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Research Article

Trajectories of Lower Extremity Physical Performance: Effects on Fractures and Mortality in Older Women

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Abstract

Background: Prior studies have only considered one measurement of physical performance in its relationship to fractures and mortality. A single measurement is susceptible to large within-person changes over time, and thus, may not capture the true association between physical performance and the outcomes of interest.

Methods: Using data from the Study of Osteoporotic Fractures, we followed 7,015 women enrolled prior to age 80 years who had outcome information beyond this age. Trajectories of walking speed (m/s) and chair stand speed (stands/s) were estimated up to the last visit prior to age 80 years using mixed-effects linear regression. Physical performance at age 80 (PF_age80) was assessed at the last visit prior to age 80 years. Hazard ratios (HRs) and 95% confidence intervals (CIs) were estimated using Cox proportional hazards regression and multivariate models adjusted for all other covariates.

Results: Greatest walking speed decline and chair stand speed decline were both associated with higher risk of hip fracture (HR: 1.28; 95% CI: 1.03, 1.58 and HR: 1.26; 95% CI: 1.03, 1.54, respectively), but not nonspine fractures. Greatest walking speed decline and chair stand speed decline were both associated with a significant 29% (95% CI: 17–42%) and 27% (95% CI: 15–39%) increased risk of mortality, respectively.

Conclusions: Greatest declines in walking speed and chair stand speed were both associated with an increased risk of hip fracture and mortality independent of PF_age80 and other important confounders. Both physical performance change and the single physical performance measurement should be considered in the etiology of hip fracture and mortality.

Keywords: Fractures—Mortality—Physical performance—Trajectories

Poor physical performance (measured at one time point via walking speed, chair stand speed, and/or grip strength) has been identified as a risk factor for hip fractures in men (1) and women (2,3). Additionally, other studies have shown an increased risk of nonspine (4) and radiographic spine (5) fractures among older men with poor performance. Conversely, researchers using data from the InCHIANTI study failed to find an association between physical performance (measured with the 5 times sit-to-stand test) and fall-related fractures (6).

In regards to mortality, two large meta-analyses found that slower walking speed and chair stand time, respectively, were associated with an increased risk of mortality (7,8). However, these studies may not capture the true association between physical performance and health decline, because they measured physical performance at a single time point, which is susceptible to large within-person changes over time. By contrast, trajectories of change in physical performance over time may better reflect the relationship between physical performance and subsequent health outcomes.

Physical performance declines with age and is associated with poor health outcomes (9); however, the temporal nature of these relationships is unclear (ie, what came first the physical performance

decline or the outcome of interest?). Although some studies have examined the concurrent association between physical performance trajectories and health outcomes (9,10), to date none have measured physical performance decline in an individual, and subsequently followed them for the outcome of interest.

It remains uncertain whether physical performance trajectories predict risk of fractures and mortality, and if so, whether these associations are as robust or more robust, and independent of the single measurement of physical performance (physical performance at age 80 [PF_age80] used throughout the manuscript). Identifying how changes in physical performance over time impact these outcomes may have important clinical and public health implications leading to intervention opportunities.

The current study examined whether trajectories of lower extremity physical performance measured up to last visit prior to age 80 years were associated with subsequent risk of fractures and mortality, in a large, well-characterized cohort of older women, and to determine whether any association between trajectory and these outcomes was independent of the single measurement of physical performance, PF_age80. We hypothesized that compared with women with moderate decline in physical performance, those with the greatest physical performance decline would have the highest risk of fractures and mortality. Conversely, women with the least decline in physical performance will have the lowest risk of these outcomes.

