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ORIGINAL RESEARCH

Accelerometer-Measured Daily Steps, Physical Function, and Subsequent Fall Risk in Older Women: The Objective Physical Activity and Cardiovascular Disease in Older Women Study

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Steps per day were measured by accelerometer for 7 days among 5,545 women aged 63–97 years between 2012 and 2014. Incident falls were ascertained from daily fall calendars for 13 months. Median steps per day were 3,216. There were 5,473 falls recorded over 61,564 fall calendar-months. The adjusted incidence rate ratio comparing women in the highest versus lowest step quartiles was 0.71 (95% confidence interval [0.54, 0.95]; p_{trend} across quartiles = .01). After further adjustment for physical function using the Short Physical Performance Battery, the incidence rate ratio was 0.86 ([0.64, 1.16]; p_{trend} = .27). Mediation analysis estimated that 63.7% of the association may be mediated by physical function (p = .03). In conclusion, higher steps per day were related to lower incident falls primarily through their beneficial association with physical functioning. Interventions that improve physical function, including those that involve stepping, could reduce falls in older adults.

Keywords*:* epidemiology, incident falls, older adults

In 2018, falls and injuries from falls among adults aged ≥65 years were the cause of nearly three million emergency room visits, 950,000 hospitalizations, and 32,000 deaths in the United States (Centers for Disease Control & Prevention, 2020). Overall, approximately 28% of older adults experience at least one fall every year (Bergen et al., 2016; Florence et al., 2018). Given the aging U.S. population (Centers for Disease Control & Prevention, 2013), the number of falls is projected to quadruple by 2030 if current trends are not addressed (Houry et al., 2016). This increase will disproportionately affect women, who experience a higher falls rate than men, and for whom a 201% increase in falls has already been observed since 1970 (Bergen et al., 2016; Burns et al., 2016; Kannus et al., 2007).

The collective understanding of fall risk in older adults relating to physical activity is that active older adults are at a decreased fall risk relative to inactive older adults (2018 Physical Activity Guidelines Advisory Committee, 2018). This understanding derives from a randomized controlled trial (Medical Advisory Secretariat, 2008), prospective cohort studies (Buchner et al., 2017; Cauley et al., 2013; Heesch et al., 2008; Iinattiniemi et al., 2008), a case-control study (Peel et al., 2006), and meta-analyses (El-Khoury et al., 2013; Gillespie et al., 2012; Zhao et al., 2017). This reduction in falls risk occurs through muscle strengthening, enhanced neuromuscular coordination and balance, cardiorespiratory health, and improvement in lower extremity physical functioning (Ganz & Latham, 2020; Sherrington et al., 2017). Walking is the most common aerobic activity among adults (2018 Physical Activity Guidelines Advisory Committee, 2018; Centers for Disease Control & Prevention, 2012), and steps per day (steps/d) is a metric that has been shown to be associated with overall health (2018 Physical Activity Guidelines Advisory Committee, 2018; Richardson et al., 2008; Tudor-Locke et al., 2011), cardiovascular disease morbidity and mortality (Hall et al., 2020), and all-cause mortality (Lee et al., 2019), although the minimum number of daily steps required for health benefits remains unclear. Furthermore, increasing ownership of wearables that measure personal steps/d (pedometers, smart watches, and activity trackers) could give rise to clear, concise, and actionable public health messaging and targets (2018 Physical Activity Guidelines Advisory Committee, 2018). This led the Physical Activity Guidelines Advisory Committee to call for further research on steps/d as a potential risk factor for falls (2018 Physical Activity Guidelines Advisory Committee, 2018).

It is well known that a major risk factor for falls in older adults is poor lower extremity physical functioning (hereinafter referred to as physical function). Low physical function may limit one's walking ability and thus the number of steps taken (Tudor-Locke et al., 2011), and may increase fear of falling, which, in turn, could further reduce ambulatory movement and physical activity (Wert et al., 2010). Therefore, it is imperative to understand the

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association between steps/d and subsequent fall risk in the context of physical functioning. The objectives of this study were to investigate the association between accelerometer-measured steps/d and subsequent fall risk and to assess the role of physical functioning, objectively measured using the Short Physical Performance Battery (SPPB), as a confounder, modifier, or mediator of this association in a community-based cohort of ambulatory, older women enrolled in the Objective Physical Activity and Cardiovascular Disease in Older Women (OPACH) Study.

Methods

Study Participants

The analytic sample for the present study was derived from OPACH, an ancillary study of the Women's Health Initiative's (WHI) Long Life Study (LLS). Details about the design, recruitment, and measures have been previously published for OPACH (LaCroix et al., 2017) and WHI (Anderson et al., 1998, 2003). All ambulatory women from the LLS (2012–2013; $n = 7{,}875$) were invited to concurrently enroll in OPACH (LaCroix et al., 2017). The sampling frame for the LLS included all surviving WHI participants from the WHI Hormone Therapy Trials and Black and Hispanic/Latina women from all other WHI components. Briefly (detailed description in Supplementary Figure S1 [available online]), of the 7,048 women, 6,118 completed a LLS home visit, were given falls calendars, and returned their triaxial accelerometer (Buchner et al., 2017). Women were excluded if they consented to OPACH but did not receive falls calendars during their LLS visit or had missing falls calendar data ($n = 333$), missing daily step counts ($n = 43$), wore their accelerometer for less than four adherent days (where a day ≥10 hr of device wear while awake was considered adherent [LaCroix et al., 2017]; $n = 193$), or had extreme values for falls or steps (>325 falls, $n = 1$; ≥60,000 steps/d, $n = 3$), leaving 5,545 women in the analytic sample (see Supplementary Figure S1 [available online]). All women provided informed consent either in writing or by telephone. The institutional review board at the Fred Hutchinson Cancer Research Center approved the study protocols for the LLS and OPACH (LaCroix et al., 2017) and the University of California, San Diego's institutional review board has approved subsequent OPACH data analysis.

Measures

Exposure Assessment

During the LLS visit, participants in OPACH were provided with and asked to wear a GT3X+ triaxial accelerometer (ActiGraph LLC, Pensacola, FL) on their right hip, above the iliac crest, using a belt for 7 days (LaCroix et al., 2017). If a device was not available during the LLS visit, one was mailed to the participant soon thereafter, and the first day of device wear was considered to be that participant's OPACH baseline. The GT3X+ device then counted all steps accrued throughout the day, including purposeful exercise and activities of daily living. The accelerometer was to be removed only during water activities (e.g., bathing, swimming; LaCroix et al., 2017). Data collected by the accelerometer while a participant was in bed was identified using self-reported sleep logs completed every night of accelerometer wear (Rillamas-Sun et al., 2015). Missing in-bed and out-of-bed times were imputed based on person-specific averages when available or population averages when no sleep logs were available (Bellettiere et al., 2019).

The triaxial accelerometers measured acceleration at 30 Hz. Data were converted to 15-s epochs using the normal filter supplied with ActiLife (version 6; ActiGraph LLC). The Choi algorithm (Choi et al., 2011) was used to remove periods of accelerometer nonwear using vector magnitude acceleration counts with a 90-min window, 30-min stream frame, and 2-min tolerance (Choi et al., 2011). The average number of steps/d was computed by summing daily steps across all adherent days and dividing by the number of adherent days. Variation in steps/d due to differences in accelerometer wear time was accounted for using the residualized method (Willett & Stampfer, 1986).

