Journals of Gerontology: MEDICAL SCIENCES
Cite journal as: J Gerontol A Biol Sci Med Sci. 2013 April;68(4):456–464
doi:10.1093/gerona/gls197

© The Author 2012. Published by Oxford University Press on behalf of The Gerontological Society of America.
All rights reserved. For permissions, please e-mail: journals.permissions@oup.com.
Advance Access publication October 9, 2012

Trajectories of Gait Speed Predict Mortality in Well-Functioning Older Adults: The Health, Aging and Body Composition Study

Daniel K. White,[1] Tuhina Neogi,[2] Michael C. Nevitt,[3] Christine E. Peloquin,[2] Yanyan Zhu,[2] Robert M. Boudreau,[4] Jane A. Cauley,[4] Luigi Ferrucci,[5] Tamara B. Harris,[6] Susan M. Satterfield,[7] Eleanor M. Simonsick,[5] Elsa S. Strotmeyer,[4] and Yuqing Zhang[2]

[1]Department of Physical Therapy and Athletic Training, College of Health and Rehabilitation Science, Sargent College, Boston University, Massachusetts.
[2]Clinical Epidemiology Research and Training Unit, Boston University School of Medicine, Massachusetts.
[3]Department of Epidemiology and Biostatistics, University of California San Francisco.
[4]Department of Epidemiology, University of Pittsburg, Pennsylvania.
[5]Clinical Research Branch, National Institute on Aging, Baltimore, Maryland.
[6]Laboratory of Epidemiology, Demography, and Biometry, National Institute on Aging, Bethesda, Maryland.
[7]Preventive Medicine, University of Tennessee, Memphis.

Address correspondence to Daniel K. White, PhD, Department of Physical Therapy and Athletic Training, Boston University, Boston, Massachusetts. Email: dwtbn@bu.edu

Background. Although gait speed slows with age, the rate of slowing varies greatly. To date, little is known about the trajectories of gait speed, their correlates, and their risk for mortality in older adults.

Methods. Gait speed during a 20-m walk was measured for a period of 8 years in initially well-functioning men and women aged 70–79 years participating in the Health, Aging and Body Composition study. We described the trajectories of gait speed and examined their correlates using a group-based mixture model. Also risk associated with different gait speed trajectories on all-cause mortality was estimated using a Cox-proportional hazard model.

Results. Of 2,364 participants (mean age, 73.5 ± 2.9 years; 52% women), we identified three gait speed trajectories: slow (n = 637), moderate (n = 1,209), and fast decline (n = 518). Those with fast decline slowed 0.030 m/s per year or 2.4% per year from baseline to the last follow-up visit. Women, blacks, and participants who were obese, had limited knee extensor strength, and had low physical activity were more likely to have fast decline than their counterparts. Participants with fast decline in gait speed had a 90% greater risk of mortality than those with slow decline.

Conclusion. Despite being well-functioning at baseline, a quarter of older adults experienced fast decline in gait speed, which was associated with an increased risk of mortality.

Key Words: Gait speed—Older adults—Mortality.

Received May 1, 2012; Accepted September 1, 2012

Decision Editor: Dr. James Goodwin

GAIT speed is a simple yet important clinical marker of current health and well-being and is a powerful predictor of mortality in older adults (1–4). As such, gait speed has been proposed as a "vital sign" of overall health and well-being. Similar to other vital signs, gait speed changes with aging. Previous studies have reported that gait speed is relatively stable up to age 65, declines 1% per year from age 65 to 69, and further declines to 4% per year for adults older than 80 years (5,6). Nevertheless, there is substantial variation in the rate of decline across individuals. At present, it is unclear whether change in gait speed follows distinct trajectories with aging and if unique factors distinguish older adults who experience more rapid decline from those with gradual decline.

One method to quantify patterns of change in gait speed is to identify unique trajectory groups rather than describe the average change across an entire sample. This approach allows assessment of risk factors for different trajectory groups as well as examination of trajectories in relation to other health outcomes. Examining trajectories of gait speed in older adults is important as underlying patterns of change precede absolute values of gait speed (7). At present, the association of these trajectories on mortality in older adults is unclear. Previous studies have shown that initial gait speed, or "baseline" gait speed, is a strong predictor of survival in older adults with walking 0.1 m/s faster being associated with a 12% increase in survival (4). Nevertheless, it is unknown whether underlying rates of

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

decline (ie, trajectories) rather than one's initial gait speed is associated with higher risk of mortality. Clarifying this issue is important since it would provide insights into the etiology of mortality in older adults.

The purpose of this study was to describe trajectories of gait speed in older adults, evaluate potential correlates of trajectories, and examine the risk of all-cause mortality associated with different trajectory patterns. We employed a group-based semiparametric mixture model to describe the trajectories of gait speed for a period of 8 years in initially well-functioning older adults using data from the Health, Aging and Body Composition (Health ABC) study. Additionally, we examined the added risk of mortality associated with trajectories of gait speed over baseline gait speed.

Method

Sample

Health ABC is a longitudinal study of the association between changes in body composition and functional decline in initially well-functioning older adults. Details of Health ABC have been previously described (8). In brief, Health ABC consists of 3,075 community-dwelling older adults aged 70–79 at baseline. Participants were recruited from a random sample of Medicare beneficiaries who were white and all-community-dwelling black residences in zip codes in and around Memphis, Tennessee and Pittsburgh, Pensylvania. Eligibility criteria included no self-reported difficulty with walking one-quarter mile, climbing 10 steps, or performing basic activities of daily living. People with terminal cancer or plans to move out of the area within 3 years of the baseline examination were excluded. The baseline examinations took place between April 1997 and June 1998. All participants provided informed consent and the study protocol was approved by the Institutional Review Boards (IRB) of the University of Tennessee, Memphis and the University of Pittsburgh. This analysis was approved by the Boston University IRB.

