regularly scheduled BLSA visit which was conducted in the clinical unit for the majority of participants. A few individuals unable or unwilling to attend a clinic visit had a home visit where the walking course was four meters.

2.5 Meaningful Decline in Usual Walking Speed

Meaningful decline in usual walking speed was defined as a walking speed decline of at least 0.05 m/s per year of follow-up (Kwon et al., 2009; Perera et al., 2006; Perera et al., 2014).

2.6 Statistical Analyses

Age was expressed in years, height in centimeters, weight in kilograms and race as either black or non-black. Usual walking speed was reported as meter/second and both anterior-posterior and medial-lateral mechanical work expenditure (MWE) were expressed as 100 J/kg. Cadence was reported in steps per minute and analyzed as 10 steps per minute. Both stride length and width were expressed in centimeters. Double stance refers to the percent of the overall gait cycle spent in double stance, that is, with both feet on the ground. Walking speed change was calculated (follow-up walking speed – initial walking speed) with negative values indicating decline. Follow-up time (date of second visit – date of first visit) was expressed in years. Meaningful decline was a dichotomous variable indicating if the participant had a decline in usual walking speed of at least 0.05 m/s/year.

Descriptive statistics were reported for demographic characteristics, walking speed and gait characteristics at the initial visit for these analyses. Bivariate correlations were reported for age, usual walking speed, gait characteristics and changes in walking speed. The associations of gait characteristics associated with meaningful decline in walking speed were evaluated using logistic regression adjusting for age, sex, race, height, weight, initial walking speed, and follow-up time. In the logistic regression cadence was scaled to represent 10 steps /minute in order to highlight the association with meaningful decline.

Analyses were conducted using SAS version 9.2 (SAS Institute, Inc., Cary, NC) and $p < .05$ were considered significant.

3. Results

The 361 participants had an average age of 72.4 (SD=8.05), 51% were female and 27% were black (Table 1). The average time to follow-up was 3.21 (1.13) years and 17% had follow-up time of 2 years or less, 34% had follow-up >2 and 3 years, 43% had follow-up >3 5 years, and 6% had follow-up >5 and 6 years. Nine participants (2%) had follow-up walking speed assessed during a home visit. Mean change in walking speed was -0.01 m/s (0.19) with an average rate of change of -0.004 (0.07) m/s/year. Eighty-two participants (23%) had meaningful decline (i.e. decline ≥ 0.05 m/s/y) in usual walking speed.

As shown in Table 2, walking speed was positively associated with mechanical work expenditure and stride length, and negatively associated with double support and walking speed change ($p < .05$). Stride length was positively associated with mechanical work expenditure and change in walking speed ($p < .05$) and negatively associated with stride width and double support ($p < .05$).

Table 3 displays logistic regression results both partially adjusted (i.e. age, sex, race, height, weight, and follow-up time) fully adjusted model (i.e. aforementioned variables and all gait characteristics). In the partially adjusted model, faster cadence [ORadj = 0.65, 95% CI (0.47,0.91)], higher MWE (anterior-posterior) [ORadj = 0.79, 95% CI (0.68,0.91)] and longer stride length [ORadj = 0.89, 95% CI (0.86,0.91)] were associated with lower odds of decline. In the fully adjusted model, faster cadence [ORadj = 0.65 95% CI (0.43,0.97)] and longer strides [ORadj = 0.87 95% CI (0.83,0.91)] were associated with lower odds of decline. Age [ORadj = 1.04 95% CI (0.99,1.10)] was not associated with meaningful decline in usual walking speed when controlling for gait characteristics and other demographics. In a sensitivity analyses (data not shown) we examined the association among gait characteristics and absolute decline in those individuals who had an absolute decline of ≥ 0.05 m/s or greater without respect to the duration of follow-up ($n=147$). In the fully adjusted model, stride length was the only gait characteristic associated with absolute decline with longer stride length being protective.

4. Discussion

In relatively healthy older adults, and independent of potential confounders, longer stride length had a cross-sectional association with faster walking speed and was protective of meaningful walking speed decline over a 3-year follow-up. In fact, for each additional centimeter of stride length there was a 17% lower likelihood of meaningful decline in usual gait speed. This association was consistent after controlling for other gait characteristics and demographic attributes, including height. In addition, after accounting for differences in gait characteristics, the effect of age on the risk of meaningful walking speed decline was no longer significant. These findings indicate that stride length is a critical gait characteristic involved in the pathways that leads to decline of walking speed in older adults.