Outcome Ascertainment

During the LLS visit, along with an accelerometer, all women also received a 13-month falls calendar (see Supplementary Figure S2 [available online]). To ensure a full year of incident falls surveillance, participants were provided with 13 months of falls calendar pages and were instructed to record daily on the calendars if they had fallen. A fall was defined as "lost balance and fell to the ground or a lower level or if they had to use a wall, rail, or other object to prevent themselves from falling to the ground" (Buchner et al., 2017). At the end of each month, participants sent that month's calendar to OPACH study staff. When a fall calendar was not received, a reminder postcard was sent via mail (LaCroix et al., 2017). The ascertainment of falls with daily recording on a fall calendar compares favorably to recall-based surveillance methods and has been accepted as a gold standard (Hale et al., 1993; Hannan et al., 2010). Incidence density rates of falls were computed as the number of reported falls divided by the number of person-months (i.e., number of calendar pages returned).

Physical Function

Lower extremity physical function was measured during the LLS visit using the SPPB (Guralnik et al., 1994, 2000). The SPPB is a series of objective physical performance tests that assess balance, gait, strength, and endurance. These are evaluated by "examining ability to stand with the feet together in the side-by-side, semi-tandem, and tandem positions," walking speed at usual pace over a standardized distance, and "time to rise from a chair and return to the seated position five times" (Guralnik et al., 1994).

Covariates

Self-reported demographic covariates included a woman's age at OPACH enrollment, race/ethnicity (non-Hispanic White/non-Hispanic Black/or Hispanic), and educational attainment (high school/equivalent or less/some college/college graduate or more). Questionnaire items most recent to the OPACH baseline (within the previous 12 months) were used to ascertain self-reported falls risk factors including: vision (excellent/very good/good/fair/poor), bodily pain (none/very mild/mild/moderate/severe), alcohol use (never/1 drink per week/1–2 per week/3–4 per week/5–6 per week/everyday), and sleep aid use (no use in past 4 weeks/less than once a week/1–2 times a week/3–4 times a week/5 or more times a week). A measure of multiple morbidity was derived as the sum of up to 11 self-reported chronic conditions (categorized as 0/1/2/≥3) from WHI self-reported and adjudicated outcomes surveillance (Rillamas-Sun et al., 2016). During the LLS visit, a participant's height and weight were measured, and body mass index was computed as weight (in kilograms) divided by height (in meters) squared.

Statistical Analyses

Women were categorized into quartiles of accelerometer-measured steps/d. Comparison of baseline covariates by quartile of steps/d were performed with chi-square tests for categorical variables and analysis of variance tests for continuous variables.

To assess the association between steps/d and subsequent fall risk, both parametric and nonparametric regression models were specified. Due to the extreme right skew of the incident fall rate distribution, we used parametric negative binomial regression models. These models were progressively adjusted as follows: Model 1 included age (continuous), race/ethnicity, and education; Model 2 introduced potential confounders in addition to the Model 1 demographics—vision, body pain, alcohol use, sleep aid use, body mass index (continuous), and number of chronic conditions (0–11, continuous). Physical function, measured by SPPB, could be conceptualized as a confounder, mediator, or an effect modifier of the steps/d and fall risk association. To assess SPPB as a confounder of the steps/d falls association, Model 3 adjusted for all Model 2 covariates and SPPB score (0–12, continuous). Effect measure modification was assessed by including a SPPB-by-steps/d product term in Model 3. p values for trend (p_{trend}) across quartiles were computed by including quartiles of steps as an ordinal term in the respective regression model. We present results for Models 1–3 in the full analytic sample, and, to further assess effect modification, SPPB-stratified samples using previously specified categories in OPACH (Buchner et al., 2017): 0–8 for low SPPB and 9–12 for high SPPB. SPPB was adjusted for within the two SPPB strata to: (a) prevent any residual confounding and (b) to assess the adjusted incidence rate ratios (IRRs) using the same modeling strategy as the unstratified analyses. These analyses employed multivariable imputation through the MICE package in R (R Foundation for Statistical Computing, Vienna, Austria) using chained equations with 100 multiple imputations to handle missing covariate data (Buuren & Groothuis-Oudshoorn, 2011). The final parametric analysis assessed SPPB as a mediator of the steps/d and fall risk association. Complete case mediation analysis was performed using the mediate_zi function of the maczic package in R (Cheng et al., 2021) to estimate the proportion of the steps/d and fall risk association that was mediated through SPPB. Mediation confidence intervals were estimated using quasi-Bayesian approximation; treatment and control values were specified at the 25th and 75th percentile cutpoints of steps/d, respectively.

Complete case, nonparametric negative binomial generalized additive models using restricted cubic splines were specified with covariates from Model 3 to consider potential nonlinear associations between incident fall rates and continuous steps/d. Predicted probabilities from these generalized additive models were used to create graphs that display the predicted risk of falling across the continuum of steps/d. Results were insensitive to the number and placement of the knots, so three knots were placed at the stratum-specific steps/d quartile cutpoints (Durrleman & Simon, 1989). Product terms were included in the generalized additive models to further explore effect measure modification of steps/d on incident falls risk by levels of SPPB, age tertiles, and past year fall history (all stratification variables specified a priori) over the full range of steps/d.

A sensitivity analysis using the multiply imputed data was conducted to determine whether intensity of steps/d was associated with subsequent falls risk. Vector magnitude counts per 15-s epoch from the accelerometer were used to classify steps as “light intensity” or “moderate-to-vigorous (MV) intensity” using the cutpoints defined in the OPACH calibration study (Evenson et al., 2015). The average number of steps/d that were accrued at vector magnitude counts of <519 and ≥519 were considered light and MV steps, respectively. Negative binomial regression models were fit to assess the association between quartiles of light and MV steps and incident falls risk using the aforementioned modeling approach.

All analyses were conducted in R (version 3.6.3; R Foundation for Statistical Computing).

Results

Study Population and Baseline Characteristics

Among the 5,545 women in the analytic sample, 5,473 falls (average 1.0 ± 2.3 falls, range 0–60) were recorded over 61,564 person-months (average 11.1 ± 3.4 person-months, range 1–13). Median steps/d were 3,216 (25th and 75th percentiles: 2,184 and 4,597, respectively). Mean accelerometer wear time while awake was 14.9 ± 1.3 hr (range 10.4–19.3). Women were aged 78.8 ± 6.7 years on average (range 63–97); 50.4% were non-Hispanic White, 32.8% non-Hispanic Black, and 16.7% Hispanic. At baseline, older age, non-Hispanic White race, lower educational attainment, higher number of chronic conditions, having a history of falls in the year prior to OPACH baseline, higher body mass index, lower SPPB score, lower alcohol use, worse vision, and worse bodily pain were associated with fewer steps/d (Table 1).