Study Subsample

We used the Year 2 Health ABC visit as this study's baseline since serial testing of gait speed began at this visit. Testing of gait speed continued annually for the next 4 years and every 2 years for the last 4 years, resulting in a total of 8 years of follow up. A total of 2,694 participants had gait speed data from the Year 2 clinic visit. Of these participants, 2,364 (87.8%) had gait speed assessed at both Year 2 and at least two follow-up visits and were included in the current analyses (9,10).

Gait Speed

Gait speed was measured over a 20-m course in an unobstructed corridor and was summarized in meters per second. Participants were instructed to walk at their usual pace from a starting point and walk past an orange cone indicating the end of the course. Timing started with the first step after the starting line and ended after the first step over the finishing line. Participants were allowed to use walking aids during the test, such as a cane. Gait speed has high test–retest reliability in older adults with intraclass correlation coefficients greater than 0.9 (11).

Correlates of Trajectories

We evaluated the following factors as possible correlates of gait speed trajectories based on previous literature linking them to gait speed (8,12–17). Correlates included age, race, sex, and education level from self-report, body mass index (BMI) computed from standardized weight and height assessments classified into World Health Organization categories (18), pain in either knee in most of the last 30 days from self-report, the mean of three maximum isokinetic knee extensor torque repetitions at 60 deg/s categorized strength into sex-specific and weight adjusted tertiles, physical activity (kcal/wk spent walking) from a self-report questionnaire developed specifically for Health ABC categorized into tertiles (19), and hospitalization defined as being a patient in a hospital for one or more nights within the past 12 months. We also counted the number of prevalent chronic conditions (coronary heart disease, peripheral arterial disease, stroke, hypertension, diabetes, and chronic obstructive pulmonary disease) based on self-report and use of relevant medications. Race, sex, education, and chronic conditions were measured from the Year 1 visit, whereas the other correlates were measured at the Year 2 visit, that is, our study baseline.

Statistical Analysis

We employed a group-based semiparametric mixture model to identify three sets of trajectories of gait speed (9). The first set described gait speed patterns for a period of 8 years. The second set described gait speed for a period of 2 years and was employed to examine the association of trajectories with mortality. The third set calculated separate trajectories for a period of 2 years stratified by baseline gait speed categories and was used to examine the association of trajectories with mortality within each baseline gait speed category. We identified distinctive trajectory groups of gait speed using a SAS macro named PROC TRAJ (20). This approach applies a multinomial modeling strategy to identify relatively homogenous clusters of developmental trajectories within a sample population, that is, the modeling strategy allows for the emergence of more than two trajectories. Trajectory parameters are derived by latent class analysis using maximum likelihood estimation. In particular, the distinctive trajectories of gait speed were derived by modeling gait speed as a function of time, that is, the number of years in the study. The number of trajectories were determined by the patterns of change in gait speed and not forced to fit a

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

Table 1. Subject Characteristics

	Overall (n = 2,364)	Slow Decline (n = 637)	Moderate Decline (n = 1,209)	Fast Decline (n = 518)	p Value between trajectory groups
Age, mean (*SD*; interquartile range)	73.5 (2.9; 71–76)	72.8 (2.6; 71–75)	73.5 (2.8; 71–76)	74.4 (2.9; 72–77)	<.0001
Women (%)	52	37	54	67	<.0001
Black (%)	37	17	37	63	<.0001
<High school education (%)	22	11	22	36	<.0001
Number of comorbidities, mean (*SD*; interquartile range)	1.1 (1.0; 0–2)	0.8 (0.9; 0–1)	1.1 (1.0;0–2))	1.4 (1.1;1–2)	<.0001
Body mass index (BMI; kg/m²), mean (*SD*; interquartile range)	27.3 (4.8; 24.1–29.9)	25.9 (3.6; 23.5–28.1)	27.2 (4.4; 24.2–29.7)	29.2 (5.9; 24.8–32.9)	<.0001
<25 (%)	33	41	32	26	
25–29 (%)	43	46	46	32	
30–34 (%)	18	12	17	25	
>35 (%)	7	1	6	16	
Knee pain in the last 30 days (%)	26	15	27	37	<.0001
Knee extensor strength [N-M/kg (*SD*)]	3.7 (1.3)	4.3 (1.3)	3.6 (1.2)	3.0 (1.1)	<.0001
Physical activity (Kcal/kg/wk), mean (*SD*; interquartile range)	7.0 (13.7; 0–9)	10.0 (17.0; 0–13.8)	6.5 (12.5; 0–8.0)	4.2 (10.8; 0–4.5)	<.0001
Highest tertile (most active; %)	36	50	35	21	
Middle tertile (%)	25	23	26	27	
Lowest tertile (least active; %)	39	27	40	52	
Hospitalization within the last 12 months (%)	13.5	12	12	20	.0003
Baseline gait speed, mean (*SD*; interquartile range)	1.15 (0.21; 1.02–1.29)	1.37 (0.13; 1.27–1.45)	1.14 (0.13; 1.06–1.22)	0.90 (0.15; 0.84–1.00)	<.0001

particular model. We assumed that each trajectory of gait speed had a linear pattern of decline. We tested this by also including a quadratic term, which tests for the possibility that change in gait speed has a curved shape (eg, faster then slower) and evaluated these patterns of decline from p values for each trajectory group. Linear but not quadratic model terms were statistically significant ($p < .05$), therefore, we only included a linear term in our final models. We considered adjacent trajectory groups with slopes differing by more than 10% to be unique given that this level of relative change is an approximation of a meaningful difference in older adults (21). We used the posterior probabilities of group membership from each individual to assess the fit of the model, which was provided by the PROC TRAJ macro. High probability of membership into a single group represents a good model fit. We compared the prevalence and means of baseline correlates across trajectory groups using chi-square tests or analysis of variance when appropriate and examined the association of correlates with each trajectory of gait speed using a multivariable polytomous regression model mutually adjusted for other correlates.