Faster cadence was also protective against meaningful decline in usual gait speed. Specifically, for each 10 steps per minute increase in cadence there was a 40% lower likelihood of meaningful decline in usual gait speed. Among NHANES participants a cadence that was ten steps per minute faster was associated with a 4% decrease in all-cause mortality and the ability to walk 100 steps per minute was associated with a reduction in cardiovascular related deaths (Brown, Harhay, & Harhay, 2014). In the latter case it is not clear if cadence is simply a gait characteristic or actually a marker for cardiovascular fitness. In fact cadence is used as an indicator of walking intensity when translating national physical activity recommendations into step based recommendations and a cadence of 100 steps per minute was identified as the lower threshold for moderate intensity physical activity (Tudor-Locke et al., 2011). It is also possible that cadence and stride length moderate the relationship between MWE and declines in gait speed. That is, higher MWE (anterior-posterior) is needed for longer stride length and faster cadence and the influence of MWE on gait speed is through changes in stride length and cadence. A better understanding of the factors conditioning both stride length and cadence can help inform prevention strategies.

The fully adjusted model also indicated that those who had more energy expenditure side to side (i.e. medial-lateral) had higher odds of meaningful decline in gait speed [OR_{adj} = 1.95, 95% CI (0.95,4.00)]. This relationship approached significance in this study and is aligned with theoretical compensatory adaptations. Movement in the sagittal plane is hypothesized to be a compensatory strategy and perhaps the higher medial-lateral mechanical work expenditure is a marker of active compensation for other biomechanical issues. In a post-hoc analyses (data not shown) medial-lateral mechanical work expenditure had a significant bivariate association with both weight and body mass index ($p < .001$). Clarifying the association between medial-lateral mechanical work expenditure and meaningful decline in walking speed is beyond the scope of this manuscript.

Translation of these findings into prevention and treatment efforts will require a better understanding the modifiable factors that modulate stride length. Physical therapists have used both motor learning and traditional exercise approaches to improve gait characteristics in older adults with mobility dysfunction (Brach, Van Swearingen, Perera, Wert, & Studenski, 2013; VanSwearingen, Perera, Brach, Wert, & Studenski, 2011). A community-based exercise program was shown to increase walking speed, lengthen stride and increase cadence among older women (Lord et al., 1996). There is even preliminary evidence that music can help older adults increase cadence and stride length (Eikema, Forrester, & Whittall, 2014). This suggests that stride length and cadence may be volitional decisions rather than strictly a functional of physical ability. Indeed psychological factors may condition gait characteristics. For instance, fear of falling is associated with slower walking speed, shorter stride length, and slower cadence in older adults (Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Mortaza, Abu Osman, & Mehdikhani, 2014). Pain has also been associated with lower walking speed and patient advocacy may be needed to ensure appropriate pain management and orthopedic care (Patel, Guralnik, Dansie, & Turk, 2013). Although the study focused on biomechanical determinants of walking speed decline, effective prevention efforts will likely address a range of putative factors.

The current findings suggest caution in generalizing longitudinal associations between gait characteristics and walking speed from cross sectional analyses. The cross-sectional analyses indicate age is associated with slower gait speed, yet the longitudinal analyses suggest that gait characteristics, not chronological age have the strongest association with declines in gait speed. Similarly caution is warranted in generalizing from bivariate associations as cadence and stride length may mediate the association among kinetic gait characteristics and gait speed declines.

The prospective study design limits our understanding of these associations and trials are needed to better understand the effect of improved gait characteristics on the development of decline. Additionally this study used a non-representative sample of older adults and although this limits the generalizability of the findings, use of a relatively healthier, better functioning, population allowed examination of gait characteristics and walking speed decline in the earliest stages of disablement. Another limitation is the assessment of usual walking speed in a laboratory setting. Assessment of cadence during free living (activity occurring during the course of a day) revealed that cadence varies during different tasks making it difficult to determine usual cadence and gait speed (Tudor-Locke & Rowe, 2012). A better understanding of gait characteristics during free-living may help with our understanding of the decline process and develop recommendations for prevention. A longer follow-up time with standardized assessment intervals could provide more insight into how these gait characteristics are associated with the development of meaningful decline. Strengths of the study include assessment of spatiotemporal and kinetic gait characteristics, a broad age range, sex and race diversity and longitudinal data.

