Title
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Journal
The Journals of Gerontology Series A, 74(9)

ISSN
1079-5006

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Publication Date
2019-08-16

DOI
10.1093/gerona/gly248

Peer reviewed

Journals of Gerontology: Medical Sciences
cite as: *J Gerontol A Biol Sci Med Sci*, 2019, Vol. 74, No. 9, 1475–1483
doi:10.1093/gerona/gly248
Advance Access publication November 1, 2018

Research Article

The Relationships Between Physical Performance, Activity Levels, and Falls in Older Men

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Received: March 5, 2018; Editorial Decision Date: October 15, 2018

Decision Editor: Anne Newman, MD, MPH

Abstract

Background: Physical performance and activity have both been linked to fall risk, but the way they are jointly associated with falls is unclear. We investigated how these two factors are related to incident falls in older men.

Methods: In 2,741 men (78.8 ± 5 years), we evaluated the associations between activity and physical performance and how they jointly contributed to incident falls. Activity was assessed by accelerometry. Physical performance was measured by gait speed, dynamic balance (narrow walk), chair stand time, grip strength, and leg power. Falls were ascertained by tri-annual questionnaires.

Results: Men were grouped into four categories based on activity and performance levels. The greatest number of falls (36%–43%) and the highest fall rate (4.7–5.4/y among those who fell) (depending on the performance test) occurred in men with low activity/low performance, but most falls (57%–64%) and relatively high fall rates (3.0–4.35/y) occurred in the other groups (low activity/high performance, high activity/high performance and high activity/low performance; 70% of men were in these groups). There were interactions between activity, performance (gait speed, narrow walk), and incident falls (p = .001–.02); predicted falls per year were highest in men with low activity/low performance, but there was also a peak of predicted falls in those with high activity.

Conclusions: In community-dwelling older men, many falls occur in those with the lowest activity/worst physical performance but fall risk is also substantial with better activity and performance. Activity/physical performance assessments may improve identification of older men at risk of falls, and allow individualized approaches to prevention.

Keywords: Aging, Activity, Observational, Function

Many people older than 65 years fall at least once per year and falls are a leading cause of injuries (1). Approaches to reduce the risk of falls have concentrated on those considered to be at highest risk due to impairments in gait and balance, comorbid conditions, visual impairment, etc (2,3). Some interventions reduce risk (4), but the complexity of fall causation represents a barrier to developing effective preventive strategies.

Activity is not typically considered as a risk factor for falls clinically or in fall risk assessment guidelines. However, lower levels of activity are associated with higher fall risk in older adults (5). In contrast, higher activity may also be associated with a propensity to fall (6–9) potentially because those with greater activity have more opportunities to fall. Similarly, lower levels of physical performance (commonly considered a risk factor for falls) are related to higher fall (7) and fracture risk (10,11), but at the same time faster gait speed has also been linked to higher fall risk (12). The fact that falls can be associated with various levels of activity and physical performance illustrates the multifaceted nature of fall causation, and the complexity of assessing fall risk.

In earlier work, we postulated that interactions between activity and physical performance are important in understanding falls in older men (13). To better determine the joint contributions of these two factors, we assessed the pattern of falls, and the risk of falls, as a function of objectively measured physical activity and performance in a cohort of 2,741 older men enrolled in the Osteoporotic Fractures in Men Study (MrOS). We were interested in whether these measures could help define the men at higher fall risk and the degree to which falls are limited to those with low activity and low performance (those traditionally considered at risk). Moreover, we examined the hypothesis that the combined assessment of activity and physical performance may be useful in identifying fallers. To determine if findings were consistent, we analyzed the associations using several assessments of activity and physical performance/muscle function.

Methods

Participants

In 2000–2002, 5,994 community-dwelling men aged 65 years and older from six U.S. regions were recruited to participate in MrOS (14). The inclusion criteria were (i) ability to walk without the assistance of another, (ii) absence of bilateral hip replacements, (iii) ability to provide self-reported data, (iv) residence near a clinical site for the duration of the study, (v) absence of a medical condition that (in the judgment of the investigator) would result in imminent death, and (vi) ability to understand and sign an informed consent. The characteristics of the men were similar to representative populations (eg, NHANES) (15). From 2007 to 2009, 4,784 surviving participants were invited to Visit 3 (V3) and 2,913 men provided valid activity data. After excluding participants who died (n = 51, 1.8%) or who had missing falls data in the year following the visit (n = 121, 4.2%), 2,741 men were available for analysis (Supplementary Figure S1). The characteristics of the men who were not included in the analysis are shown in Supplementary Table S1. The institutional review board at each participating institution approved the study protocol, and informed consent was obtained from all participants.