To examine the risk of mortality, we identified a second set of trajectories over the first 2 years (ie, gait speed assessed at Year 2, Year 3, and Year 4) using the same methodology described previously. Person-years of follow up for each participant was computed as the amount of time starting from the end of the gait speed trajectory to the date of either death or the Year 14 contact. Mortality rates for each trajectory group were calculated by dividing the number of deaths by person-years of follow up. We used Kaplan–Meier methods to construct survival curves to determine the mortality rate for each gait speed trajectory. In particular, we used failure rates to calculate the cumulative incidence of mortality for each gait speed trajectory. We fitted Cox-proportional hazards models to assess the relation of gait speed trajectories to the risk of death, adjusting for correlates as well as gait speed at Year 2, which would be considered a baseline measure of gait speed. Gait speed at Year 2 was treated both as a continuous and a categorical correlate(>1.22 m/s, <1.22 and >1.0 m/s, and <1.0 m/s) in separate models. Walking 1.22 m/s is a minimum speed needed to cross a street at a timed crosswalk (22) and walking less than 1.0 m/s is a risk factor for mortality (2). The association of gait speed trajectories with mortality was also assessed within each stratum of these gait speed categories to examine the relative association of initial gait speed and trajectories of gait speed. For the within-stratum analyses, the third set of gait speed trajectory groups were defined using only observations within each baseline speed stratum.

Results

Of the 2,364 participants in the analytic cohort, 52% were women and 37% were black. The mean (±*SD*) age was 73.5 (±2.9) years and mean BMI was 27.3 (±4.8) kg/m² at study baseline. The majority (78%) of participants had at least a high school education and less than 20% had two or more comorbidities. (Table 1)

Gait Speed Trajectories for More Than 8 Years

We identified three gait speed trajectories: slow, moderate, and fast decline. (Figure 1) The mean (±*SD*) gait speed for participants in the slow decline trajectory (n = 637, 27%) started at 1.37 m/s (±0.13) and dropped 0.020 m/s per year (95% CI

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

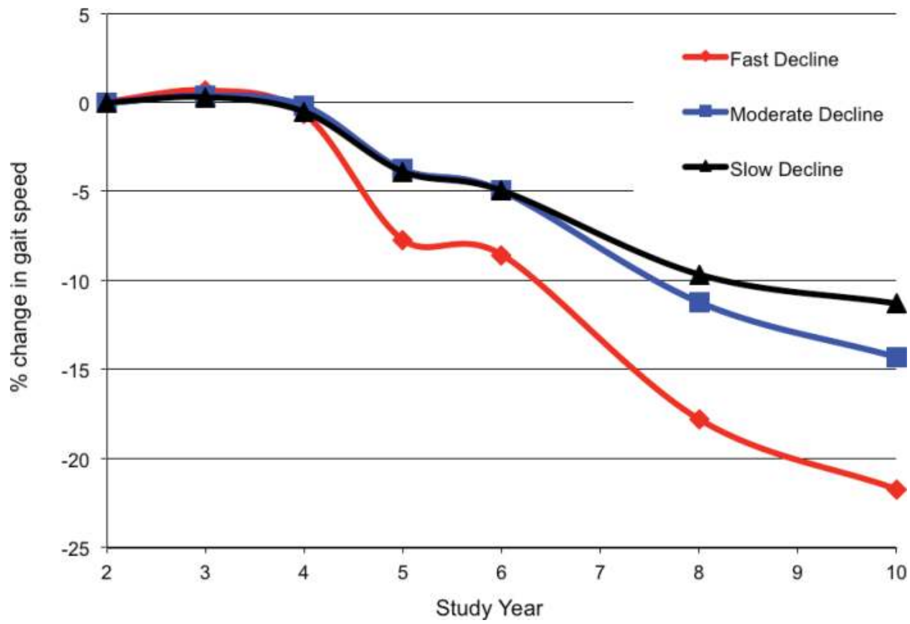

Figure 1. Relative change* in gait speed for each 8-year trajectory, $N = 2,364$. *Note:* *Relative change was calculated as [(follow up − baseline)/baseline] for gait speed values. Study Year 2 was considered baseline.

[−0.019, −0.022]) for an absolute decline of 1.9% per year or relative decline of 11.3% for a period of 8 years compared with baseline. In contrast, participants in the fast decline trajectory ($n = 518$, 22%) started at 0.9 m/s (±0.15) and slowed at 0.030 m/s per year [−0.028, −0.033] for an absolute decline of 2.4% per year or a relative decline of 21.7% for a period of 8 years. Participants in the moderate decline trajectory ($n = 1,209$, 51%) started at 1.14 m/s (±0.13) and slowed at 0.023 m/s per year [−0.022, −0.024] for and absolute decline of 2.0% per year decline or relative decline of 14.3% for a period of 8 years. We found the posterior probability of allocating each study participant into the slow, moderate, and fast decline groups to be 0.94, 0.94, and 0.95, respectively, indicating a good fit of the model of group trajectories to individual trajectories. We found loss to follow up from the baseline to the eighth year of follow up, highest in the fast decline trajectory (63%) followed by the moderate decline group (43%) and lowest in the slow decline group (21%).