Accelerometer-Measured Steps/d Quartiles and Subsequent Falls

In the total sample, crude incidence rates of falls decreased with each successively higher quartile of steps/d (Table 2). IRRs and respective 95% confidence intervals adjusted for age, race/ethnicity, and education (Model 1) showed a higher rate of falls for women in the lowest quartile of steps/d as compared with those in the remaining quartiles. After adjustment for demographic characteristics and potential confounders (Model 2), associations were attenuated but remained statistically significant (adjusted IRRs [aIRRs] = 0.77 [0.61, 0.97], 0.72 [0.56, 0.93], and 0.71 [0.54, 0.95] for Q2, Q3, and Q4, respectively; $p_{\text{trend}} = .01$). Of the six additional covariates adjusted for in Model 2, bodily pain accounted for the largest attenuation between Model 1 and Model 2 aIRRs. After further adjustment for SPPB (Model 3), all associations were further attenuated, 95% confidence intervals included the null value, and the test for trend was no longer statistically significant (aIRRs = 0.85 [0.67, 1.07], 0.84 [0.64, 1.09], and 0.86 [0.64, 1.16] for Q2, Q3, and Q4 relative to Q1, respectively; $p_{\text{trend}} = .27$). There was no statistically significant interaction between quartiles of steps/d and continuous SPPB ($p_{\text{interaction}} = .14$).

In the low physical functioning stratum (SPPB 0–8), crude fall rates followed the same pattern of decreasing risk as steps/d increased, but the rates were higher than those of the total sample (135.1, 93.2, 91.0, 87.3 falls per 1,000 person-months in Q1, Q2, Q3, and Q4, respectively; Table 2). All Model 1 aIRRs in the low physical functioning stratum were weaker relative to the aIRRs observed in the total sample (Q2, Q3, and Q4 aIRRs vs. Q1: 0.75 [0.57, 0.99], 0.71 [0.52, 0.98], 0.63 [0.42, 0.94]; $p_{\text{trend}} = .01$). There were no statistically significant results in Models 2 and 3 in the low physical functioning stratum, but the point estimates suggested inverse associations that generally followed a similar pattern of attenuation that was observed in the overall cohort.

Table 1 Participant Characteristics by Accelerometer-Measured Average Daily Step Quartiles in the Selected OPACH Sample, 2012–2014 ($N = 5{,}545$)

Characteristic[a]	Quartile 1 <2,184 Steps ($n = 1{,}386$)	Quartile 2 ≥2,184 and ≤3,216 ($n = 1{,}387$)	Quartile 3 >3,216 and ≤4,597 ($n = 1{,}386$)	Quartile 4 >4,597 ($n = 1{,}386$)	p value[b]
Steps/d, mean (SD)	1,489.1 (538.5)	2,707 (293.1)	3,829.9 (383.5)	6,435.4 (1,787.6)	**<.001**
Age, mean (SD)	82.3 (6.1)	79.8 (6.2)	77.8 (6.3)	75.3 (6.0)	**<.001**
SPPB, mean (SD)	6.7 (2.6)	8.0 (2.4)	8.8 (2.2)	9.5 (2.0)	**<.001**
Number of chronic conditions, mean (SD)	2.6 (7.5)	2.3 (7.9)	1.7 (4.7)	1.5 (6.0)	**<.001**
BMI, mean (SD)	29.0 (6.3)	29.1 (6.1)	28.0 (5.2)	26.2 (4.6)	**<.001**
Race/ethnicity, *n* (%)					**<.001**
White, non-Hispanic	859 (62.0)	731 (52.7)	629 (45.4)	578 (41.7)	
Black, non-Hispanic	426 (30.7)	480 (34.6)	484 (34.9)	430 (31.0)	
Hispanic	101 (7.3)	176 (12.7)	273 (19.7)	378 (27.3)	
Educational attainment, *n* (%)					**<.001**
High school/GED or less	305 (22.0)	287 (20.7)	279 (20.1)	254 (18.3)	
Some college	573 (41.3)	543 (39.1)	533 (38.5)	486 (35.1)	
College graduate or more	500 (36.1)	550 (39.7)	560 (40.4)	640 (46.2)	
Fall history, *n* (%)					**<.001**
No falls	861 (62.1)	959 (69.1)	965 (69.6)	993 (71.6)	
1 fall in past year	306 (22.1)	277 (20.0)	281 (20.3)	275 (19.8)	
2 or more falls in a past year	219 (15.8)	150 (10.8)	140 (10.1)	118 (8.5)	
Injurious fall in past 12 months,[c] *n* (%)	243 (17.5)	197 (14.2)	178 (12.8)	177 (12.8)	.52
Alcohol use past 3 months, *n* (%)					**<.001**
Never	581 (41.9)	520 (37.5)	447 (32.3)	360 (26.0)	
Less than 1 per week	426 (30.7)	424 (30.6)	463 (33.4)	427 (30.8)	
1 or more drinks per week	239 (17.2)	330 (23.8)	376 (27.1)	519 (37.4)	
Use of sleep aid G.E. 1 time/week, *n* (%)	217 (15.7)	223 (16.1)	221 (15.9)	209 (15.1)	.68
Excellent or very good vision, *n* (%)	594 (42.9)	627 (45.2)	683 (49.3)	762 (55.0)	**<.001**
Mild to severe body pain, *n* (%)	842 (60.8)	787 (56.7)	721 (52.0)	551 (39.8)	**<.001**

Note. Bold indicates significance at the $p < .05$ level. ANOVA = analysis of variance; SPPB = Short Physical Performance Battery; OPACH = Objective Physical Activity and Cardiovascular Disease Health in Older Women.
[a]Percentages may not sum to 100% due to missing data. [b]*P* value for continuous variables from the one-way ANOVA and chi-square goodness-of-fit test for categorical variables across daily step quartiles. [c]Of women with at least one fall in past 12 months.

In the high physical functioning stratum, all aIRRs were <1 and slightly weaker relative to those in the low physical functioning stratum (Table 2), but all confidence intervals included the null value, and no significant linear trends were observed.

Mediation Analysis

We estimated that 63.7% of the association between steps/d and falls risk was mediated by physical function, as scored by the SPPB (95% confidence interval [28.1%, 272%]; $p = .03$).

Nonparametric Modeling of Steps/d

Figure 1 shows the association of steps/d and predicted fall risk within categories of SPPB. The higher SPPB categories (7–9 and 10–12) were associated with reduced predicted fall risk, as visualized in Figure 1, though there was no statistical evidence of interaction between steps/d and these SPPB categories on falls risk ($p_{\text{interaction}} = .57$). However, the association between steps/d on a continuous scale and subsequent fall risk appeared null within each of these higher SPPB categories after adjusting for Model 2 covariates. For example, those with SPPB scores between 10 and 12 had a predicted fall risk of approximately 81 falls per 1,000 person-months, and this risk did not vary across the step count distribution. Within the SPPB category of lower scores (0–6), we observed that those taking the fewest steps/d had the highest predicted risk of falls and that those who are taking more steps/d had a lower predicted falls risk.

Stratification by fall history prior to OPACH baseline showed an inverse association between steps/d and fall risk in those with ≥2 falls in the past year (using Model 3; Figure 2a). Those with a history of one fall in the past year had a lower risk of falling, and this risk was unaffected by steps/d. Those with no history of falling had the lowest risk of falling, and this risk was unaffected by steps/d. There was no statistically significant interaction between steps/d and falls history ($p_{\text{interaction}} = .48$). Stratification by age tertiles (Figure 2b), after adjusting for all Model 3 covariates, showed that increasing steps/d does not affect the risk of falls ($P_{interaction} = .46$).