Methods

Study Population

We used data from the Study of Osteoporotic Fractures (SOF), an ongoing prospective cohort study of 9,704 white women, aged 65 years and older, and recruited from four U.S. clinics from 1986 to 1988 (11). For this analysis, we excluded women enrolled after age 80 (n = 773) and women who had no physical performance trajectory prior to age 80 (n = 456), because our main predictor was physical function trajectory measured up to the last visit prior to age 80, to maximize our follow-up period. For mortality analyses, we further excluded women who withdrew from the study (n = 225) or died prior to age 80 years (n = 1,235). Therefore, our analytic sample (n = 7,015) comprised SOF participants who had physical performance trajectory prior to age 80 years and had outcome information beyond this age (Supplementary Figure 1).

Lower Extremity Physical Performance Measurements

We examined the separate impact of trajectories in two physical performance measurements on our outcomes: (i) walking speed (m/s) measured using a 6-m walk course and the average time to complete two trials and (ii) chair stand speed (stands/s) estimated as the speed to complete 5-chair stands without using arms (2). Physical performance was measured approximately every 2 years. Overall, all SOF women completed a median number of six (interquartile range [IQR]: 3–7) assessments of walking speed (mean time between first and last visit: 10.0 [SD = 6.1] years). The median number of chair stand tests was 5 (IQR: 3–7). The mean time between first and last measures was 10.0 (SD = 6.1) years. Women who refused or could not complete the walking speed and chair stand activities received a score of 0 m/s and 0 stands/s, respectively.

Outcomes

Participants were contacted every 4 months from SOF enrollment through December 2009 to ascertain incident nonspine fractures and vital status. During a mean (SD) follow-up of 9.0 (4.0) years for the outcome of mortality, more than 95% of these contacts were completed. We examined two fracture outcomes: hip fracture (n = 6,720) any nonspine fracture (n = 4,725) (Supplementary Figure 1). Nonspine fractures included any fractures other than clinical spine fractures. The most common nonspine fractures were hip (31.2%), wrist (15.0%), humerus (8.6%), rib (7.9%), pelvis (5.1%), foot (4.8%), and ankle (4.5%) fractures. We excluded spine fractures from our analyses, because they were collected via self-report and then adjudicated, and thus, were likely subject to misclassification. A prior study showed that agreement between self-reported vertebral fractures and adjudicated fractures was only 0.51 (12). We also did not include spine fractures, because they have a different pathogenesis than other fractures—almost entirely due to decreased bone density and quality of vertebral bodies, particularly trabecular bone and, therefore, not likely to be related to trajectories of physical function. The analytic sample sizes varied, because we excluded women with unconfirmed or traumatic fractures. Traumatic fractures were defined as fractures resulting from severe trauma (eg, motor vehicle accidents, being struck by a car, falls from greater than a standing height [eg, from a ladder] or other rapidly moving subjects, or assaults) (13). Moreover, for each fracture outcome, women with the fracture of interest prior to age 80 years were excluded. All fractures and deaths were centrally adjudicated via physician review of radiology reports and death certificates, respectively.

Potential Confounding Variables

Potential confounding variables were measured only at the first SOF visit (1986–1988) with the exception of total hip bone mineral density (BMD; measured at Visit 2, 1989–1990). Variables were considered to be potential confounders if they have been known to be associated with both physical performance and our study outcomes, but not in the causal pathway (2,14,15). Weight was measured using a balance beam scale, and height was measured using a Harpenden Stadiometer (Dyfed, UK). Walking for exercise, smoking, alcohol use, calcium use, estrogen use, history of falls in past 12 months, prevalent fracture after age 50 years, stroke, hypertension, and diabetes were self-reported and categorized as yes or no. Health status was categorized as excellent/good versus fair/poor/very poor via self-report. Cognitive function was measured using the modified Mini-Mental State Examination (mMMSE) (16), scores 0–26, with higher scores indicative of better cognitive functioning (17). Total hip BMD (g/cm^2) was measured using dual-energy x-ray absorptiometry (Hologic QDR 1000; Hologic, Bedford, MA). Details of the measurement methods and densitometry quality control procedures have been published elsewhere (18,19).