Correlates of Gait Speed Trajectories for More Than 8 Years

As shown in Table 2, all correlates were associated with both fast and moderate decline trajectories in gait speed after mutual adjustment, except for hospitalization. The magnitude of association was stronger for fast decline than for moderate decline in gait speed. For each 2-year increment in age, there was more than a 2- and 1.4-fold increase in odds of fast and moderate decline, respectively. Women, blacks, and participants who were obese, had weak knee extensor strength, and had low levels of physical activity were also more likely to have moderate or fast decline in gait speed than their counterparts.

Table 2. Mutually Adjusted Correlates of Gait Speed Trajectories

	Fast Decline (n = 518) vs Slow Decline (n = 637) OR (95% CI)	Moderate Decline (n = 1209) vs Slow Decline (n = 637) OR (95% CI)
Age (per 2 years)	2 (1.7, 2.2)	1.4 (1.3, 1.6)
Women	5.7 (4, 8.2)	2.8 (2.1, 3.6)
Black	10.0 (6.7, 15.1)	3.4 (2.4, 4.8)
<High school	3.0 (1.9, 4.6)	1.7 (1.1, 2.5)
Number of comorbidities	1.7 (1.5, 2.1)	1.4 (1.2, 1.6)
BMI categories		
<25	1.0 Reference	1.0 Reference
25–29	1.0 (0.6, 1.4)	1.2 (0.9, 1.6)
30–34	1.8 (1.1, 3)	1.5 (1.0, 2.3)
>35	5.8 (1.9, 17.7)	3.1 (1.1, 9.1)
p for trend	$p < .0001$	$p < .0001$
Knee Pain	3.0 (2.0, 4.5)	2.0 (1.4, 2.8)
Knee extensor strength		
Strongest tertile	1.0 Reference	1.0 Reference
Middle tertile	3.4 (2.2, 5.2)	1.6 (1.2, 2.2)
Weakest tertile	7.6 (4.9, 11.9)	2.6 (1.9, 3.7)
Physical activity		
Highest tertile (most active)	1.0 Reference	1.0 Reference
Middle tertile	2.1 (1.4, 3.3)	1.3 (1.0, 1.8)
Lowest tertile (least active)	2.7 (1.8, 4.1)	1.8 (1.4, 2.5)
Hospitalization	1.3 (0.8, 2)	0.9 (0.6, 1.4)

Note: BMI = body mass index; CI = confidence interval; OR = odds ratio.

All-Cause Mortality Across Gait Speed Trajectories for a Period of 2 Years

The cumulative incidence of all-cause death for a period of 10 years of follow up was 27%, 41%, and 56% for participants in slow, moderate, and fast decline trajectories,

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

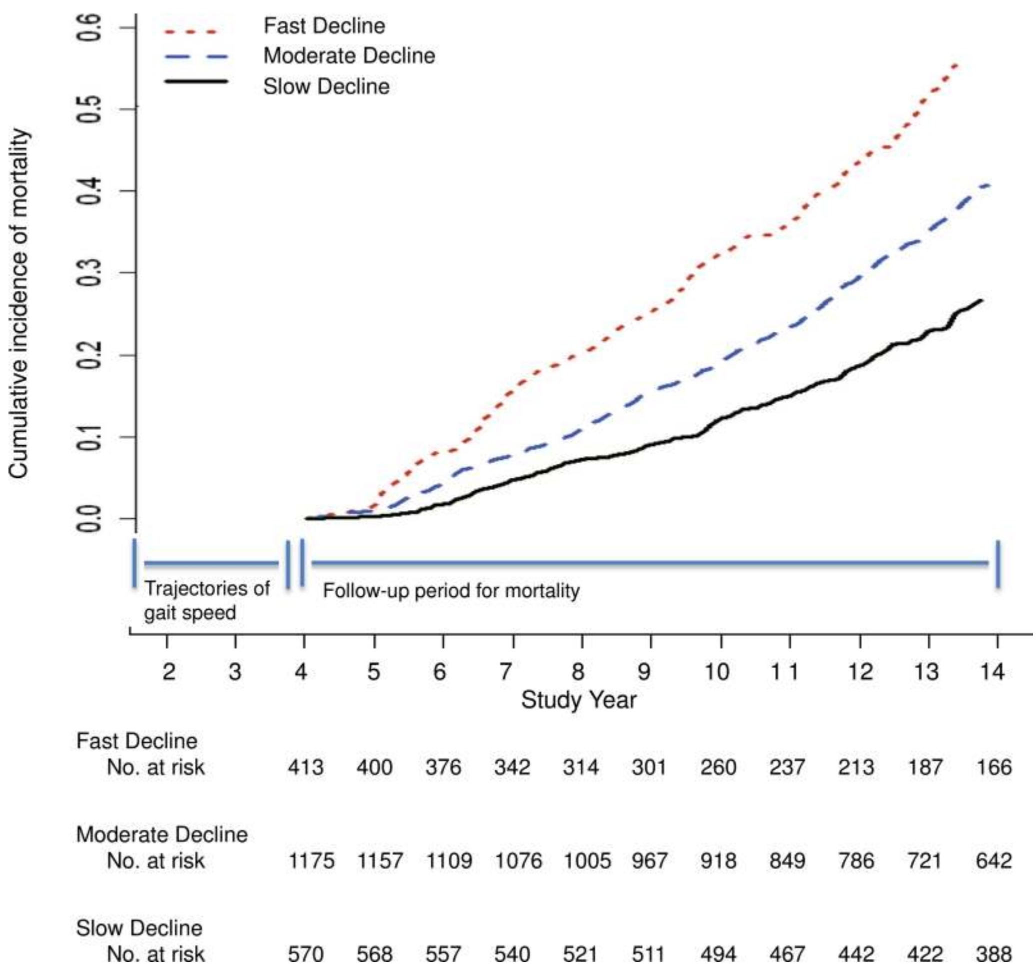

Figure 2. Cumulative incidence of mortality by 2-year gait speed trajectory groups.

respectively (Figure 2). Compared with those in the slow decline trajectory for a period of 2 years, participants in the fast and moderate decline trajectories had 1.9 (95% CI [1.3, 2.8]) and 1.4 [1.1, 1.8] times the risk of all-cause mortality, respectively, after adjusting for correlates and gait speed as a categorical correlate. Adjusting for gait speed as a continuous correlate, participants in the fast and moderate decline trajectories had 2.1 (95% CI [1.4, 3.1]) and 1.5 [1.2, 1.9] times the risk of all-cause mortality compared with those in the slow decline trajectory.