General Measurements

Weight was measured with balance beam or digital scales, and height with wall-mounted stadiometers. Questionnaires and interviews were used to obtain demographic, lifestyle, and health data including age, race (white or other), use of a walking aid, self-reported health status (excellent/good vs fair/poor/very poor), and falls in the previous 12 months. Frailty status was defined using criteria similar to those proposed by Fried and colleagues (16–18) and status was categorized in three levels: frail, pre-frail, and non-frail.

Fall Ascertainment

Participants reported fall events at 4-month intervals using mailed questionnaires sent in March, July, and November of each year (8). These included questions about the number of falls sustained in the past 4 months. Specifically, participants were asked "How many times have you fallen in the last 4-month period; 1, 2, 3, 4, 5 or more." The response rates to the mailed questionnaire were high (≥96%).

Physical Activity and Physical Performance Measures

We used accelerometry to objectively assess physical activity (19). Participants wore an activity monitor (SenseWear Pro Armband; BodyMedia, Inc., Pittsburgh, PA) over the right triceps at all times (except for bathing and water activities) for a 7-day period following V3. Accelerometry data were used to calculate metabolic equivalents (MET; energy expenditure divided by the constant value of 1 kcal/kg/h) (20,21) and total daily energy expenditure (kcal/d). METs were used to estimate time spent (min/24 h) in sedentary behavior (MET level ≤ 1.50) and light (MET level 1.51–2.99), moderate (MET level 3.00–5.9), and vigorous activity (MET level ≥ 6.0) (22). We excluded men who wore the activity monitor less than 90% of the time or did not wear it on at least one weekend day. Activity measures were averaged over all days. Very few men reported any vigorous activity. Because all results were essentially the same when using light, moderate, or vigorous activity categories, or the sum of all three, we report results using the sum (ie, time in non-sedentary activity). In addition, self-reported physical activity was assessed using the Physical Activity Scale for the Elderly (PASE) (23).

Physical performance was measured with walking speed, narrow walk time, chair stand time, and assessments of muscle function including grip strength and leg power. As described (10), we measured walking speed (m/s) at usual pace over 6 m, dynamic balance as time to walk a narrow path (20 cm) over 6 m, the time to complete five repeated chair stands, grip strength using Jamar dynamometers (Sammons Preston Rolyan, Bolingbrook, IL) (24), and leg power (watts) using the Nottingham Power Rig (Nottingham University, Nottingham, England). If the participant was unable to complete a task, the measure was set to missing. To illustrate the characteristics of the fallers, we also utilized a score to summarize the results of the physical performance tests (Table 1). It categorized (0–3) the participants by the number of the three main physical performance tests (gait speed, narrow walk, and chair stands) in which performance was in the worst quartile (0 = none of the tests in the worst quartile; 3 = all three tests in the worst quartile).

Statistical Methods

Falls analysis

Using every 4-month questionnaires, we analyzed falls in the 12 months after Visit 3. For the 4-month interval that overlapped V3, we scaled the reported falls to be proportional to the period covered after the visit. We then used the full interval of the next two questionnaires, and the fourth questionnaire to make up the difference of the first questionnaire (for 12 months of follow-up).

Participant characteristics and falls

Participant characteristics were summarized overall and by fall categories (no falls, one fall, and >1 fall). Differences by fall categories were assessed using analysis of variance for continuous variables or chi-squared tests and Fisher's exact test for nominal variables.

Table 1. Descriptive Statistics of the Analytic Sample by the Number of Falls in the Year After V3

	No Falls (n = 1,777)		One Fall (n = 327)		Two or More Falls (n = 637)		
Characteristics	Mean or n	SD or %	Mean or n	SD or %	Mean or n	SD or %	p Value[a]
Age (range 71–98)	78.4	4.9	79.0	5.1	80.0	5.4	<.001
Race[b]							
White	1,576	88.7	310	94.8	588	92.3	0.009
African American	60	3.4	2	0.6	14	2.2	
Asian	76	4.3	7	2.1	13	2.0	
Hispanic	40	2.3	6	1.8	14	2.2	
Other	25	1.4	2	0.6	8	1.3	
BMI (range 18.00–44.23)	27.1	3.6	26.9	3.5	27.2	4.0	0.644
Number of falls (range 0–30)					6.3	5.2	
≥Light activity (min/d)	160.8	88.2	156.4	89.9	141.9	89.1	<.0001
≥Moderate activity (min/d)	90.0	61.5	88.0	62.0	77.8	60.6	0.001
PASE score	140.1	65.2	136.7	69.9	127.4	68.0	0.001
Seconds to complete five stands	11.2	3.2	11.6	3.3	12.3	4.4	<.0001
Narrow walk (m/s)	1.1	0.2	1.1	0.3	1.1	0.3	<.0001
Walk speed (m/s)	1.2	0.2	1.2	0.2	1.1	0.3	<.0001
Number of comorbidities (range 0–6)[c]	1.1	1.0	1.2	1.1	1.3	1.1	<.001
Health status							
Fair, poor, very poor	172	9.7	40	12.2	109	17.1	<.001
Good, excellent	1,602	90.3	287	87.8	528	82.9	
Number of medications	8.0	4.6	8.5	4.5	9.2	4.9	<.001
Walking aid							
None	1,675	94.3	301	92.1	527	82.7	<.001
Cane	81	4.6	22	6.7	87	13.7	
Wheelchair	21	1.2	4	1.2	23	3.6	
Falls reported in previous 12 mo							
0: No	1,445	81.3	213	65.1	305	47.9	<.001
1: Yes	332	18.7	114	34.9	332	52.1	
Frailty status							
Non-frail	698	39.3	132	40.4	200	31.5	<.001
Pre-frail	922	51.9	149	45.6	225	35.4	
Frail	155	8.7	46	14.1	211	33.2	
Summary physical performance score[d]							
0 (best)	819	46.1	134	41.0	157	24.7	<.001
1–2	620	34.9	105	32.1	352	55.3	
≥3 (worst)	336	18.9	88	26.9	128	20.1	