Statistical Analysis

Analysis of variance and chi-square tests were used to examine differences in SOF enrollment characteristics by walking speed and chair stand speed trajectory slope quintiles. The cognitive function measure (mMMSE) did not follow a normal distribution, and thus, a nonparametric test (Kruskal–Wallis) was used as the test of difference.

Mixed-effects models for estimation of person-level physical performance trajectory slopes and PF_age80

To reduce survival bias and improve the internal validity of our study, we estimated annualized change in physical performance for all women younger than 80 years of age at enrollment and those

who had at least one physical performance trajectory prior to age 80 (n = 8,475) using random slope and intercept models (PROC MIXED procedure in SAS 9.2, SAS Institute, Cary, NC) with age as the time variable. We chose to estimate physical performance only up to age 80 years for several reasons. The assessment of physical performance beyond age 80 years became more problematic, with high rates of missing or imputed data (eg, imputing unable to perform as a poor result) and the possibility of selection bias (those living the longest and returning for assessment are the primary ones who can demonstrate a decline even though they are better off than those not being assessed). We therefore used the physical trajectory over mid-old age (65 to <80 years) to predict subsequent outcomes after age 80 years. Age 80 years was selected based on having enough power (event rates increase significantly in the 80s) to detect an association and being old enough to demarcate "old-old." The modeling approach we used allows each woman to have a unique estimated intercept (physical performance at age of enrollment) and estimated trajectory (slope or change in physical function with each year of increasing age). Change in physical performance was nonlinear, and thus, a quadratic term was added to the regression equation to accommodate steeper declines at older ages. There was a statistically significant interaction between age and clinic site, therefore, clinic-specific trajectory slopes were estimated. Individual-level slopes were based on both individual measurements of physical performance as well as the clinic-level relationship (fixed effect) within the overall rate of change in function. At least one measurement of physical performance was required for inclusion in the analysis. We used the mixed model fit to calculate person-specific changes in physical performance from the enrollment to the last visit prior to age 80 years. We estimated physical performance slopes for an individual with only one measurement, because the mixed-effects regression model can be used to estimate individual-level slopes for all participants, based on the population-level effect (fixed effect) on the overall rate of change (20). This allowed us to avoid subjective rules for including or excluding participants. We chose to define our measures of trajectory a priori rather than use exploratory methods such as latent class growth curve modeling (21) that allow the data to suggest trajectory patterns. Although we may have missed some unexpected trajectory patterns, we preferred the advantage of a more confirmatory analysis and more readily interpretable results. Physical performance changes were subsequently grouped into quintiles (ie, Q1 = greatest decline and Q5 = least decline). Because we were interested in the risk of our outcomes at the "extremes" of physical performance decline (greatest and least), we considered women in Q2–Q4 as the referent category for intermediate decliners. PF_age80 was the actual or predicted (model-based estimates for missing physical performance values) physical performance measurement (walking speed/chair stand speed) at the last visit prior to age 80 years, and was also divided into quintiles, and grouped similarly (comparing middle quintiles with extremes).

Among the 7,015 women in the analytic cohort, 5,650 (80.5%) had measured walking speed and 1,365 (19.5%) had predicted walking speed; 5,612 (80.0%) had measured chair stand speed and 1,403 (20.0%) had predicted chair stand value. Furthermore, in the analytic sample, the number of individuals in each trajectory quintile of walking speed was Q1 (n = 1,348), Q2 (n = 1,416), Q3 (n = 1,434), Q4 (n = 1,354), and Q5 (n = 1,463), and for each trajectory quintile of chair stand speed was Q1 (n = 1,356), Q2 (n = 1,491), Q3 (n = 1,372), Q4 (n = 1,306), and Q5 (n = 1,490).

We also performed secondary analyses using the physical performance quintile with the lowest decline (Supplementary Table 2) and the fastest PF_age80 quintile (Supplementary Table 3) as reference groups, respectively, to determine the risk of fractures and mortality for those with greater decline or lower PF_age80.