Table 2 Adjusted IRR of Subsequent Falls by Accelerometer-Measured Average Daily Step Quartiles in the Selected OPACH Sample, 2012–2014 (*N* = 5,545)

Sample	Quartile 1 <2,184 steps	Quartile 2 ≥2,184 and ≤ 3,216	Quartile 3 >3,216 and ≤4,597	Quartile 4 >4,597	*p* value for trend
All participants[d]					
Number of falls	1,814	1,298	1,200	1,161	
Person-months	14,562	15,108	15,656	16,238	
Crude fall rate per 1,000 P-M	124.57	85.91	76.65	71.5	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.72 [0.58, 0.91]	0.65 [0.50, 0.83]	0.61 [0.46, 0.79]	**<.001**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.77 [0.61, 0.97]	0.72 [0.56, 0.93]	0.71 [0.54, 0.95]	**.01**
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.85 [0.67, 1.07]	0.84 [0.64, 1.09]	0.86 [0.64, 1.16]	.27
Low physical functioning (0–8 SPPB)					
Number of falls	1,250	720	565	353	
Person-months	9,250	7,727	6,212	4,043	
Crude fall rate per 1,000 P-M	135.14	93.18	90.95	87.31	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.75 [0.57, 0.99]	0.71 [0.52, 0.98]	0.63 [0.42, 0.94]	**.01**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.78 [0.59, 1.03]	0.76 [0.55, 1.06]	0.74 [0.48, 1.13]	.06
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.85 [0.64, 1.13]	0.85 [0.61, 1.19]	0.83 [0.54, 1.27]	.27
High physical functioning (9–12 SPPB)					
Number of falls	314	427	550	715	
Person-months	3,573	6,000	8,433	10,893	
Crude fall rate per 1,000 P-M	87.88	71.17	65.22	65.64	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.82 [0.52, 1.31]	0.75 [0.48, 1.19]	0.79 [0.50, 1.25]	.36
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.86 [0.54, 1.38]	0.81 [0.51, 1.29]	0.88 [0.54, 1.41]	.63
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.87 [0.54, 1.40]	0.83 [0.52, 1.33]	0.90 [0.56, 1.47]	.74

Note. SPPB = Short Physical Performance Battery; P-M = person/falls calendar-months; CI = confidence interval; IRR = incidence rate ratio; OPACH = Objective Physical Activity and Cardiovascular Health in Older Women. Education, vision, body pain, alcohol use, sleep aid use, body mass index, and SPPB multiply imputed.
[a]Adjusted for age, race/ethnicity, and education. [b]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, and number of chronic conditions. [c]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, number of chronic conditions, and SPPB.
[d]Including those with missing SPPB. Continuous: age, BMI, number of chronic conditions, and SPPB. Bold values indicates significance at the $p < .05$ level.

Sensitivity Analysis

Results from the sensitivity analysis indicated that the intensity of daily steps accrued does not alter the association with incident falls risk. The crude, partially adjusted, and fully adjusted rates of falls in quartiles of light and moderate to vigorous steps/d were comparable with one another in the overall cohort and when stratified on SPPB physical function score (Appendix Tables 1 and 2).

Discussion

To our knowledge, this is the first study that prospectively examines accelerometer-measured steps/d and subsequent fall risk in the context of objectively measured physical functioning in a community-dwelling cohort of older ambulatory women. The confounder-adjusted risk (Model 2) of falls was reduced by 23% and 28% in the middle two quartiles and by 29% in the highest quartile of steps compared with the lowest. After further adjustment for SPPB (Model 3), the adjusted risk of falls were 15%, 16%, and 14% reduced for Q2, Q3, and Q4, respectively. SPPB mediated about 63.7% (95% confidence interval [28.1%, 272%]; p = .03) of the association between steps/d and falls. Nonparametric splines indicated that, except for the lowest SPPB category, variation in steps/d was not associated with fall risk; however, there was a strong, graded association of increased fall risk with lower SPPB scores.

Our findings contribute to the growing body of evidence (2018 Physical Activity Guidelines Advisory Committee, 2018) that higher levels of physical activity, in this case quantified by step counts, are not associated with increased fall risk, and may decrease fall risk through their relationship with better lower extremity physical function, as supported by our mediation analysis. In a previous OPACH report examining accelerometer-measured physical activity intensity, the highest risk of falls was observed in those with the least amount of time spent doing moderate to vigorous physical activity (Buchner et al., 2017). In addition, a cohort study of German men and women with a similar average age (75.6 years) and fall ascertainment method found that those who walked <1 hr/day sustained more falls per hour walked compared with those who walked for a greater amount of time, although this finding was not adjusted for physical functioning (Klenk et al., 2015). Other studies have reported that higher amounts of physical activity increased fall risk under certain circumstances (Chan et al., 2007; Jefferis et al., 2015; Lawton et al., 2008). For example, in older British men with no mobility limitations, only step counts (≥9,000 steps/d) were associated with an increased risk of experiencing a fall, while there was no observed association at lower step counts (Jefferis et al., 2015). In men with mobility limitations, lower counts of steps/d were associated with an increased fall risk. No study, to our knowledge, has investigated fall risk across the full range of steps/d as a continuous variable, but instead have examined steps/d in broad or binary categories.

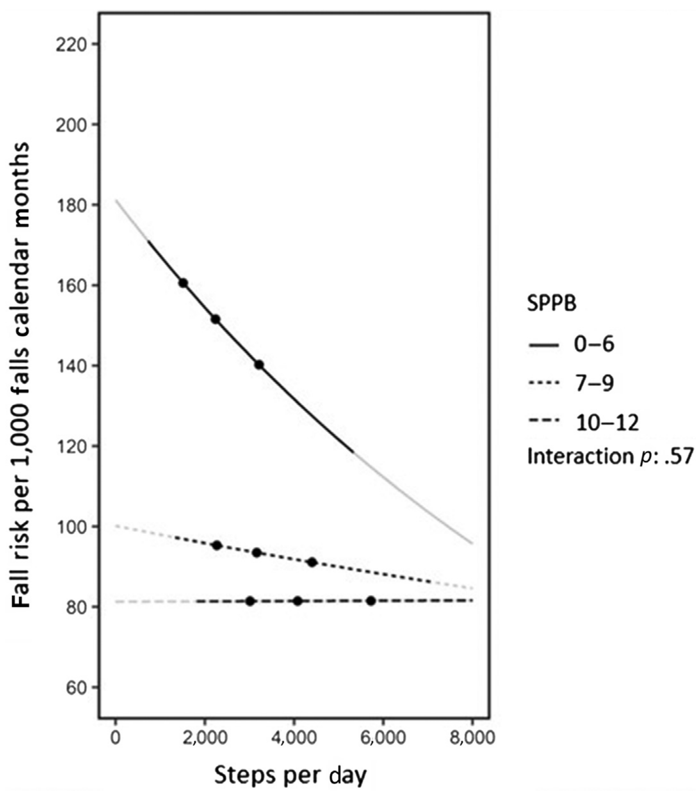

Figure 1 — Dose–response trajectories of incident fall risk by level of the SPPB. Associations are adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, BMI, and the number of chronic conditions. SPPB scores range from 0 (lowest functioning) to 12 (highest functioning). Dots are at the 25th, 50th, and 75th percentile of the SPPB-specific step distribution. The highlighted portion represents the fifth to the 95th percentile of each stratum's step distribution. Interaction *p* value from the corresponding parametric model. BMI = body mass index; SPPB = Short Physical Performance Battery.