Notes: BMI = body mass index; na = xxx; PASE = Physical Activity Scale for the Elderly.

[a]*p* values assessed using analysis of variance for continuous variables and chi-squared tests for nominal variables, unless otherwise noted. [b]*p* value assessed using Fisher's exact test. [c]Self-report of physician-diagnosed cardiovascular disease, hypertension, diabetes mellitus, chronic obstructive pulmonary disease, Alzheimer's disease, Parkinson's disease, kidney disease, or liver disease and non-skin cancers. [d]Number of tests with poor performance as defined as the worst performance quartile.

Pearson's correlations among activity and performance measures were calculated.

Activity and physical performance analyses

To depict the distribution of falls, and to construct related figures, we summarized activity and performance measures by quartiles. For further analyses based on activity and performance, we grouped men into four groups (quadrants): Quadrant 1—above the median in activity and performance (eg, third and fourth quartiles for both), Quadrant 2—below in median in activity (first and second quartiles) and above the median in performance (third and fourth quartiles), Quadrant 3—below the median in activity and performance (first and second quartiles for both), and Quadrant 4—above the median in activity (third and fourth quartiles) and below the median in performance (first and second quartiles). In each quadrant group, we summarized the total number of men, total number of falls, number of men with no falls, one fall and more than one fall, and overall rate of falls per man per year. To avoid excessively skewed data, we examined the average number of falls in 1 year among those men who fell at least once. We utilized the quadrant groupings to compare numbers of falls and fall risk, and to examine interactions between activity, performance, and falls, we modeled the rate of falls using negative binomial regression.

Covariates

To examine the possible associations of other factors that might affect fall risk, we adjusted the estimate of fall rate for age, history of two or more falls in the last year (yes/no), the use of walking aids (cane/walker/wheelchair), and number of medications. In prior studies, the latter is a proxy for an individual's underlying health and comorbidity and much more strongly associated with falls and fall injuries than number of chronic conditions (25,26). A wide variety of other measures could also be considered as covariates but have relatively modest effects (27). We have not included measures of frailty because that would overlap with the physical performance measures. A number of other potential mediators of the effects of activity and performance on fall risk (eg, vision, neuropathy, cognition) have not been included because appropriate measures were not available in this cohort and an exploration of the pathways responsible for the impact of activity and performance on fall risk was not the scope of this analysis.

Tests for interactions

To test for a formal interaction between of activity and performance, we modeled the rate of falls as above. Models were adjusted for age and included main effects for activity and for performance, as well as an activity by performance interaction. To test the interactions after adjusting for covariates, we then added number of medications, history of multiple falls in the last year (yes/no), and the use of walking aids (cane/walker/wheelchair) to the model. From the fully adjusted model, we estimated the predicted number of falls for each subject and calculated the average, 2.5th percentile, and 97.5th percentile predicted falls by activity/performance quadrant. Additionally, based on previous findings in MrOS (8), we hypothesized that the association between performance, activity, and falls could differ according to age. To address this, we tested for a three-way interaction of age, activity, and performance and performed analyses stratified by age group (<80 vs ≥80 years, including the main effect for age). To help understand the nature of interactions detected in the models, we graphed the predicted number of falls from the regression model by activity and performance.

Analyses were performed in SAS version 9.3 (Cary, NC), and the R package "ggplot2" and "plotly" were used for figures. A .05 significance level was used.