Risk of All-Cause Mortality by Baseline Gait Speed Stratums

Within each 2-year gait speed trajectory stratum, gait speed trajectories of fast decline were associated with all-cause mortality (See Figure 3 and Table 3). Even among participants with a gait speed greater than 1.22 m/s at Year 2, those in a trajectory of fast decline had 1.9 times the risk of all-cause mortality compared with those in the slow decline trajectory. Similar trends were observed within the other two strata of baseline gait speed.

Discussion

We identified three distinctive gait speed trajectories (slow, moderate, and fast decline) for a period of 8 years in 2,364 older adults. Although all study participants were considered well-functioning at baseline, more than 20% had fast decline in gait speed slowing 2.4% per year. Participants who were older, women, and black and those who had higher BMI, knee pain, muscular weakness, and low physical activity were more likely to be in a fast decline trajectory of gait speed than their counterparts. Participants with a fast decline trajectory had 1.9 and 2.1 times the risk of all-cause mortality compared with those in the slow decline trajectory, adjusting for baseline gait speed as a categorical and continuous correlate, respectively. Even among participants walking at a similar speed at baseline, Year 2, higher mortality was observed among those with fast or moderate decline compared with those with slow decline in gait speed.

Although gait speed itself, especially when slower than 1.0 m/s, is a known risk factor for death (4), this study found that the trajectory of gait speed for a period of 2 years is strongly associated with subsequent mortality even after

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

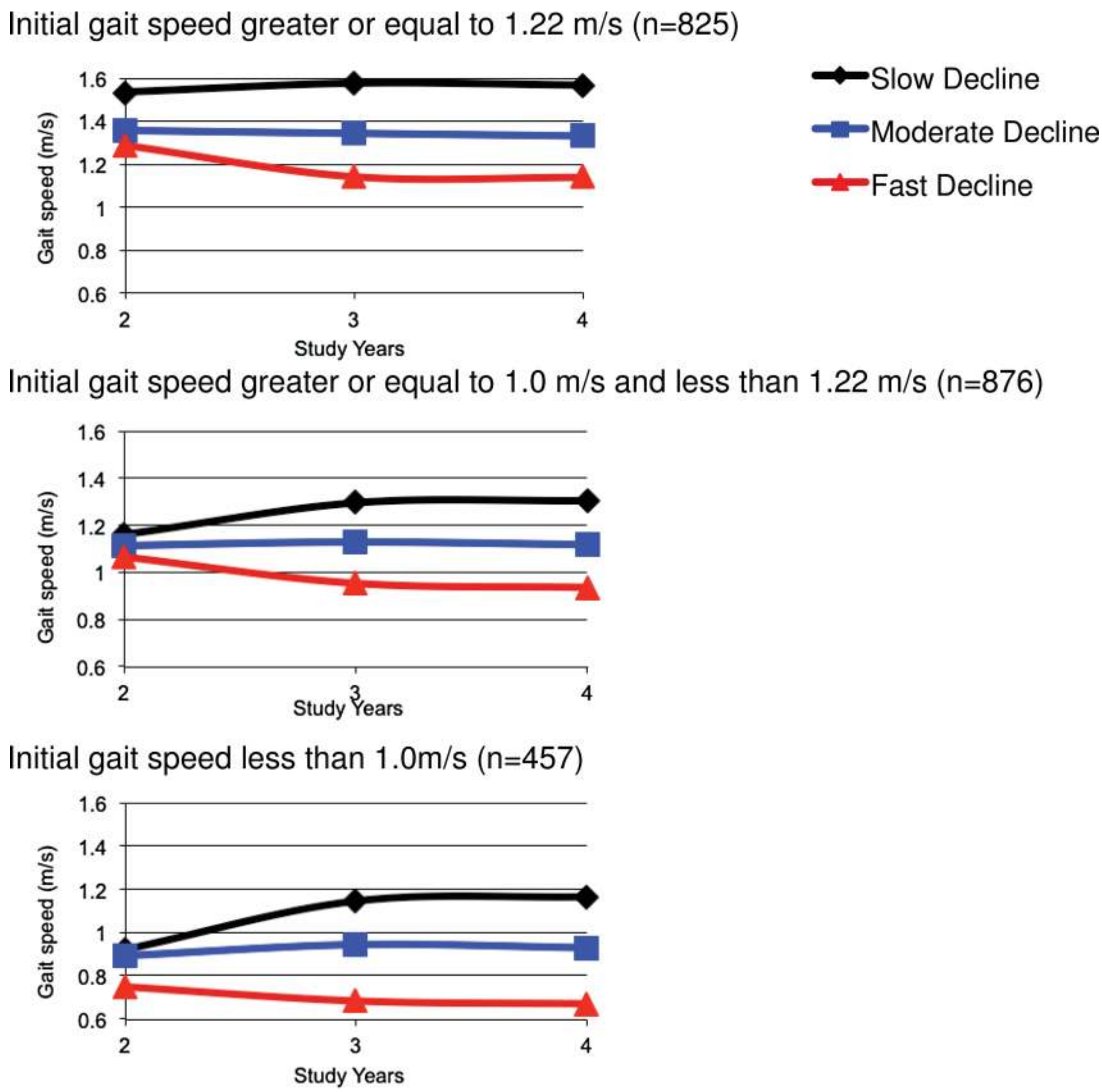

Figure 3. Stratified trajectories of gait speed for a period of 2 years by baseline gait speed (Year 2) groups (≥1.22 m/s, ≥1.0 m/s and <1.22 m/s, and <1.0 m/s).

