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Accelerometer-measured sedentary patterns are associated with incident falls in older women

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Abstract

Background/Objective: Falls cause significant problems for older adults. Sedentary time is associated with lower physical function and could increase risk for falls.

Design: Prospective study

Setting: Sites across the U.S.

Participants: Older women (N = 5545, mean age 79 years) from the Women's Health Initiative Objective Physical Activity and Cardiovascular Health study

Measurements: Accelerometers worn at the hip for up to one-week collected measures of daily sedentary time and the mean sedentary bout duration, a commonly used metric for sedentary accumulation patterns. For up to 13 months after accelerometer wear, women reported daily whether they had fallen on monthly calendars.

Results: In fully-adjusted models, the IRR (95% CI) for quartiles 1 (lowest), 2, 3, and 4 of sedentary time respectively were 1.0 (ref.), 1.07 (0.93-1.24), 1.07 (0.91-1.25), and 1.14 (0.96-1.35; p-trend=0.65) and for mean sedentary bout duration was 1.0 (ref), 1.05 (0.92-1.21), 1.02 (0.88-1.17), and 1.17 (1.01-1.37; p-trend=0.01). Women with a history of 2 or more falls had stronger associations between sedentary time and falls incidence compared to women with a history of no or one fall (p for interaction = .046).

Conclusions: Older women in the highest quartile of mean sedentary bout duration had a significantly increased risk of falling. Women with a history of frequent falling may be at higher risk for falling if they have high sedentary time. Interventions testing whether shortening total sedentary time and/or sedentary bouts lowers fall risk are needed to confirm these observational findings.

Keywords

Sedentary behavior; physical activity; fall risk

Introduction

One-third of community-dwelling older adults fall each year.[1,2] About half of falls result in injury, including serious events such as hip fractures and hospitalizations.[3,4] In the United States (U.S.), annual direct medical costs for fall-related injuries exceed $19 billion.[5] While physical activity is a known risk factor for falls, sedentary behavior represents a class of behaviors distinct from low physical activity that has not been adequately studied in fall prevention research. Sedentary behaviors are defined by the Sedentary Behavior Research Network as "any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents [METs] while in a sitting, reclining, or lying posture."[6] This is distinguished from physical inactivity which explicitly refers to "insufficient physical activity to meet present physical activity recommendations."[6] Common sedentary behaviors include sitting while watching television, using a computer, or riding in a car. Interventions to reduce sedentary time use different techniques than those that aim to increase physical activity, such as providing standing desks[7,8] and/or prompting devices to remind people to limit the duration of sitting bouts.[9] Sedentary behavior is associated with worse physical function and other indicators of poor health, but little is known about whether objectively-measured sedentary time contributes to fall risk.[10–13] Sedentary time could contribute to worse lower extremity stability, neuromuscular function, strength and balance, which could plausibly lead to falls. On the other hand, people who are more sedentary may have fewer opportunities to fall, and thus a lower fall risk.

The potential contribution that sedentary time imposes on falls susceptibility is complex and challenging to evaluate, in part, because measuring sedentary time is difficult. Self-reported sedentary time has been associated with an increased risk for falling in older adults.[14,15] However, self-reported measures of both total sedentary time and sedentary accumulation patterns (such as how long sedentary bouts last) are limited by poor participant recall.[16,1712,18] Thus, device-measures have an important role in measuring free-living sedentary time for epidemiologic investigations.

A few studies have examined device-measured sedentary time and prospective falls in older adults. Two showed that men with higher levels of accelerometer-measured total sedentary time were at increased risk of falls but only among those with mobility limitations [19] or aged 80 years and older;[20] another study found no association.[21] There are no available studies examining whether sedentary accumulation patterns (shorter vs. longer average sedentary bout lengths) affect risk of falling. If high sedentary time and more prolonged sitting accumulation patterns are risk factors for falling, novel interventions could be developed and tested.