Results

Participant Characteristics

Cohort characteristics are provided in Table 1 according to category of falls. The average age was 78.8 ± 5 years (range 71–98). Falls were common: at least one incident fall occurred in 35% during the 1-year follow-up, and 23% reported two or more falls. Those men not included in these analyses because of unavailable activity data or follow-up for falls (Supplementary Table S1) were on average less healthy, and had lower physical performance and reported activity levels.

Those who reported falls had lower average energy expenditure ($p = .004$) and less time in non-sedentary activity ($p < .001$) (Table 1), but these differences were modest; there was a wide and overlapping range of activity across all groups. Similarly, there was wide variation in the levels of physical performance within the fall groups.

Measures of Activity and Physical Performance Were Modestly Correlated

Correlations between physical performance and activity were significant but generally low ($r = .2–.3$) (Supplementary Table S2). In contrast, the proportion of time spent in sedentary activity was inversely related to the time spent in non-sedentary activities; the correlation was moderate in magnitude ($r = –.65$, $p < .0001$).

Categorizing Participants on the Basis of Activity and Physical Performance

Figure 1 plots the distribution of participants as a function of both their time spent in non-sedentary activity and objective measures of their physical performance (gait speed, narrow walk, and chair stand time). To enable comparisons, we show each measure in quartiles and identify four groups (Figure 1, Key) (see Statistical Methods).

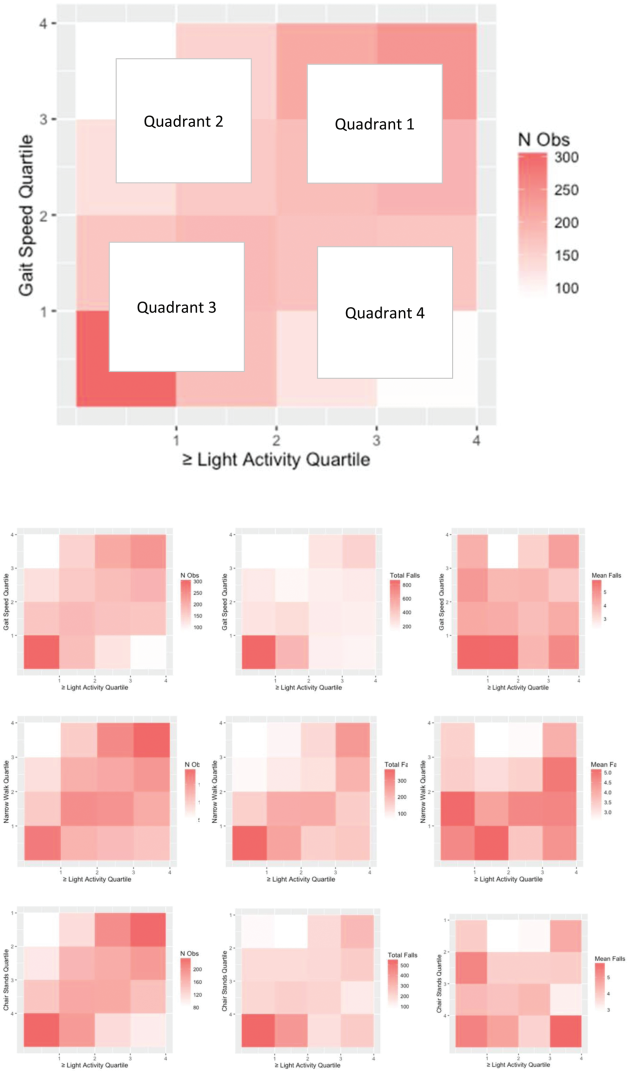

Figure 1. Key for identifying tile plot quadrants. Quartiles of activity (time spent in >light activity) are plotted on the abscissa and quartiles of physical performance on the ordinate. The example of non-sedentary activity vs gait speed is used to illustrate the approach. (**A**) Activity vs gait speed. (**B**) Activity vs narrow walk time. (**C**) Activity vs chair stand time.

The left panels of Figure 1A–C show that the physical activity and physical performance characteristics of the overall cohort and provide useful context for the data in the other comparisons. In Table 2, we show these trends quantitatively. Physical activity and physical performance varied widely in the cohort. For instance, 30% of men had both low levels of non-sedentary activity and low gait speed (Figure 1A, quadrant 3), while a comparable percentage (30.1%) were both more active and had better physical performance (Figure 1A, quadrant 1). Fewer but substantial numbers of men spent little time in non-sedentary activity but had good physical performance (19.3%) or had higher levels of activity but poor physical performance (20.2%) (Figure 1A, quadrants 2 and 4, respectively). Very similar patterns were apparent with the other measures of physical performance (Figure 1B and C, left panels). Data from the questionnaire-based measure of activity (PASE) were also similar (Supplementary Figure S2 and Supplementary Table S3).