Decreased physical functioning is a direct risk factor for falling in older populations (2018 Physical Activity Guidelines Advisory Committee, 2018; Veronese et al., 2014). In the present study, adjustment for SPPB resulted in the largest attenuation between steps/d and fall risk. The temporal, and perhaps bidirectional association, of steps/d and physical functioning has not been well defined: Does decreased physical functioning cause a person to step less because of their lower function, or does a lack of steps/d cause a decrease in physical functioning? We postulate that a feedback loop may exist between physical functioning and steps/d such that reducing steps/d could lead to lower physical functioning, which in turn could lead to even fewer steps/d in the future. Thus, physical functioning may be acting as a true intermediate, a true confounder, or a simultaneous cause and effect of steps/d when adjusted in these models. Thus, in our study, analyses were designed to consider SPPB in each role. Lower physical functioning could accelerate leg muscle atrophy and functional deterioration, which may lead to fewer steps/d, which may exacerbate the deterioration in leg muscle function and its contribution to balance, and which may increase subsequent fall risk. Future studies should investigate how steps/d influence changes in SPPB over time to improve our understanding of temporality and possible bidirectionality.

About two-thirds of the steps/d and fall risk association (63.7%) was shown to be mediated by physical function. This large percentage mediation should be interpreted cautiously given the wide confidence interval. Moreover, in the OPACH study, SPPB was measured concurrently with accelerometer-measured steps/d, so whether SPPB was affected by past steps/d cannot be assessed. Given the strong association of SPPB levels with fall rates irrespective of step counts, this study suggests that interventions targeting SPPB improvement, many of which include stepping, are paramount for reducing the risk of subsequent falls in older women (Giné-Garriga et al., 2014; Sherrington et al., 2017).

Strengths and Limitations

While we were unable to study repeated measures of step counts to confirm that women did not change their steps/d within the observation period, previous studies have shown that a 7-day accelerometer wear yields a stable, reliable estimate of a participant's step/d habits (Keadle et al., 2017; Saint-Maurice et al., 2020). As noted above, while the data collected in OPACH are robust and longitudinal, these data were not best suited for a mediation analysis, which would optimally include repeated measures of steps/d and SPPB over time. Finally, step counts measured by an accelerometer have been shown in some small studies to underestimate the true number of steps/d taken, particularly at slower gait speeds. However, since there was no association between steps/d and subsequent falls across a range of SPPB levels including low levels with slow gait speeds, our findings are likely to be unaffected by this source of measurement error, if it does exist. Generalizability of these findings to men and younger populations will need to be assessed in future studies.

One of the biggest strengths of this study is the prospective follow-up with daily ascertainment of falls using monthly falls calendars. This has been shown to be the most valid method for ascertaining falls and avoids recall bias from asking questions about falls retrospectively (Hale et al., 1993; Hannan et al., 2010). OPACH enrolled a large WHI subcohort of racially and ethnically diverse older women, objectively measured steps/d using an accelerometer with movement intensity calibrated to the types of activity relevant to older women's lives, and collected data that enabled adjustment for a variety of risk factors. Finally, the conclusions drawn from these data are robust across our statistical approaches—parametric, nonparametric, and spline figures. The varied methods considering SPPB as a confounder, modifier, and mediator ultimately contribute to a consistent and unified narrative.

Conclusion

Number of steps taken per day was not significantly associated with fall risk in older women after adjustment for physical functioning. Higher step counts may decrease the risk of falls through their relationship with improved lower extremity physical function, as supported by our mediation analysis. These data also support the safety of taking more steps/d, which other studies have shown to have a myriad of health benefits up to and including reduced risk of mortality (Araiza et al., 2006; Lee et al., 2019; Murtagh et al., 2010) and should be recommended by physicians if not contraindicated. Interventions designed to strengthen lower extremity function, several of which involve improving daily step counts (Giné-

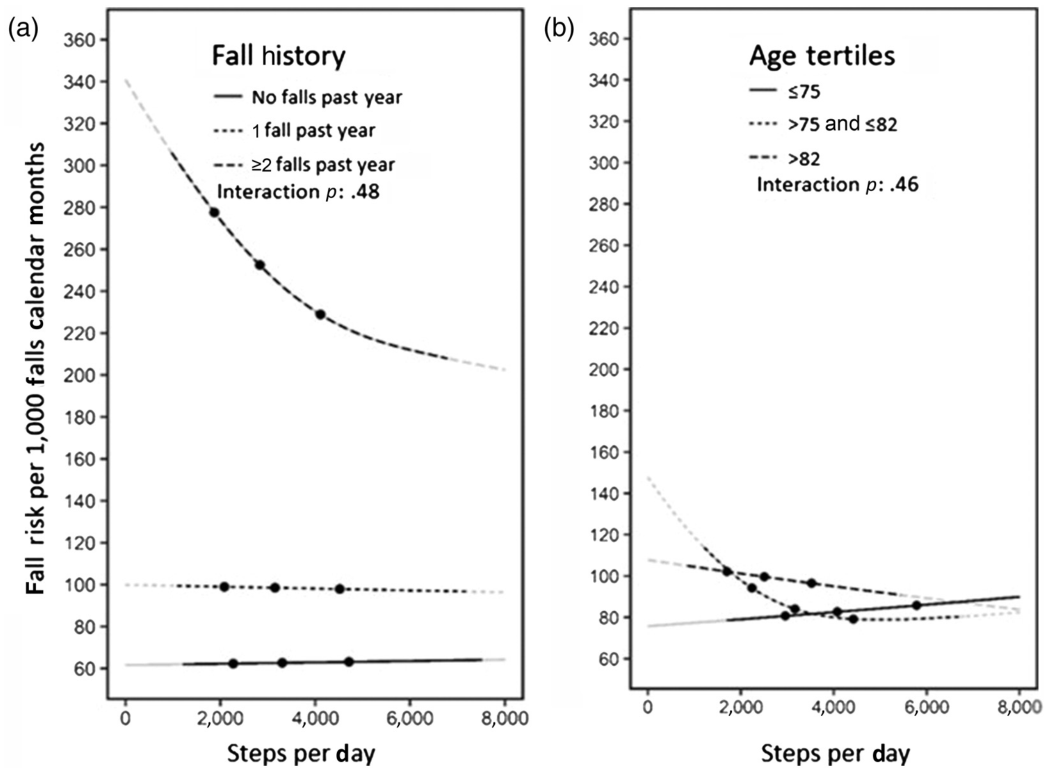

Figure 2 — Dose–response trajectories of incident fall risk by fall history (a) and age tertiles and (b) adjusting for levels of the Short Physical Performance Battery. Associations are adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, number of chronic conditions, and the Short Physical Performance Battery. Dots are at the 25th, 50th, and 75th percentile of the strata-specific step distribution. The highlighted portion represents the fifth to the 95th percentile of each stratum's step distribution. Interaction *p* value from the corresponding parametric model.

Garriga et al., 2014; Sherrington et al., 2017), would likely reduce the daunting burden of falls risk in older women.