Table 3. Adjusted* Hazard Ratios and 95% Confidence Intervals (CI) for All-Cause Mortality by Trajectories Stratified by Baseline Gait Speed Categories

Baseline	Trajectory (*n*)	Number of Deaths	Rate (100 Person-Years)	Hazard Ratio [95% CI]
>1.22 m/s	Slow decline (107)	21	2.10	1.0 REF
	Moderate decline (517)	142	3.10	1.01 [0.69, 1.60]
	Fast decline (201)	88	5.29	1.89 [1.11, 3.20]
>1.0 m/s and < 1.22 m/s	Slow decline (164)	12	1.23	1.0 REF
	Moderate decline (570)	98	2.52	1.15 [0.84, 1.58]
	Fast decline (142)	43	4.22	1.70 [1.13, 2.54]
<1.0 m/s	Slow decline (76)	16	2.89	1.0 REF
	Moderate decline (307)	80	3.63	1.36 [0.84, 2.20]
	Fast decline (74)	31	6.37	2.38 [1.41, 4.00]

Note: *Adjusted for age, sex, body mass index (BMI), comorbidities, race, knee pain, education, knee extensor strength, and physical activity.

adjustment for gait speed at what would be considered a baseline measure. Assessing gait speed at any one point in time may not provide sufficient insight regarding the risk of adverse outcomes, particularly when simple threshold values such as 1.0 m/s are applied (2). For instance, an individual may be on a trajectory of fast decline but assessed at a time before falling below 1.0 m/s. Similarly, an individual may chose to walk at a slow speed independent of health status and be on a trajectory of slow gradual decline, and at the same time be at low risk of poor health

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

outcomes. Inquiring about recent change in gait speed may help identify older adults progressively slowing over time and who are subsequently at risk of poor health outcomes. However, slowing at a rate observed in the fast decline trajectory, 0.03 m/s per year, may not be readily noticed apart from objective longitudinal evaluations of gait speed.

We found a strong correlation between baseline gait speed and subsequent trajectories in gait speed. Participants who had an initial gait speed less than 1.0 m/s tended to show fast decline in gait speed over the subsequent 8 years. This phenomenon has also been observed in the other numerical quantities of physiological measures, such as blood pressure in adults (23) and knee cartilage loss among people with osteoarthritis (24). The strong correlation between an absolute value and the rate of change is akin to a "horse-racing" effect; one would expect the fast horses to be out in front at any given time point (7). Thus, older adults with a slow gait speed do not "start" slowly at the beginning of a longitudinal study but rather were in a trajectory of fast decline well before the start of the study. We acknowledge that while Peto's horse-racing effect was not originally applied to gait speed, its principle is relevant for understanding the etiology of trajectory patterns. Nevertheless, we believe most older adults who are on a trajectory of fast decline did walk faster earlier in life. The lower 95% confidence interval bound for gait speeds of healthy adults up to their sixth decade of life walk is 1.1 m/s according to a meta-analysis of walking speed (25). Given the average baseline walking speed of older adults from Health ABC on a trajectory of fast decline was 0.9 m/s, we believe it is reasonable to assume most of these older adults have slowed since their fourth and fifth decades of life. However, we acknowledge that it is possible that other trajectory patterns may exist whereby adults decline in gait speed from their fifth and sixth decades of life but then plateau and remain on a stable trajectory thereafter. Exploring such alternative trajectory patterns was beyond the scope of this study, however of interest and importance for future research.

We believe that although differences in rates of decline per year between trajectory groups were small, they are nonetheless important. First, the rate of decline in each trajectory group represented the mean or average change among all group participants and therefore should not be interpreted as an individual's specific change. Second, the consequence of the different trajectory patterns becomes greater over time. Assuming all study participants started with the same initial gait speed at some point prior to enrollment in the study, the slight but different underlying trajectory patterns have resulted in more apparent differences in their gait speeds at study entry and over follow up. Hence, the average difference in slopes of decline, although small, is of importance.

We found that several modifiable correlates of gait speed trajectories, such as knee extensor strength, knee pain, physical activity, and BMI. For instance, muscular weakness was associated with 8 times the odds of fast decline in gait speed. Previous studies have shown that strength training has modest effects on increasing gait speed in older adults (26,27). Improving upon these modifiable factors may be able to shift a trajectory of gait speed toward slower decline. Similarly, intervention to reduce knee pain and obesity may slow the rate of decline in gait speed. However, future research is needed to further investigate these relationships in the context of clinical trials.