Table 2. Falls, Non-sedentary Activity, and Physical Performance

	Overall	Quadrant 1 (Best Activity, Best Performance)		Quadrant 2 (Least Activity, Best Performance)		Quadrant 3 (Least Activity, Least Performance)		Quadrant 4 (Best Activity, Least Performance)		
Activity (≥Light) vs Gait Speed										
	N	*n*	%	*n*	%	*n*	%	*n*	%	*p*[a]
Number of men	2,727	820	30.1	525	19.3	831	30.5	551	20.2	
Total falls	4,312	1,009	23.4	603	14.0	1,910	44.3	790	18.3	
No falls	1,770	563	68.7	363	69.1	477	57.4	367	66.6	<.001
One fall	326	96	11.7	60	11.4	99	11.9	71	12.9	
More than one fall	631	161	19.6	102	19.4	255	30.7	113	20.5	
Fall rate falls/man/y		1.23		1.15		2.31		1.43		
Predicted fall rate (man/y) (2.5th and 97.5th percentile)[b]		1.14 (0.61, 2.86)		1.26 (0.56, 3.14)		2.38 (0.81, 7.31)		1.45 (0.68, 4.04)		
		Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	***p*[d]**
Falls/y[c]		3.93	4.1	3.72	4.3	5.40	5.5	4.29	4.7	<.001
Activity (≥Light), Narrow Gait										
		n	%	*n*	%	*n*	%	*n*	%	*p*[a]
Number of men	2,117	657	31.0	365	17.2	573	27.1	522	24.7	
Total falls	2,792	745	26.7	319	11.4	998	35.7	730	26.1	
No falls	1,432	456	69.4	260	71.2	362	63.2	354	67.8	.002
One fall	259	88	13.4	50	13.7	65	11.3	56	10.7	
More than one fall	426	113	17.2	55	15.1	146	25.5	112	21.5	
Fall rate falls/man/y		1.13		0.87		1.74		1.40		
Predicted fall rate (man/y) (2.5th, 97.5th percentile)[b]		1.07 (0.57, 2.76)		1.17 (0.56, 3.12)		2.09 (0.73, 7.01)		1.44 (0.66, 3.75)		
Falls/y[c]		**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	***p*[d]**
		3.71	4.2	3.04	3.3	4.73	4.9	4.35	4.6	.006
Activity (≥Light), Chair Stands										
		n	%	*n*	%	*n*	%	*n*	%	*p*[a]
Number of men	2,540	797	31.4	460	18.1	743	29.3	540	21.3	
Total falls	3,634	930	25.6	554	15.2	1,373	37.8	777	21.4	
No falls	1,694	555	69.6	324	70.4	457	61.5	358	66.3	.004
One fall	298	91	11.4	47	10.2	91	12.2	69	12.8	
More than one fall	548	151	18.9	89	19.3	195	26.2	113	20.9	
Fall rate falls/man/y		1.15		1.20		1.85		1.47		
Predicted fall rate (man/y) (2.5th, 97.5th percentile)[b]		1.07 (0.57, 2.76)		1.17 (0.56, 3.13)		2.09 (0.73, 7.01)		1.44 (0.66, 3.76)		
Falls/y[c]		**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	***p*[d]**
		3.84	4.1	4.07	4.1	4.80	5.0	4.27	4.4	.08

Note: [a]*p* value assessed using chi-squared tests to assess if the distribution of falls differs by activity/performance category. [b]The average (2.5th percentile, 97.5th percentile) predicted number of falls from fully adjusted negative binomial regression models by performance/activity quadrant. [c]Among fallers. [d]*p* value assessed using analysis of variance.

Importantly, the pattern of falls by activity and performance was similar when alternative measures of activity and performance were substituted for the primary measures of non-sedentary activity and gait speed. For instance, of the 239 men in the upper right segment of the gait speed–activity plot (left panel, Figure 1A; 1/16 of all men tested), 86% remained in the upper right quadrant in analyses of narrow walk (left panel, Figure 1B) and 80% in the upper right quadrant in analyses of chair stand time (left panel, Figure 1C). Formal testing of concordance of patient characteristics between physical performance testing revealed similar results, with gamma statistics of .65–.77 when comparing the all quadrants of gait speed–activity to narrow walk-activity, and between .35 and .49 comparing quadrants of gait speed–activity to chair stand time–activity.

The characteristics among the men in these four quadrants (for gait speed and non-sedentary activity) are shown in Supplementary Table S4. As expected, those in quadrant 3 (least activity/slowest gait speed) tended to be older and more frail, reported worse health status and more comorbidities, and had fallen more often in the previous 12 months.