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References

2018 Physical Activity Guidelines Advisory Committee. (2018). *2018 Physical Activity Guidelines Advisory Committee scientific report*. Washington, DC: U.S. Department of Health and Human Services. https://health.gov/sites/default/files/2019-09/PAG_Advisory_Committee_Report.pdf

Anderson, G., Cummings, S., Freedman, L., Furberg, C., Henderson, M., Johnson, S., Kuller, L., Manson, J., Oberman, A., Prentice, R., Rossouw, J., Finnegan, L., Hiatt, R., Pottern, L., McGowan, J., Clifford, C., Caan, B., Kipnis, V., Ettinger, B., . . . Clark, A. (1998). Design of the Women's Health Initiative clinical trial and observational study. *Controlled Clinical Trials, 19*(1), 61–109. https://doi.org/10.1016/S0197-2456(97)00078-0

Anderson, G.L., Manson, J., Wallace, R., Lund, B., Hall, D., Davis, S., Shumaker, S., Wang, C.-Y., Stein, E., & Prentice, R.L. (2003). Implementation of the Women's Health Initiative study design. *Annals of Epidemiology, 13*, 5–17. https://doi.org/10.1016/S1047-2797(03)00043-7

Araiza, P., Hewes, H., Gashetewa, C., Vella, C.A., & Burge, M.R. (2006). Efficacy of a pedometer-based physical activity program on parameters of diabetes control in type 2 diabetes mellitus. *Metabolism, 55*(10), 1382–1387. https://doi.org/10.1016/j.metabol.2006.06.009

Bellettiere, J., Zhang, Y., Berardi, V., Full, K.M., Kerr, J., LaMonte, M.J., Evenson, K.R., Hovell, M., LaCroix, A.Z., & Di, C. (2019). Parameterizing and validating existing algorithms for identifying out-of-bed time using hip-worn accelerometer data from older women. *Physiological Measurement, 40*(7), Article 75008. https://doi.org/10.1088/1361-6579/ab1c04

Bergen, G., Stevens, M.R., & Burns, E.R. (2016). Falls and fall injuries among adults aged ≥65 years — United States, 2014. *Morbidity and Mortality Weekly Report, 65*(37), 993–998. https://doi.org/10.15585/mmwr.mm6537a2

Buchner, D.M., Rillamas-Sun, E., Di, C., LaMonte, M.J., Marshall, S.W., Hunt, J., Zhang, Y., Rosenberg, D.E., Lee, I.M., Evenson, K.R., Herring, A.H., Lewis, C.E., Stefanick, M.L., & LaCroix, A.Z. (2017). Accelerometer-measured moderate to vigorous physical activity and incidence rates of falls in older women. *Journal of the American Geriatrics Society, 65*(11), 2480–2487. https://doi.org/10.1111/jgs.14960

Burns, E.R., Stevens, J.A., & Lee, R. (2016). The direct costs of fatal and non-fatal falls among older adults—United States. *Journal of Safety Research, 58,* 99–103. https://doi.org/10.1016/j.jsr.2016.05.001

Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate Imputation by Chained Equations in R. *Journal of Statistical Software, 45*(3), 1–67. https://www.jstatsoft.org/v45/i03/

Cauley, J.A., Harrison, S.L., Cawthon, P.M., Ensrud, K.E., Danielson, M.E., Orwoll, E., & Mackey, D.C. (2013). Objective measures of physical activity, fractures and falls: The osteoporotic fractures in men study. *Journal of the American Geriatrics Society, 61*(7), 1080–1088. https://doi.org/10.1111/jgs.12326

Centers for Disease Control and Prevention. (2012). Vital signs: Walking among adults—United States, 2005 and 2010. *Morbidity and Mortality Weekly Report, 61*(31), 595–601. https://www.ncbi.nlm.nih.gov/pubmed/22874838

Centers for Disease Control and Prevention. (2013). *The state of aging and health in America 2013*. Centers for Disease Control and Prevention, U.S. Dept of Health and Human Services.

Centers for Disease Control and Prevention. (2020). *WISQARS — Web-based injury statistics query and reporting system*. National Center for Injury Prevention and Control. https://www.cdc.gov/injury/wisqars/index.html

Chan, B.K., Marshall, L.M., Winters, K.M., Faulkner, K.A., Schwartz, A.V., & Orwoll, E.S. (2007). Incident fall risk and physical activity and physical performance among older men: The osteoporotic fractures in men study. *American Journal of Epidemiology, 165*(6), 696–703. https://doi.org/10.1093/aje/kwk050

Cheng, N., Guo, Z., & Cheng, J. (2021). *maczic: Mediation analysis for count and zero-inflated count data* (R package version 0.2.0.). https://cran.r-project.org/package=maczic

Choi, L., Liu, Z., Matthews, C.E., & Buchowski, M.S. (2011). Validation of accelerometer wear and nonwear time classification algorithm. *Medicine & Science in Sports & Exercise, 43*(2), 357–364. https://doi.org/10.1249/MSS.0b013e3181ed61a3

Durrleman, S., & Simon, R. (1989). Flexible regression models with cubic splines. *Statistics in Medicine, 8*(5), 551–561. https://doi.org/10.1002/sim.4780080504

El-Khoury, F., Cassou, B., Charles, M.A., & Dargent-Molina, P. (2013). The effect of fall prevention exercise programmes on fall induced injuries in community dwelling older adults: Systematic review and meta-analysis of randomised controlled trials. *BMJ, 347,* Article f6234. https://doi.org/10.1136/bmj.f6234

Evenson, K.R., Wen, F., Herring, A.H., Di, C., LaMonte, M.J., Tinker, L.F., Lee, I.M., Rillamas-Sun, E., LaCroix, A.Z., & Buchner, D.M. (2015). Calibrating physical activity intensity for hip-worn accelerometry in women age 60 to 91years: The Women's Health initiative OPACH calibration study. *Preventive Medicine Reports, 2,* 750–756. https://doi.org/10.1016/j.pmedr.2015.08.021

Florence, C.S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical costs of fatal and nonfatal falls in older adults. *Journal of the American Geriatrics Society, 66*(4), 693–698. https://doi.org/10.1111/jgs.15304

Ganz, D.A., & Latham, N.K. (2020). Prevention of falls in community-dwelling older adults. *New England Journal of Medicine, 382*(8), 734–743. https://doi.org/10.1056/NEJMcp1903252

Gillespie, L.D., Robertson, M.C., Gillespie, W.J., Sherrington, C., Gates, S., Clemson, L.M., & Lamb, S.E. (2012). Interventions for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews, 9,* Article CD007146. https://doi.org/10.1002/14651858.CD007146.pub3

Giné-Garriga, M., Roqué-Fíguls, M., Coll-Planas, L., Sitjà-Rabert, M., & Salvà, A. (2014). Physical exercise interventions for improving performance-based measures of physical function in community-dwelling, frail older adults: A systematic review and meta-analysis. *Archives of Physical Medicine and Rehabilitation, 95*(4), 753–769.e3. https://doi.org/10.1016/j.apmr.2013.11.007

Guralnik, J.M., Ferrucci, L., Pieper, C.F., Leveille, S.G., Markides, K.S., Ostir, G.V, Studenski, S., Berkman, L.F., & Wallace, R.B. (2000). Lower extremity function and subsequent disability: Consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences, 55*(4), M221–231. https://doi.org/10.1093/gerona/55.4.m221

Guralnik, J.M., Simonsick, E.M., Ferrucci, L., Glynn, R.J., Berkman, L.F., Blazer, D.G., Scherr, P.A., & Wallace, R.B. (1994). A short physical performance battery assessing lower extremity function: Association with self-reported disability and prediction of mortality and nursing home admission. *Journal of Gerontology, 49*(2), M85–M94. https://doi.org/10.1093/geronj/49.2.m85