Based on the lack of evidence, we examined associations between device-measured sedentary time (both total sedentary time and sedentary bout duration) and incidence of falls over a 13-month surveillance period in older community-living ambulatory women. To further identify potentially at-risk populations, we also evaluated whether these associations varied based on moderate-to-vigorous physical activity (MVPA), physical function, and history of falling. Finally, we described data on fall-related injuries and hospitalizations by sedentary time.

Methods

Overview of Study Sample and Procedures

Participants were women enrolled in the Objective Physical Activity and Cardiovascular Disease Health (OPACH) Study, an ancillary study to the Women's Health Initiative (WHI) Long Life Study.[22] The WHI[23,24] and OPACH[22] study have been previously described. Briefly, in the WHI study, postmenopausal women, aged 50-79 years, were enrolled from 40 sites across the U.S. and completed baseline assessments between 1993 and 1998. The WHI Long Life Study (2012-2013) was an ancillary study of the WHI's second extension study (2010-2015), including 7875 WHI participants who completed a home examination that included the Short Physical Performance Battery (SPPB)[25] and self-reported health. The current analysis included a sub-cohort of the Long Life Study including 7048 women who consented to participate in the OPACH study between March 2012 and April 2014. All WHI and OPACH study procedures were approved by the Fred Hutchinson Cancer Research Center Institutional Review Board.

Exposure Measures

Participants wore ActiGraph GT3X+ (ActiGraph Corp, Pensacola, FL) accelerometers at the iliac crest of their hip on a belt for 7 days (including while asleep) except during bathing or swimming. The device was initialized to measure data in 30 hertz (30 times per second). Actilife software (versions 6.0.0 to 6.101; Firmware version v2.4) was used to download data in 15-second epochs, which were aggregated to 1-minute epochs for the analysis of sedentary time. Periods of accelerometer non-wear were identified using an algorithm applied to the vector magnitude accelerometer counts per minute with a 90 minute window, 30 minute streamframe and 2 minute tolerance.[2627] Periods when participants reported being in-bed were self-reported for each night of accelerometer wear using sleep logs and removed from the data. Missing sleep log data were imputed using each participant's mean in-bed and/or out-of-bed time if available or using the mean from the entire population otherwise. Those who wore the devices for 10 or more hours on at least 4 days were included in the analysis.[28]

Total sedentary time was defined based on results of the OPACH calibration study.[29] Each 15-second epoch with vector magnitude (VM) counts between 0 and 18 were classified as sedentary time and total sedentary time was computed as the arithmetic mean number of sedentary minutes over all adherent wear days. Sedentary bout duration was measured by integrating data to 1-minute epochs, then classifying each epoch as sedentary if the vertical axis counts were below 100 based on our prior work. [30–3233] The mean sedentary bout duration was computed as the average length of all sedentary bouts during all adherent days.

Outcome Measure

Falls were collected prospectively using self-reported fall calendars for up to 13 months following accelerometer wear.[22,34] Participants were instructed to record daily whether they had a fall. Calendar pages were mailed back to study researchers each month. Reminder postcards were sent if monthly pages were not received. A sample of participants who reported falls on calendars were interviewed by telephone about events that led to the fall, location of the fall, and whether injuries occurred. A total of 5776 (94.4%) returned at least one month of fall calendar data and 4246 (73.5%) returned 12 -13 months of data. Overall, 5980 falls were reported from the calendars and 1492 women completed interviews pertaining to 3375 falls.

Covariates and stratification variables

Covariates were based on self-reports administered at the same time period as OPACH (severity of body pain, sleep aid frequency, vision, alcohol use, and multimorbidity.[35] Heights and weights were measured at the Long Life Study home visit..