Our study has several clinical implications. Clinicians should measure gait speed when possible and consider an older adult's underlying trajectory of gait speed to assess future health outcomes. Hardy and colleagues (28) previously reported the association of improvement of gait speed with better survival in older adults. Our study adds that a trajectory of rapid decline is associated with a higher risk of mortality compared with those with slow decline. Therefore, clinicians may consider that change in gait speed is indeed important and that the underlying trajectory of gait speed may provide additional information about future health risk in addition to their present gait speed (4). For instance, our findings suggest that even among older adults with a similar gait speed at a given time point, it is the overall trajectory path that is relevant for survival in older adults. In other words, the patient on a trajectory of decline is at higher risk of mortality compared with his/her counterparts who have the same gait speed but are on a more stable trajectory. We acknowledge that the use of trajectories collected over annual visits may have less clinical utility compared with using a single baseline gait speed when attempting to predict the risk of mortality in older adults. However, given our study findings, we believe that if a decline in gait speed is noted over shorter intervals of time, such change is likely to be a risk factor for future poor health outcomes and clinicians may consider referral to rehabilitation to increase gait speed (29) and possibly alter the underlying trajectory pattern of decline. These findings provide greater understanding that gait speed at any given time is largely determined by the trajectory of gait speed change. In the same manner, our findings suggest that the preservation of gait speed may be more beneficial if promoted earlier rather than later in older adulthood before decline takes hold. This is based on the hypothesis that older adults had healthy walking speeds in their sixties in general tended to have little or no decline in gait speed through their seventies. A recent meta-analysis of gait speed among nondiseased older adults reported men and women between the ages of 60–69 years walked at 1.33 and 1.24 m/s, respectively (25). Study participants from Health ABC walking at these speeds at the start of the study were more likely to be in a slow rather than fast decline trajectory. Therefore, clinicians may consider promoting the preservation of gait speed earlier in the aging process, for example, in the sixth decade of life, rather than starting to address gait speed in later decades. This can be

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

accomplished through a healthy lifestyle such as adhering to physical activity guidelines for aerobic and strengthening components of fitness (30) as well as maintaining a healthy weight (31).

There are several strengths to this study. First, the data were collected from a large study that systematically assessed gait speed for a period of 8 years and this sample provided sufficient numbers and follow-up time to describe trajectories of gait speed. These data are important as they provide a means to describe the natural history of change in gait speed in healthy older adults. Second, we employed a novel methodology to describe change in gait speed over time. Previous longitudinal studies have charted the individual variability of gait speed around a mean population trend (32–35). A limitation to this approach is that meaningful subgroups of change that follow a distinct trajectory cannot be identified (9). We employed a group-based analysis that differs from growth curve modeling with regards to the underlying assumptions of the distribution of trajectories in the population. Growth curve modeling assumes that the population distribution of trajectories is continuous and normally distributed. In contrast, a group-based analysis allows for the emergence of distinct trajectories of gait speed and affords the ability to investigate unique patterns within a sample instead of assuming a common rate of decline.

Our study has some limitations that should be acknowledged. First, there was differential loss to follow up due between the 8-year trajectory groups, for example, mobility disability or death for the three gait speed trajectories with the fast decline group experiencing the most loss to follow up from the baseline to the eighth year of follow up. This could possibly bias the gait speed trajectories observed in the study with more participants missing in the fast decline trajectory than the slow decline group. Nevertheless, given that gait speed is slowest just prior to functional limitation or death, our estimates of absolute and relative change in speed within trajectory groups are likely to be underestimated. Moreover, mortality was the outcome of interest in the survival analyses, hence loss to follow up due to death would not bias the study findings. Second, we only examined gait speed trajectories over one distance, 20 m, which may limit the generalizability of our findings to gait speeds taken at shorter and longer walking distances. Third, we did not adjust for depressive symptoms since only 4% of study participants had major depressive symptoms. We reran study analyses adjusting for depressive symptoms and found similar results. Fourth, we did not examine the effects of intercurrent events, such as hospitalization or illness, occurring within follow-up periods. We believe understanding how such events alters trajectory patterns is important and needed for study in future research.

In conclusion, we found three distinctive gait speed trajectories in initially well-functioning older adults. One fifth of well-functioning older adults had a fast decline trajectory of gait speed and had a twofold increased risk of all-cause mortality compared with those on a slow decline trajectory. Correlates of fast decline included modifiable characteristics, such as knee strength, pain, and BMI. Even among study participants with similar baseline gait speeds, those on a fast decline trajectory of gait speed had the highest risk of all-cause mortality. Future studies should evaluate if early intervention for those older adults who do not yet walk slowly but exhibit a trajectory of fast decline can successfully avoid or slow the rate of further decline.

Funding

This work was supported by National Institute on Aging (NIA) (grant numbers N01-AG-6-2101, N01-AG-6-2103, N01-AG-6-2106, R01-AG028050) the National Institute of Nursing Research (grant number R01-NR0124590; the Boston Claude D. Pepper Older Americans Independence Center from the National Institutes on Aging (grant number P30-AG031679); the Foundation for Physical Therapy Geriatrics Research Grant; the American College of Rheumatology Research and Education Foundation Rheumatology Investigator Award; and the National Institute of Arthritis and Musculoskeletal and Skin at the National Institutes of Health (grant number AR47785).

Acknowledgments

This research was supported in part by the Intramural Research Program of the NIH, National Institute on Aging.