Hale, W.A., Delaney, M.J., & Cable, T. (1993). Accuracy of patient recall and chart documentation of falls. *Journal of the American Board of Family Medicine, 6*(3), 239–242. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/8503294

Hall, K.S., Hyde, E.T., Bassett, D.R., Carlson, S.A., Carnethon, M.R., Ekelund, U., Evenson, K.R., Galuska, D.A., Kraus, W.E., Lee, I.M., Matthews, C.E., Omura, J.D., Paluch, A.E., Thomas, W.I., & Fulton, J.E. (2020). Systematic review of the prospective association of daily step counts with risk of mortality, cardiovascular disease, and dysglycemia. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 78. https://doi.org/10.1186/s12966-020-00978-9

Hannan, M.T., Gagnon, M.M., Aneja, J., Jones, R.N., Cupples, L.A., Lipsitz, L.A., Samelson, E.J., Leveille, S.G., & Kiel, D.P. (2010). Optimizing the tracking of falls in studies of older participants: Comparison of quarterly telephone recall with monthly falls calendars in the MOBILIZE Boston Study. *American Journal of Epidemiology, 171*(9), 1031–1036. https://doi.org/10.1093/aje/kwq024

Heesch, K.C., Byles, J.E., & Brown, W.J. (2008). Prospective association between physical activity and falls in community-dwelling older women. *Journal of Epidemiology and Community Health, 62*(5), 421–426. https://doi.org/10.1136/jech.2007.064147

Houry, D., Florence, C., Baldwin, G., Stevens, J., & McClure, R. (2016). The CDC Injury Center's response to the growing public health problem of falls among older adults. *American Journal of Lifestyle Medicine, 10*(1), 74–77. https://doi.org/10.1177/1559827615600137

Iinattiniemi, S., Jokelainen, J., & Luukinen, H. (2008). Exercise and risk of injurious fall in home-dwelling elderly. *International Journal of Circumpolar Health, 67*(2–3), 235–244. https://doi.org/10.3402/ijch.v67i2-3.18279

Jefferis, B.J., Merom, D., Sartini, C., Wannamethee, S.G., Ash, S., Lennon, L.T., Iliffe, S., Kendrick, D., & Whincup, P.H. (2015). Physical activity and falls in older men: The critical role of mobility limitations. *Medicine & Science in Sports & Exercise, 47*(10), 2119–2128. https://doi.org/10.1249/MSS.0000000000000635

Kannus, P., Niemi, S., Parkkari, J., Palvanen, M., & Sievänen, H. (2007). Alarming rise in fall-induced severe head injuries among elderly people. *Injury, 38*(1), 81–83. https://doi.org/10.1016/j.injury.2006.08.027

Keadle, S.K., Shiroma, E.J., Kamada, M., Matthews, C.E., Harris, T.B., & Lee, I.-M. (2017). Reproducibility of accelerometer-assessed physical activity and sedentary time. *American Journal of Preventive Medicine, 52*(4), 541–548. https://doi.org/10.1016/j.amepre.2016.11.010

Klenk, J., Kerse, N., Rapp, K., Nikolaus, T., Becker, C., Rothenbacher, D., Peter, R., Denkinger, M.D., & ActiFE Study Group. (2015). Physical activity and different concepts of fall risk estimation in older people—Results of the ActiFE-Ulm study. *PLoS One, 10*(6), Article e0129098. https://doi.org/10.1371/journal.pone.0129098

LaCroix, A.Z., Rillamas-Sun, E., Buchner, D., Evenson, K.R., Di, C., Lee, I.M., Marshall, S., LaMonte, M.J., Hunt, J., Tinker, L.F., Stefanick, M., Lewis, C.E., Bellettiere, J., & Herring, A.H. (2017). The objective physical activity and cardiovascular disease health in older women (OPACH) study. *BMC Public Health, 17*(1), 192. https://doi.org/10.1186/s12889-017-4065-6

Lawton, B.A., Rose, S.B., Elley, C.R., Dowell, A.C., Fenton, A., & Moyes, S.A. (2008). Exercise on prescription for women aged 40-74 recruited through primary care: Two year randomised controlled trial. *BMJ, 337,* Article a2509. https://doi.org/10.1136/bmj.a2509

Lee, I.M., Shiroma, E.J., Kamada, M., Bassett, D.R., Matthews, C.E., & Buring, J.E. (2019). Association of step volume and intensity with all-cause mortality in older women. *JAMA, 179*(8), 1105–1112. https://doi.org/10.1001/jamainternmed.2019.0899

Medical Advisory Secretariat. (2008). Prevention of falls and fall-related injuries in community-dwelling seniors: An evidence-based analysis. *Ontario Health Technology Assessment Series, 8*(2), 1–78. https://www.ncbi.nlm.nih.gov/pubmed/23074507

Murtagh, E.M., Murphy, M.H., & Boone-Heinonen, J. (2010). Walking: The first steps in cardiovascular disease prevention. *Current Opinion in Cardiology, 25*(5), 490–496. https://doi.org/10.1097/HCO.0b013e32833ce972

Peel, N.M., McClure, R.J., & Hendrikz, J.K. (2006). Health-protective behaviours and risk of fall-related hip fractures: A population-based case-control study. *Age and Ageing, 35*(5), 491–497. https://doi.org/10.1093/ageing/afl056

Richardson, C.R., Newton, T.L., Abraham, J.J., Sen, A., Jimbo, M., & Swartz, A.M. (2008). A meta-analysis of pedometer-based walking interventions and weight loss. *Annals of Family Medicine, 6*(1), 69–77. https://doi.org/10.1370/afm.761

Rillamas-Sun, E., Buchner, D.M., Di, C., Evenson, K.R., & LaCroix, A.Z. (2015). Development and application of an automated algorithm to identify a window of consecutive days of accelerometer wear for large-scale studies. *BMC Research Notes, 8,* 270. https://doi.org/10.1186/s13104-015-1229-2

Rillamas-Sun, E., LaCroix, A.Z., Bell, C.L., Ryckman, K., Ockene, J.K., & Wallace, R.B. (2016). The impact of multimorbidity and coronary disease comorbidity on physical function in women aged 80 years and older: The women's health initiative. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences, 71*(Suppl. 1), S54–61. https://doi.org/10.1093/gerona/glv059

Saint-Maurice, P.F., Sampson, J.N., Keadle, S.K., Willis, E.A., Troiano, R.P., & Matthews, C.E. (2020). Reproducibility of accelerometer and posture-derived measures of physical activity. *Medicine & Science in Sports & Exercise, 52*(4), 876. https://journals.lww.com/acsm-msse/Fulltext/2020/04000/Reproducibility_of_Accelerometer_and.13.aspx

Sherrington, C., Michaleff, Z.A., Fairhall, N., Paul, S.S., Tiedemann, A., Whitney, J., Cumming, R.G., Herbert, R.D., Close, J.C.T., & Lord, S.R. (2017). Exercise to prevent falls in older adults: An updated systematic review and meta-analysis. *British Journal of Sports Medicine, 51*(24), 1750–1758. https://doi.org/10.1136/bjsports-2016-096547