5. Conclusion

In a sample of relatively healthy older adults 23% demonstrated a meaningful decline in usual walking speed during an average three years of follow-up. Longer stride length and faster cadence was associated with lower odds of meaningful decline in usual walking speed and this association was found after controlling for other gait characteristics. In the fully adjusted model, cadence and stride length, but not age, was associated with walking speed decline. This suggests that decline in usual walking speed was more closely associated with gait characteristics than chronological age. It is yet to be determined if modification of gait characteristics can attenuate walking speed declines previously characterized as age-related.

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Highlights

- Among healthy older adults, 23% experienced a meaningful decline in walking speed within three years.
- Persons with a longer stride were less likely to experience meaningful decline in usual walking speed.
- Persons with a faster cadence were less likely to experience meaningful decline in usual walking speed.

Table 1

Participant Demographics, Gait Characteristics and Walking Speed

	Total
	N=361
	M(SD)
Demographics	
Age (years)	72.34(8.01)
Height (cm)	168.46(8.96)
Weight (kg)	76.59(14.52)
Female n(%)	183(51)
Black n(%)	99(27)
Gait Characteristics	
Cadence (steps/min)	112.8(9.7)
Mechanical Work Expenditure	
Anterior-Posterior (100 J/kg)	1.3(0.2)
Medial-Lateral (100 J/kg)	0.2(0.2)
Stride Length (cm)	1.2(0.2)
Stride Width (cm)	0.1(0.0)
Double Stance (percent of gait cycle)	0.3(0.0)
Walking Speed	
Usual Walking speed (m/s)	1.1(0.2)
Change in Usual Gait Speed	-0.003(0.01)
Meaningful Decline in Walking Speed n(%)	82(23)

Table 2

Correlation between Gait Characteristics and Walking Speed Decline

	1	2	3	4	5	6	7
1. Usual Walking speed (m/s)							
2. Cadence (steps/min)	.36*						
3. MWE Anterior-Posterior (100 J/kg)	.52*	.45*					
4. MWE Medial-Lateral (100 J/kg)	.24*	.05	.33*				
5. Stride length (cm)	.65*	.22*	.67*	.29*			
6. Stride width (cm)	-.10	-.11*	-.19*	-.03	-.19*		
7. Double Support (percent of gait cycle)	-.27*	.15*	-.12*	.01	-.46*	.25*	
8. Walking speed Change (m/s)	-.29*	-.01	.04	-.02	.14*	-.07	-.04

Note. MWE = Mechanical Work Expenditure. m/s = meter/second.

* indicates p .05.

Table 3

Association of Meaningful Decline in Usual Walking Speed and Gait Characteristics

	Partially Adjusted ¹		Fully Adjusted ²	
	n=361		n=361	
	OR	95% CI	OR	95% CI
Age	1.03	(1.00,1.07)	1.04	(0.99,1.10)
Cadence (10 steps/min)	0.65	(0.47,0.91)	0.65	(0.43,0.97)
Mechanical Work Expenditure				
Anterior-Posterior (100 J/kg)	0.79	(0.68,0.91)	1.14	(0.92,1.42)
Medial-Lateral (100 J/kg)	1.11	(0.62,1.99)	1.95	(0.95,4.00)
Stride Length (cm)	0.89	(0.86,0.91)	.87	(0.83,0.91)
Stride Width (cm)	1.11	(0.99,1.23)	.99	(0.87,1.11)
Double Support (percent of gait cycle)	1.10	(1.03,1.72)	1.01	(0.93,1.10)

Note. 95% CI = 95% confidence interval. Meaningful decline indicates change -0.05 m/s per year.

¹ model was adjusted for initial gait speed, age, sex, race, height, weight, follow-up time.

² model was adjusted for variables in model 1 and gait characteristics listed.