A sensitivity analysis excluding hip fractures from the nonspine fracture analysis did not change the overall results, so only the results of all nonspine fractures are shown.

Risk of fractures and mortality by change in physical function

To estimate the effects of physical performance trajectories on incident fractures and mortality after age 80 years, we used Cox proportional hazards regression. Age was used as the time-to-event variable because we observed that the hazard rate of fracture and mortality was more likely to change as a function of age rather than time-in-study. Additionally, using age as time-to-event variable allows for a completely nonparametric age effect (22). A counting process approach was used to identify the at-risk interval for each woman, using age at the last visit prior to age 80 and age at event (fracture or death) or right censoring as the time interval endpoint (23). Three sets of Cox regression models were performed: (i) the base model which included an adjustment of an interaction term between enrollment age and physical performance trajectory, (ii) the base model plus PF_age80 and the interaction between enrollment age and PF_age80, and (iii) the "full multivariate model" adjusted for age, interaction between age and physical performance trajectory, PF_age80, interaction between age and PF_age80, weight, height, walk for exercise, smoking, alcohol use, calcium use, estrogen use, falls in past 12 months, prevalent fracture after age 50 years, stroke, hypertension, diabetes, cognitive function, and hip BMD obtained at SOF enrollment visit.

A secondary analysis was performed to determine whether the PF_age80 score was independent of physical performance trajectories and all other variables in our multivariate model.

Results

The mean age for PF_age80 measurement was 78.8 (SD = 1.3) years. Among the 8,475 participants, and during at least one assessment throughout the study, 590 (7.0%) refused to perform and 68 (0.8%) couldn't complete the walking speed test, whereas 676 (8.0%) refused to perform and 1,351 (15.9%) couldn't complete the chair stand test. Compared with the 2,689 women who were not in the analytic cohort, the 7,015 women were significantly younger (70.4 vs 75.0 years), heavier (26.6 vs 26.3 kg/m^2), more likely to walk for exercise (53.1% vs 42.4%), more likely to report excellent/good health (85.7% vs 76.7%), less likely to report a prevalent fracture (35.2% vs 42.1%), less likely to be a smoker (8.6% vs 13.6%), and less likely to have comorbidities (diabetes: 5.7% vs 10.5%; stroke: 2.3% vs 5.0%; hypertension: 35.8% vs 46.1%), and had higher total hip BMD (0.77 vs 0.72 g/cm^2). The stark differences are due to the fact that we only included women who were younger than age 80 in the analysis, and thus, it is not surprising that women in the analytic cohort were younger and generally healthier. The average rates of decline for each walking speed trajectory quintile (in m/s/year) were as follows: Q1 = 0.027, Q2 = 0.020, Q3 = 0.016, Q4 = 0.011, and Q5 = 0.004. The average rates of decline for each chair stand speed trajectory quintile (in stands/s/year) were as follows: Q1 = 0.013, Q2 = 0.008, Q3 = 0.006, Q4 = 0.004, and Q5 = 0.00008. For both physical performance parameters, all women declined as they got older. The correlation between walking speed and chair stand speed trajectories was ρ = .57, p < .001). The average PF_age80 for each walking speed quintile (in m/s/year) were as follows: Q1 = 0.64,

Q2 = 0.83, Q3 = 0.91, Q4 = 0.96, and Q5 = 1.07, and the average chair stand speed (in stands/s/year) for each chair stand speed quintile were as follows: Q1 = 0.29, Q2 = 0.38, Q3 = 0.42, Q4 = 0.44, and Q5 = 0.50. The participant characteristics at SOF enrollment (1986–1988) for women who were younger than 80 years at enrollment and had at least one physical performance trajectory prior to age 80 (n = 8,475) are shown in Supplementary Table 1. Women with the least walking speed decline enrolled at a younger age, had greater body mass index, and were more likely to report excellent/good health, walking for exercise, and alcohol use than those with greatest decline. Least walking speed decline was also associated with lower self-report of falls, fracture after age 50 years, stroke, hypertension, diabetes, estrogen use, and BMD. The characteristics of women across quintiles of chair stand speed trajectory were analogous to the walking speed trajectory results (data not shown).