The Number of Incident Falls as a Function of Activity and Physical Performance

To appreciate the fall rate data shown below, it is useful to show the distribution of falls among the groups. The middle panels of Figure 1 show the total number of incident falls as a function of activity and physical performance. The corresponding quantitative data are in provided in Table 2. A small proportion of all falls occurred in men who had limited activity and good physical performance (eg, only 14% of all falls occurred in men with low activity and more rapid gait speed). A somewhat higher proportion of all falls occurred in men with high activity and rapid gait speed (23.4%) and in men with high activity but slow gait speed (18.3%). The highest proportion (44%) occurred in men with low activity and slow gait speed. A similar pattern was apparent in analyses of narrow walk speed and chair stand time (Figure 1B and C, middle panels), when we assessed activity with a questionnaire-based tool (PASE) (Supplementary Figure S2, and Supplementary Table S3) or analyzed other performance measures (grip strength, leg power) (data not shown).

The Rate of Incident Falls as a Function of Activity and Physical Performance

An analysis of average number of incident falls in men who reported at least one fall during the 1-year follow-up period (Figure 1A–C, right panels and Table 2) revealed that the rate was somewhat higher in men with low activity and low physical performance (4.7–5.4/y) but was also substantial in the other groups (3.0–4.35/y). We observed analogous patterns when we examined the fall rate in all men (Table 2), or when activity was assessed with PASE (Supplementary Figure S2 and Supplementary Table S3) or other measures of performance (grip strength, leg power) (data not shown). After adjusting for potential confounders, the pattern of fall rates between activity/performance groups did not change appreciably (Table 2).

Interactions Among Activity, Performance, and Age

To test for a formal interaction between activity, performance, and number of falls per person, negative binomial regression models evaluated main effects and interaction terms for activity and performance, adjusted for age. There were significant interactions between activity and gait speed ($p = .001$) and narrow walk ($p = .02$), but not chair stands ($p = .15$) (Supplementary Table S5). The adjusted results from the multivariable models were comparable: activity and gait speed ($p = .016$), narrow walk ($p = .07$), and chair stands ($p = .32$).

To help understand the nature of interactions, we graphed the predicted number of falls from the regression model by activity and performance. The models are illustrated in Figure 2. Interactive versions of those figures (available in Supplementary Material) display these interactions more effectively. Observed levels of activity and performance are plotted against the model's predicted number of falls per person. When considering narrow walk and gait speed, predicted falls per year (from the negative binomial model) were highest in men with low activity and low performance, but there was also a peak of predicted falls in those with high activity. Predicted falls were lowest in men with better performance and less activity.

In gait speed and chair stands models, falls were significantly higher with age (for model with gait speed, rate ratio [RR] = 1.03 per year of age, 95% CI = 1.01–1.05; for model with chair stands, RR = 1.03 per year of age, 95% CI = 1.01–1.05). To further evaluate the role of age, we tested for a three-way interaction of age, performance, and activity, but the results were not significant for models with gait speed, narrow walk, or chair stands ($p = .32$, .73, and .35, respectively). However, after stratifying at age 80 years and older, the interaction of activity and gait speed was significant ($p = .004$) in men younger than 80 years but not in men older than 80 years. No significant interactions were observed for narrow walk and chair stands after age stratification.

Discussion

In this large, prospective study of community-dwelling older men, falls were common and occurred across the spectrum of activity and physical performance levels. While activity and physical performance levels were modestly correlated, they were each independently associated with falls, suggesting that they both provide unique information about fall propensity. The largest proportion of falls and the highest fall rate were observed in men with both low physical performance and low activity, but most falls and relatively high fall rates occurred in the other groups, including in those with high performance and high activity, a group that would not usually receive clinical attention for fall prevention. That fall rates for each combination of activity and performance (high–high, high–low, low–high, and low–low) did not substantially depend on which measure of physical activity, nor upon which performance measure, was used reinforces the validity of our findings. Our results suggest large heterogeneity in the associations of activity level and physical performance capacity in the genesis of falls in older men. The significant interactions between activity and physical performance support the value of examining the *combined* characteristics of activity and physical performance to inform the understanding of falls. In a clinical context, these results raise the possibility that fall prevention strategies should be tailored to address specific activity and performance characteristics that contribute to risk.

In our analyses, and in previous research, activity and physical performance are both associated with fall risk. Confirming previous findings that many falls occur in men with low levels of activity or physical activity, our research demonstrate that a substantial proportion of all falls (35%–45%, depending on the physical performance measure) occurred in the approximately 30% of men with both low activity and low physical performance. The rate of falls was also highest in that group. However, it is remarkable that the fall rate was substantial in the other three groups and most falls occurred in those groups. In fact, the group with high activity and low performance—a group intuitively at risk of falls—had a fall rate almost as high as those with low activity and low performance.