Tudor-Locke, C., Craig, C.L., Aoyagi, Y., Bell, R.C., Croteau, K.A., De Bourdeaudhuij, I., Ewald, B., Gardner, A.W., Hatano, Y., Lutes, L.D., Matsudo, S.M., Ramirez-Marrero, F.A., Rogers, L.Q., Rowe, D.A., Schmidt, M.D., Tully, M.A., & Blair, S.N. (2011). How many steps/day are enough? For older adults and special populations. *International Journal of Behavioral Nutrition and Physical Activity, 8,* 80. https://doi.org/10.1186/1479-5868-8-80

Veronese, N., Bolzetta, F., Toffanello, E.D., Zambon, S., De Rui, M., Perissinotto, E., Coin, A., Corti, M.C., Baggio, G., Crepaldi, G., Sergi, G., & Manzato, E. (2014). Association between short physical performance battery and falls in older people: The Progetto Veneto Anziani study. *Rejuvenation Research, 17*(3), 276–284. https://doi.org/10.1089/rej.2013.1491

Wert, D.M., Talkowski, J.B., Brach, J., & VanSwearingen, J. (2010). Characteristics of walking, activity, fear of falling, and falls in community-dwelling older adults by residence. *Journal of Geriatric Physical Therapy, 33*(1), 41–45. https://www.ncbi.nlm.nih.gov/pubmed/20503733

Willett, W., & Stampfer, M.J. (1986). Total energy intake: Implications for epidemiologic analyses. *American Journal of Epidemiology, 124*(1), 17–27. https://doi.org/10.1093/oxfordjournals.aje.a114366

Zhao, R., Feng, F., & Wang, X. (2017). Exercise interventions and prevention of fall-related fractures in older people: A meta-analysis of randomized controlled trials. *International Journal of Epidemiology, 46*(1), 149–161. https://doi.org/10.1093/ije/dyw142

Appendix Table 1: Adjusted IRR of Subsequent Falls by Accelerometer-Measured Average Moderate- to Vigorous-Intensity Daily Step Quartiles in the Selected OPACH Sample, 2012–2014 ($N = 5{,}545$)

Sample	Quartile 1 <656 Steps	Quartile 2 ≥656 and ≤1,295	Quartile 3 >1,295 and ≤ 2,411	Quartile 4 > 2,411	*p* value for trend
All participants[d]					
Number of falls	1,698	1,381	1,260	1,134	
Person-months	14,567	15,217	15,561	16,219	
Crude fall rate per 1,000 P-M	116.56	90.75	80.97	69.92	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.86 [0.68, 1.08]	0.77 [0.6, 0.98]	0.67 [0.5, 0.87]	**<.001**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.85 [0.66, 1.09]	0.82 [0.62, 1.08]	0.78 [0.57, 1.06]	**.09**
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.9 [0.69, 1.18]	0.9 [0.66, 1.21]	0.94 [0.67, 1.3]	.63
Low physical functioning (0–8 SPPB)					
Number of falls	1,194	770	572	352	
Person-months	9,131	7,782	6,142	4,177	
Crude fall rate per 1,000 P-M	130.76	98.95	93.13	84.27	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.89 [0.66, 1.18]	0.81 [0.57, 1.13]	0.68 [0.43, 1.02]	**.05**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.91 [0.66, 1.25]	0.78 [0.53, 1.14]	0.83 [0.52, 1.29]	.23
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.94 [0.69, 1.29]	0.86 [0.58, 1.27]	0.92 [0.57, 1.44]	.54
High physical functioning (9–12 SPPB)					
Number of falls	316	447	537	706	
Person-months	3,884	6,058	8,046	10,911	
Crude fall rate per 1,000 P-M	81.36	73.79	66.74	64.71	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.89 [0.55, 1.45]	0.9 [0.56, 1.44]	0.89 [0.56, 1.44]	.7
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.83 [0.5, 1.41]	0.91 [0.55, 1.51]	0.9 [0.54, 1.51]	.83
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.84 [0.5, 1.42]	0.92 [0.56, 1.54]	0.92 [0.55, 1.56]	.91

Note. SPPB = Short Physical Performance Battery; P-M = person/falls calendar-months; CI = confidence interval; IRR = incidence rate ratio; OPACH = Objective Physical Activity and Cardiovascular Health in Older Women.

[a]Adjusted for age, race/ethnicity, and education. [b]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, and number of chronic conditions. [c]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, number of chronic conditions, and SPPB. [d]Including those with missing SPPB. Continuous: age, BMI, number of chronic conditions, and SPPB. Bold values indicates significance at the $p < .05$ level.

Appendix Table 2: Adjusted IRR of Subsequent Falls by Accelerometer-Measured Average Light-Intensity Daily Step Quartiles in the Selected OPACH Sample, 2012–2014 (*N* = 5,545)

Sample	Quartile 1 <1,325 Steps	Quartile 2 ≥1,325 and ≤1,774	Quartile 3 >1,774 and ≤2,272	Quartile 4 >2,272	*p* value for trend
All participants[d]					
Number of falls	1,787	1,308	1,157	1,221	
Person-months	14,882	15,179	15,651	15,852	
Crude fall rate per 1,000 P-M	120.08	86.17	73.92	77.02	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.79 [0.62, 0.99]	0.65 [0.5, 0.83]	0.67 [0.52, 0.86]	**<.001**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.84 [0.65, 1.08]	0.7 [0.53, 0.93]	0.73 [0.55, 0.97]	**.01**
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.91 [0.7, 1.2]	0.77 [0.57, 1.03]	0.86 [0.64, 1.17]	.19
Low physical functioning (0–8 SPPB)					
Number of falls	1,146	730	566	446	
Person-months	8,863	6,968	6,534	4,867	
Crude fall rate per 1,000 P-M	129.3	104.76	86.62	91.64	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.91 [0.68, 1.22]	0.68 [0.48, 0.94]	0.7 [0.48, 1.02]	**.02**
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.92 [0.67, 1.27]	0.7 [0.48, 1.01]	0.71 [0.4, 1.08]	.04
Model 3, IRR [95% CI][c]	1.00 [ref.]	1.02 [0.73, 1.41]	0.78 [0.53, 1.12]	0.82 [0.52, 1.25]	.19
High physical functioning (9–12 SPPB)					
Number of falls	402	439	481	684	
Person-months	4,439	6,690	7,990	9,780	
Crude fall rate per 1,000 P-M	90.56	65.62	60.2	69.94	
Model 1, IRR [95% CI][a]	1.00 [ref.]	0.81 [0.51, 1.28]	0.74 [0.47, 1.18]	0.87 [0.57, 1.35]	.62
Model 2, IRR [95% CI][b]	1.00 [ref.]	0.77 [0.47, 1.26]	0.74 [0.46, 1.22]	0.87 [0.55, 1.39]	.7
Model 3, IRR [95% CI][c]	1.00 [ref.]	0.76 [0.47, 1.25]	0.75 [0.46, 1.22]	0.87 [0.55, 1.4]	.74

Note. SPPB = Short Physical Performance Battery; P-M = person/falls calendar-months; CI = confidence interval; IRR = incidence rate ratio; OPACH = Objective Physical Activity and Cardiovascular Health in Older Women.
[a]Adjusted for age, race/ethnicity, and education. [b]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, and number of chronic conditions. [c]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, number of chronic conditions, and SPPB. [d]Including those with missing SPPB. Continuous: age, BMI, number of chronic conditions, and SPPB. Bold values indicates significance at the $p < .05$ level.