After age 80, women were followed for a median (IQR) of 7.7 (4.4–11.2), 8.9 (5.5–11.7), and 9.2 (6.0–11.9) years to assess nonspine fractures, hip fractures, and mortality, respectively. The median (IQR) age for incidence of nonspine fractures was 87 (83–89) years; for hip fractures it was 87 (84–90) years; and for mortality it was 88 (85–90) years. At follow-up, of these 7,015 women, 1,518 (32.1%) had a nonspine fracture, 805 (12.0%) experienced a hip fracture, and 3,682 (52.5%) died.

The Association Between Physical Performance Trajectories and Fractures and Mortality

Nonspine fracture

There were no associations between the least physical performance declines (walking speed and chair stand speed) and nonspine fracture. The associations between the greatest walking speed decline and nonspine fracture were no longer significant after adjusting for walking speed PF_age80. However, the greatest chair stand speed decline was associated with a 19% increased risk of nonspine fracture after accounting for chair stand speed PF_age80 (hazard ratio [HR]: 1.19; 95% confidence interval [CI]: 1.03, 1.37). The relationship attenuated after further adjustment of other potential cofounders though (Table 1).

Hip fracture

The significant increased risks of incident hip fractures among women with the greatest physical performance trajectories (walking speed decline and chair stand speed decline) were not explained by PF_age80. In the full multivariate model, the association between greatest walking speed decline and chair stand speed decline and increased risk of hip fractures remained significant (HR: 1.28; 95% CI: 1.03, 1.58 and HR: 1.26; 95% CI: 1.03, 1.54, respectively). However, there were no associations between the least physical performance declines (walking speed and chair stand speed) and hip fracture.

Mortality

Women with the greatest walking speed decline had a 29% increased significant risk of mortality (Table 1). In contrast, the protective effect on mortality for women with the least walking speed decline was accounted for by walking speed PF_age80 (HR: 0.97; 95% CI: 0.87, 1.09). The greatest chair stand speed decline was also associated with an increased risk of mortality (HR: 1.27; 95% CI: 1.15, 1.39; Table 1). Similarly, the chair stand speed PF_age80 explained the association between women with the least chair stand speed decline and mortality (HR: 0.96; 95% CI: 0.85, 1.08).

The Association Between PF_age80 and Fractures and Mortality

Women in the lowest quintile of walking speed (slowest speed) PF_age80 had a significantly higher risk of nonspine fractures (HR: 1.20; 95% CI: 1.00, 1.44), hip fractures (HR: 1.32; 95% CI: 1.05, 1.66), and mortality (HR: 1.51; 95% CI: 1.36, 1.67) compared with

Table 1. Cox Regression Analysis (n = 7,015) of the Association Between Trajectories of Physical Performance* and Incident Fractures and Mortality