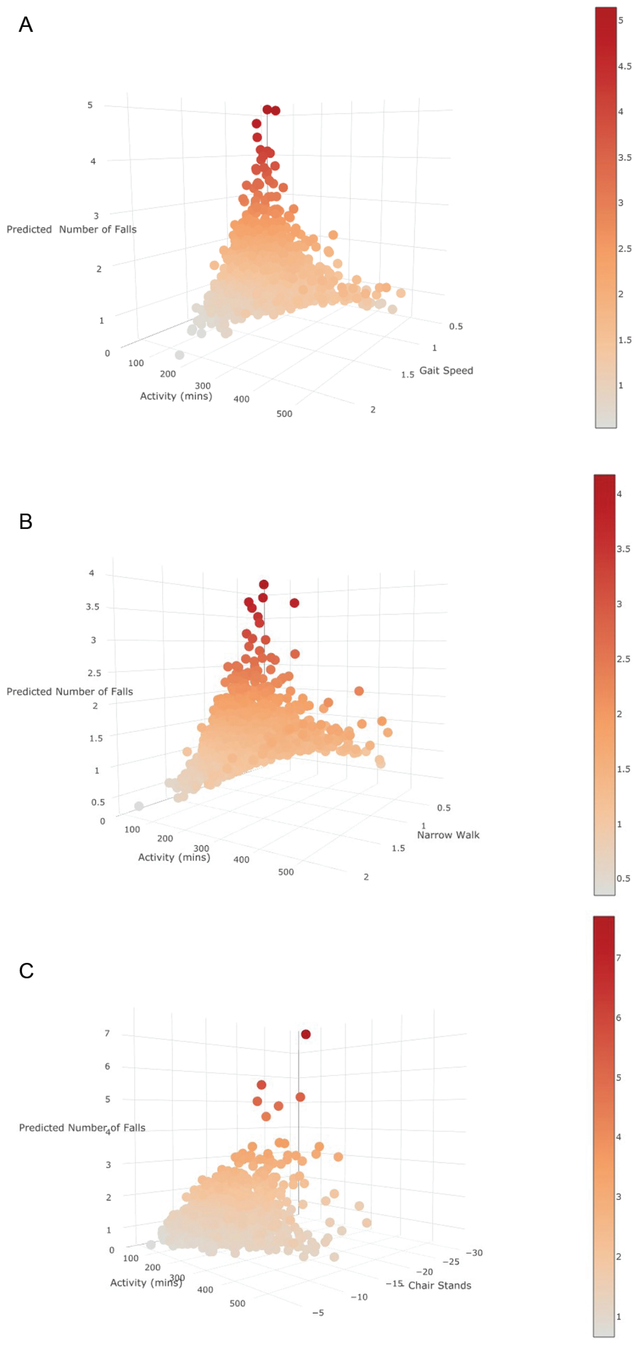

Figure 2. The relationships between physical activity, performance, and falls. (**A**) Gait speed and activity. (**B**) Narrow walk speed and activity. (**C**) Chair stand time and activity.

Moreover, men who had high activity and high performance, presumably because of their exposure to risk, contributed a high proportion of falls, including repeated falls. Given that 20%–30% of all falls are associated with moderate–severe injuries in older individuals (28,29), those who have high activity and repeated falls may be group deserving of special clinical attention. These findings emphasize that the risk of falls in men is not limited to those typically considered frail, and that men of high activity and/or performance are also at risk, although their fall rate is somewhat lower than those typically considered frail.

Our analyses examining interactions between activity level and performance suggests that predicted falls are widely distributed across the activity-performance axis, but are highest in men with low activity/low performance and those with high activity/high performance. Cauley and colleagues (8) reported that high activity is associated with higher fall risk in those younger than 80 years, and low activity with higher risk in men older than 80 years. Our models also show that interactions between activity and performance are significant in men younger than 80 years but not older men, potentially because activity declines with age and higher activity becomes less important as a fall risk factor.

The traditional risk factors for falls are lower extremity muscle weakness and poor balance, and the exercise interventions to prevent falls emphasize strength and balance training. However, since activity and physical performance are both, and independently, associated with falls, and are both potentially modifiable risk factors, our findings may have implications for the development of individualized preventive strategies targeted to address the underlying causes of falls. For instance, interventions aimed at increasing activity and performance appear to be effective in men with low activity and low performance. In the LIFE Study, Gill and colleagues (28) recently reported that a program designed to increase activity and performance reduced the likelihood of a serious fall injury in older men. To our knowledge, effective programs to reduce falls in those with high performance and high activity have not been developed, but would presumably involve measures to maintain activity while improving safety by optimizing forms of activity, addressing vision or cognition challenges, etc. In those with high activity and low performance, an approach that emphasized improving performance (30) and ensuring continued but safe activity may be appropriate. Thus, our results could be helpful in classifying men based on the specific factors that may increase fall risk. That hypothesis would require testing in appropriately designed clinical trials.