References

1. Hall WJ. Update in geriatrics. *Ann Intern Med*. 2006;145:538–543.
2. Cesari M, Kritchevsky SB, Penninx BW, et al. Prognostic value of usual gait speed in well-functioning older people–results from the Health, Aging and Body Composition Study. *J Am Geriatr Soc*. 2005;53:1675–1680.
3. Ayis S, Ebrahim S, Williams S, Jüni P, Dieppe P. Determinants of reduced walking speed in people with musculoskeletal pain. *J Rheumatol*. 2007;34:1905–1912.
4. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. *JAMA*. 2011;305:50–58.
5. Himann JE, Cunningham DA, Rechnitzer PA, Paterson DH. Age-related changes in speed of walking. *Med Sci Sports Exerc*. 1988;20:161–166.
6. Forrest KY, Zmuda JM, Cauley JA. Correlates of decline in lower extremity performance in older women: A 10-year follow-up study. *J Gerontol A Biol Sci Med Sci*. 2006;61:1194–1200.
7. Peto R. The horse-racing effect. *Lancet*. 1981;2:467–468.
8. Newman AB, Simonsick EM, Naydeck BL, et al. Association of long-distance corridor walk performance with mortality, cardiovascular disease, mobility limitation, and disability. *JAMA*. 2006;295:2018–2026.
9. Nagin D. *Group-Based Modeling of Development*. Cambridge, MA: Harvard University Press; 2005.
10. Hejazi S, Dahinten VS, Marshall SK, Ratner PA. Developmental pathways leading to obesity in childhood. *Health Rep*. 2009;20:63–69.
11. Steffen TM, Hacker TA, Mollinger L. Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Phys Ther*. 2002;82:128–137.
12. Eyler AA, Brownson RC, Bacak SJ, Housemann RA. The epidemiology of walking for physical activity in the United States. *Med Sci Sports Exerc*. 2003;35:1529–1536.
13. Penninx BW, Guralnik JM, Ferrucci L, Simonsick EM, Deeg DJ, Wallace RB. Depressive symptoms and physical decline in community-dwelling older persons. *JAMA*. 1998;279:1720–1726.
14. Sayers SP, Guralnik JM, Thombs LA, Fielding RA. Effect of leg muscle contraction velocity on functional performance in older men and women. *J Am Geriatr Soc*. 2005;53:467–471.

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022

15. Shah RC, Buchman AS, Boyle PA, et al. Musculoskeletal pain is associated with incident mobility disability in community-dwelling elders. *J Gerontol A Biol Sci Med Sci*. 2011;66:82–88.
16. Samson MM, Crowe A, de Vreede PL, Dessens JA, Duursma SA, Verhaar HJ. Differences in gait parameters at a preferred walking speed in healthy subjects due to age, height and body weight. *Aging (Milano)*. 2001;13:16–21.
17. Woo J, Ho SC, Lau J, Chan SG, Yuen YK. Age-associated gait changes in the elderly: pathological or physiological? *Neuroepidemiology*. 1995;14:65–71.
18. World Health Organization (WHO). *Obesity: Preventing and Managing the Global Epidemic.* Report of a WHO Consultation. WHO Technical Report Series 894. Geneva, Switzerland: World Health Organization; 2000.
19. Peterson MJ, Giuliani C, Morey MC, et al. Physical activity as a preventative factor for frailty: the health, aging, and body composition study. *J Gerontol A Biol Sci Med Sci*. 2009;64:61–68.
20. Jones B, Nagin D, Roeder K. A SAS procedure based on mixture models for estimating developmental trajectories. *Social Methods Res*. 2001;29:374–393.
21. Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. *J Am Geriatr Soc*. 2006;54:743–749.
22. Langlois JA, Keyl PM, Guralnik JM, Foley DJ, Marottoli RA, Wallace RB. Characteristics of older pedestrians who have difficulty crossing the street. *Am J Public Health*. 1997;87:393–397.
23. Peto, R. The horse-racing effect. *The Lancet* 1981:467–468.
24. Bartlett SJ, Ling SM, Mayo NE, Scott SC, Bingham CO 3rd. Identifying common trajectories of joint space narrowing over two years in knee osteoarthritis. *Arthritis Care Res (Hoboken)*. 2011;63:1722–1728.
25. Bohannon RW, Williams Andrews A. Normal walking speed: a descriptive meta-analysis. *Physiotherapy*. 2011;97:182–189.
26. Liu CJ, Latham NK. Progressive resistance strength training for improving physical function in older adults. *Cochrane Database Syst Rev.* 2009:CD002759.
27. Lopopolo RB, Greco M, Sullivan D, Craik RL, Mangione KK. Effect of therapeutic exercise on gait speed in community-dwelling elderly people: a meta-analysis. *Phys Ther*. 2006;86:520–540.
28. Hardy SE, Perera S, Roumani YF, Chandler JM, Studenski SA. Improvement in usual gait speed predicts better survival in older adults. *J Am Geriatr Soc*. 2007;55:1727–1734.
29. Chou CH, Hwang CL, Wu YT. Effect of exercise on physical function, daily living activities, and quality of life in the frail older adults: a meta-analysis. *Arch Phys Med Rehabil*. 2012;93:237–244.
30. Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report. Washington, DC: U.S. Department of Health and Human Services; 2008. Available at http://www.health.gov/paguidelines/guidelines/default.aspx
31. Villareal DT, Chode S, Parimi N, et al. Weight loss, exercise, or both and physical function in obese older adults. *N Engl J Med*. 2011;364:1218–1229.
32. Onder G, Penninx BW, Lapuerta P, et al. Change in physical performance over time in older women: the Women's Health and Aging Study. *J Gerontol A Biol Sci Med Sci*. 2002;57:M289–M293.
33. Wang L, van Belle G, Kukull WB, Larson EB. Predictors of functional change: a longitudinal study of nondemented people aged 65 and older. *J Am Geriatr Soc*. 2002;50:1525–1534.
34. Beckett LA, Brock DB, Lemke JH, et al. Analysis of change in self-reported physical function among older persons in four population studies. *Am J Epidemiol*. 1996;143:766–778.
35. Buchner DM, Cress ME, Esselman PC, et al. Factors associated with changes in gait speed in older adults. *J Gerontol A Biol Sci Med Sci*. 1996;51:M297–M302.

Downloaded from https://academic.oup.com/biomedgerontology/article/68/4/456/536223 by guest on 20 August 2022