	Base Model†		Base Model + PF_age80‡		Full Multivariate Model¶	
	Q1	Q5	Q1	Q5	Q1	Q5
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Nonspine fracture						
Walking speed	1.19 (1.03, 1.37)	1.01 (0.87, 1.18)	1.10 (0.95, 1.28)	1.07 (0.91, 1.27)	1.09 (0.92, 1.29)	1.04 (0.87, 1.24)
Chair stand	1.26 (1.10, 1.44)	0.85 (0.73, 1.01)	1.19 (1.03, 1.37)	0.92 (0.77, 1.10)	1.16 (1.00, 1.36)	0.93 (0.77, 1.12)
Hip fracture						
Walking speed	1.50 (1.25, 1.80)	0.96 (0.77, 1.19)	1.33 (1.10, 1.61)	1.04 (0.82, 1.32)	1.28 (1.03, 1.58)	0.95 (0.74, 1.22)
Chair stand	1.45 (1.21, 1.73)	0.95 (0.76, 1.18)	1.36 (1.13, 1.64)	1.02 (0.81, 1.29)	1.26 (1.03, 1.54)	1.01 (0.78, 1.29)
Mortality						
Walking speed	1.67 (1.53, 1.81)	0.78 (0.70, 0.87)	1.33 (1.21, 1.45)	0.97 (0.87, 1.09)	1.29 (1.17, 1.42)	0.95 (0.84, 1.07)
Chair stand	1.47 (1.35, 1.59)	0.79 (0.71, 0.89)	1.27 (1.17, 1.39)	0.96 (0.85, 1.08)	1.27 (1.15, 1.39)	0.93 (0.81, 1.06)

Notes: BMD = bone mineral density; BMI = body mass index; CI = confidence interval; HR = hazard ratio; PF_age80 = physical performance at age 80.

*Trajectory quintile for physical performance was calculated using records up to the last visit prior to age 80. The 2nd–4th quintiles (Q2–Q4) were grouped together as the reference group or intermediate decliners. Quintile 1 (Q1) represents greatest decline and quintile 5 (Q5) represents least decline.

†Adjusted for age at enrollment and interaction between age and physical performance trajectory.

‡Actual or predicted physical performance score at the last visit prior to age 80 years divided into quintiles. Model also adjusted for interaction between age and PF_age80 value.

¶Adjusted for age at enrollment, interaction between age and physical performance trajectory, PF_age80, interaction between age and physical performance, BMI, walk for exercise, smoking, alcohol use, calcium use, estrogen use, health status, falls in past 12 months, prevalent fracture after age 50 years, stroke, hypertension, diabetes, cognitive function, and hip BMD.

women in the intermediate quintiles. This association was independent of walking speed trajectories and all other covariates in the full multivariate model (Table 2). Conversely, there was no relationship between women in the highest quintile of walking speed (fastest speed) PF_age80 and nonspine fracture and hip fracture. However, the walking speed PF_age80 was a significant predictor of mortality after accounting for changes in walking speed (HR: 0.73; 95% CI: 0.66, 0.81).

Being in the top quintile of chair stand speed, PF_age80 was significantly associated with lower risk of mortality (HR: 0.80; 95% CI: 0.72, 0.88). Women in the lowest quintile of chair stand speed PF_age80 had a significantly increased risk of nonspine fracture and mortality (Table 2). There was no association between chair stand speed PF_age80 and hip fracture after accounting for chair stand speed trajectory.

A summary of the multivariate findings for both physical performance trajectories and PF_age80 is shown in Table 3. Greatest walking and chair stand speed decline were both associated with an increased risk of hip fractures and mortality. Fastest walking and chair stand speed were both associated with a decreased risk of mortality. There was an increased risk of nonspine fractures and mortality among those with either the slowest walking speed PF_age80 or the slowest chair stand speed PF_age80. Slowest walking speed PF_age80 was associated with an increased risk of hip fractures.

The results of the secondary analyses using the physical performance quintile with the lowest decline and the fastest PF_age80 quintile as the reference groups suggest that women with intermediate physical performance decline or intermediate PF_age80 are at an increased risk of mortality (Supplementary Tables 2 and 3).

Discussion

To our knowledge, this is the first study to examine the association between trajectories of physical performance and incident fractures and mortality. We found that greatest declines in walking speed and chair stand speed before age 80 were both significantly associated with an increased risk of hip fracture and mortality, but not nonspine fractures, after age 80 years. Furthermore, intermediate physical performance decline was associated with an increased risk of mortality compared with the lowest physical performance groups.