Although we studied only older men, in light of other literature our results may also provide additional insight into sex differences in the causation of falls. Martin and colleagues (31) reported that older men more often maintain moderate–vigorous activity while reducing overall activity and increasing sedentary time, thus potentially increasing the vulnerability for falls in men when impaired physical performance is accompanied by higher levels of activity. Despite declines in self-reported disability, women preserve both upper- and lower-extremity capacity better than men (32). In fact, Duckham and colleagues found that the circumstances of injurious falls were different in men and women (men more often had injurious falls outside the home) (33) and Ensrud and colleagues reported that men more often fracture because of traumatic events, suggesting that more vigorous activity (and potentially risk taking behavior) may underlie those falls and fractures (34). Pham and colleagues (35) found that quadriceps strength was more important in the genesis of fragility fracture in men than in women, and in the LIFE Study, a physical activity regimen that improved physical performance resulted in a major reduction in serious fall injuries, including fractures, in men but not in women (28). Thus, fall risk in men may be particularly influenced by the effects of higher activity interposed with performance capacity.

These analyses include both strengths and limitations. We studied a large, community-dwelling cohort of older men. We employed relatively frequent ascertainments of incident falls, and an objective assessment of activity and tests of physical performance. Our findings were consistent (multiple tests of activity and performance revealed similar associations). The patterns were discernable using relatively simple, clinically applicable measures of activity and function. While we purposefully based our primary analyses of activity on an objective measure (accelerometry), our findings were mirrored using a more practical activity questionnaire (PASE).

Potential limitations include that MrOS is a study of primarily white men. Similar evaluations in women and other racial groups are important. The MrOS participants not included in these analyses because of unavailable activity measures or fall follow-up were generally less healthy, less active, and had lower performance levels. Thus, the associations we report here could be different in these particularly frail men. Our method of fall ascertainment (by tri-annual questionnaire) might have underestimated the rate of falls compared to more rigorous methods such as monthly fall diaries (36). Although falls are an important outcome, the consequences of falls may be different in the activity-performance groups we identified. An important limitation is that we do not know the consequences of falls—it is possible that the highly active men with excellent performance are having falls that do not lead to injury and the cascade of de-conditioning and inactivity that can occur with injurious falls. We predict that the fall circumstances are different across the spectrum of activity and performance, and we did not assess fall-related injuries or capture circumstances of falls. These issues should be addressed in subsequent research. Finally, we specifically focused on the associations of physical activity and performance. When we adjusted for other potential risk factors for falls (age, previous fall history, number of medications, the use of walking aids), our results were essentially unchanged. The effects of other potential risk factors (eg, sedative use), which were not considered in our analyses, could be arguably mediated through the effects on physical performance or activity, and thus their actions may be incorporated in these analyses.

In sum, in a large cohort of older men, we found that levels of physical activity and physical performance are independent predictors of fall risk. Many falls occur in those with low activity/low performance, but most falls occur in older men with relatively high activity and/or reasonable performance characteristics. These results highlight the heterogeneous nature of falls in older men and suggest that measurement of physical activity in conjunction with physical performance measures may result in effective tailored interventions to decrease fall risk in this population.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

Funding

This work was supported by National Institutes of Health. The Osteoporotic Fractures in Men (MrOS) Study was supported by the National Institute on Aging; the National Institute of Arthritis and Musculoskeletal and Skin Diseases; the National Center for Advancing Translational Sciences; the National Institutes of Health Roadmap for Medical Research (grant numbers U01 AG027810, U01 AG042124, U01 AG042139, U01 AG042140, U01 AG042143, U01 AG042145, U01 AG042168, U01 AR066160, and UL1 TR000128); an Academic Leadership Award from the National Institute on Aging (grant number K07 AG043587) (to T.M.G.); and the Claude D. Pepper Older Americans Independence Center (grant number P30 AG021342) (to T.M.G.).

Acknowledgments

Authors' roles: Study concept and design: E.S.O., N.F.F., and J.L. Acquisition of subjects and/or data: E.S.O., J.A.C., E.S.S., K.E.E., D.M.K., E.B.-C., D.C.B., and P.M.C. Analysis and interpretation of data: all the authors. Preparation of manuscript: E.S.O. and N.F.F. The funding agencies that supported the research had no role in the development of these analyses or the preparation of the manuscript.

Conflict of Interest

E.S.O. receives grant support from Merck and Lilly unrelated to this project. P.M.C. receives grant support from GSK unrelated to this project. The other authors have no conflicts.

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