Our finding that greatest walking speed decline and slowest walking speed PF_age80 were associated with an increased risk of hip fractures is consistent with prior research showing that lower walking/gait speed is associated with a higher risk of hip fractures (1,3). Walking speed test primarily assesses functional mobility and

Table 3. Summary of Multivariate Findings Showing the Associations Between Both Trajectories of Physical Performance and PF_age80 and Incident Fractures and Mortality

Physical Performance	Nonspine Fracture	Hip Fracture	Mortality
Walking speed trajectory			
Greatest decline	Null	Increased	Increased
Least decline	Null	Null	Null
Chair stand speed trajectory			
Greatest decline	Null	Increased	Increased
Least decline	Null	Null	Null
Walking speed PF_age80			
Fastest	Null	Null	Decreased
Slowest	Increased	Increased	Increased
Chair stand speed PF_age80			
Fastest	Null	Null	Decreased
Slowest	Increased	Null	Increased

Note: Decreased = exposure associated with lower risk of outcome; Increased = exposure associated with higher risk of outcome; Null = no association between exposure and outcome; PF_age80 = physical performance at age 80.

Table 2. Cox Regression Analysis (n = 7,015) of the Association Between PF_age80* and Fractures and Mortality

	Base Model†		Base Model + Trajectory‡		Full Multivariate Model¶	
	Q1	Q5	Q1	Q5	Q1	Q5
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Nonspine fracture						
Walking speed	1.26 (1.08, 1.47)	0.92 (0.81, 1.04)	1.21 (1.03, 1.42)	0.92 (0.80, 1.05)	1.20 (1.00, 1.44)	0.92 (0.79, 1.07)
Chair stand	1.21 (1.06, 1.40)	0.85 (0.75, 0.97)	1.14 (0.99, 1.33)	0.89 (0.78, 1.02)	1.18 (1.01, 1.39)	0.91 (0.78, 1.06)
Hip fracture						
Walking speed	1.54 (1.27, 1.86)	0.86 (0.72, 1.04)	1.38 (1.13, 1.69)	0.89 (0.73, 1.09)	1.32 (1.05, 1.66)	0.85 (0.69, 1.04)
Chair stand	1.29 (1.07, 1.55)	0.87 (0.73, 1.04)	1.16 (0.96, 1.41)	0.91 (0.75, 1.10)	1.15 (0.93, 1.43)	0.90 (0.73, 1.11)
Mortality						
Walking speed	1.92 (1.77, 2.09)	0.66 (0.60, 0.72)	1.71 (1.56, 1.87)	0.70 (0.63, 0.77)	1.51 (1.36, 1.67)	0.73 (0.66, 0.81)
Chair stand	1.49 (1.37, 1.62)	0.71 (0.65, 0.78)	1.35 (1.24, 1.48)	0.76 (0.69, 0.83)	1.23 (1.12, 1.36)	0.80 (0.72, 0.88)

Notes: BMD = bone mineral density; BMI = body mass index; CI = confidence interval; HR = hazard ratio; PF_age80 = physical performance at age 80.

*Actual or predicted physical performance score at the last visit prior to age 80 years divided into quintiles. The 2nd–4th quintiles (Q2–Q4) were grouped together as the reference group or intermediate speeds. Quintile 1 (Q1) represents slowest speed and quintile 5 (Q5) represents fastest speed.

†Adjusted for age at enrollment and interaction between age and PF_age80 quintiles.

‡Trajectory quintile for physical performance was calculated using records up to the last visit prior to age 80. The 2nd–4th quintiles were grouped together as the reference group or intermediate decliners. Q1 represents greatest decline and Q5 represents least decline. Model also adjusted for interaction between age and physical performance trajectory.

¶Adjusted for age at enrollment, interaction between age and PF_age80, physical performance trajectory, interaction between age and physical performance trajectory, BMI, walk for exercise, smoking, alcohol use, calcium use, estrogen use, health status, falls in past 12 months, prevalent fracture after age 50 years, stroke, hypertension, diabetes, cognitive function, and hip BMD.

gait, and thus, interventions that improve gait are needed for women with declining or poor walk speed. Poor physical performance as defined by the chair stands test is a robust risk factor for incident hip fractures in men (1) and women (2). Our results extend these findings to include greatest chair stand speed decline over time as an independent risk factor for hip fracture. Cawthon and colleagues showed that men with the slowest chair stand time had 3.7 times the risk of a hip fractures compared with men with the best chair stand time (fastest quartile) (1). Cummings and colleagues found that the inability to stand from a chair was associated with a two-fold increased risk of hip fractures in older women (2). The chair stand test primarily examines lower body leg strength and endurance and is a direct measure of lower extremity power. Clinicians should consider patients with declining lower extremity function to be at an increased risk of hip fracture.

We did not find an association between physical performance decline measures and risk of nonspine fractures. Conversely, women with the slowest walking speed or chair stand speed were at an increased risk of nonspine fractures. Lewis and colleagues found that baseline physical performance measured as the inability to complete a narrow walk trial was associated with a 70% increased risk of nonspine fractures in older men (4). The lack of an association between physical performance change and all nonspine fractures may suggest that physical performance change may play a larger role for frailty type fracture (eg, hip fractures). Furthermore, all nonspine fractures are heterogeneous outcomes.

Both greatest and intermediate physical performance decline (for both walking speed and chair stand speed) were associated with an increased risk of mortality independent of PF_age80 and many covariates. Additionally, both PF_age80 measures were associated with mortality. A meta-analysis using five studies on walking speed and chair stand rise time found that the risk of mortality was about three and two times higher among participants in the slowest versus highest quarter of walking speed and chair stand risk time, respectively (7). Furthermore, a meta-analysis of nine cohort studies showed that higher gait speed was associated with increased survival in older adults (8). Our results extend these findings to include trajectories measured over about 10 years and imply that repeat assessment of chair stand ability and walking speed may be important in clinical settings.

Accounting for physical performance trajectories in the analysis largely attenuated the association between PF_age80 and some of our study outcomes. For instance, the associations between chair stand speed and hip fractures and nonspine fractures were no longer significant after adjusting for chair stand speed trajectory. Moreover, although PF_age80 was slightly more likely to predict fractures and mortality, the magnitude of the associations were comparable with physical performance trajectories. This suggests that there should be an emphasis on single measurement levels of physical performance, but also that the role of physical performance improvement and maintenance may enhance our ability to identify women at high risk of fractures and death.

Strengths of our study include a large analytic sample size, study follow-up of up to 9 years, the use of age as the time-to-event variable to better capture the change in the hazard rate of fracture and mortality, objective physical performance measures that were assessed an average of 5 times over 10 years, and objective ascertainment of fractures and deaths. Nonetheless, our study had several limitations. Our study population consisted of older community-dwelling generally healthy white women, and thus, our findings may not be generalizable to nonwhite women or men. A future study that uses a complex sampling design to ensure a more representative sample of the United States is needed. Additionally, because we did not have repeated measurements for each potential confounder, our analysis did not account for time-varying covariates, which may influence the impact of the physical function trajectories on our outcomes. Finally, although we adjusted for many potential confounders including PF_age80, residual confounding is a feature of all observational studies. For instance, we did not have information on comorbidities such as history of myocardial infarction at the study enrollment.

In summary, greatest walking speed decline and chair stand speed decline were both associated with an increased risk of hip fractures and mortality independent of the single measurement of physical performance (PF_age80) and other important potential confounders. Our findings suggest that greater dissemination of physical activity interventions (24,25) designed to improve and maintain adequate lower extremity physical performance in older adults by increasing gait, balance, and lower muscle strength are needed in clinical and community settings.

Supplementary Material

Please visit the article online at http://gerontologist.oxfordjournals.org/ to view supplementary material.

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