Measures used as stratification variables included the Short Physical Performance Battery (SPPB) physical function score (scores of 1-8 were considered low physical function; scores of 8-12 were considered high physical function) [36] and self-reported history of falls in the year prior to accelerometer wear (0-1 vs 2+). We also examined moderate-to-vigorous physical activity (MVPA; median split as <44 minutes per day vs. 44 or more minutes per day) as assessed by accelerometer, defined using a threshold of >518 VM counts per 15-second epoch based on the OPACH calibration study.[29]

Analysis

To adjust for variation in total sedentary time due to differences in waking time spent wearing devices, we used a residualization method;[37] no adjustments were made to mean sedentary bout duration since it is not associated with waking wear time.[32] Sedentary time was categorized into quartiles then demographic and health-related characteristics were summarized across quartiles of sedentary time. Statistically significant differences in these characteristics were evaluated using chi-square tests for categorical variables and analysis of variance for continuous variables. Incident fall rates were calculated as the number of falls reported on the calendars divided by the total person-months at risk for falling (i.e., total monthly calendar pages). Because falls were positively skewed, negative binomial regression models were used to examine associations of sedentary time and mean sedentary bout duration with incident fall rates, using women from the first quartile as the reference group and complete case analysis. Three models were executed in the following sequential order: model 1 adjusted for age, race/ethnicity, education; model 2 included additional adjustment for vision, body pain, alcohol use, sleep medication use, BMI, and number of chronic conditions; and model 3 included additional adjustment for MVPA. To examine whether physical function (SPPB), MVPA, or falls history were effect modifiers on sedentary time and incident falls associations, negative binomial regression models using the variables from Model 2 above were executed stratified by high and low levels of SPPB score (8 or lower vs. 9 or higher), MVPA (below vs. above the median of 44 minutes per day) and falls in past year (0-1 vs. 2 or more). Statistically significant effect modification was tested by evaluating the multiplicative interaction terms of the sedentary time metrics and the stratification variables (all in continuous functional form except falls history which was included in binary form) for model 2. Nominal p-values for interaction are reported. To evaluate whether observed associations were heavily influenced by women with poor physical functioning, we completed a sensitivity analysis excluding women with SPPB scores <4.[38] Reported injuries and types of medical care received were examined by quartiles of total sedentary time for women with fall interview data (2495 falls); we tested for statistically significant differences using generalized estimating equations to account for within-woman correlations. Analyses were conducted using SAS v9.3 (SAS Institute, Cary, NC) and R.[39]

Results

There were 5,545 women who returned at least one month of falls calendars and met the criteria for adherent accelerometer wear (average wear time = 14.9 hours/day; average wear days = 6.5 days). Mean sedentary time was 9.3 hours per day. In the 13 months of follow-up with falls calendars, there were 5,461 falls recorded among 2,426 women who reported at least one fall. Women were, on average, age 78.8 years (range 63-99) and 51% were white, 33% African American, and 17% Hispanic. Women in the highest vs. lowest quartile of total sedentary time were more likely to be older, white, non-drinkers, report poor self-assessed balance and vision, report more severe body pain, have higher BMI, more chronic conditions, lower SPPB scores, and more falls in the previous year (Table 1).

Crude falls incidence rates per 1000 person-months were higher as quartiles (Q) of total sedentary time (Q1=76.3, Q2=87.0, Q3=87.4, Q4=105.8) and mean sedentary bout duration (Q1=76.4, Q2=83.0, Q3=83.9, Q4=112.6; Table 2) increased. The IRRs comparing Q4 relative to Q1 and adjusting for age, race-ethnicity, and education were 1.26 (95% CI: 1.10-1.44; p-trend=0.01) for total sedentary time and 1.24 (1.09-1.42; p-trend<0.001) for mean sedentary bout duration. Additional adjustment for health status related confounders in Model 2 attenuated these associations, although mean sedentary bout duration remained associated with a 16% higher fall rate in the highest vs. lowest quartiles (IRR for mean sedentary bout duration=1.16, 95% CI: 1.01-1.33; p-trend=0.01). Additional adjustment for MVPA (Model 3) did not appreciably change the results.

The association between total sedentary time and incident fall rate was higher for women with a history of 2 or more falls (Q4 vs Q1: IRR=1.70, 95% CI=1.19-2.43) compared to women with a history of 0-1 falls (Q4 vs Q1: IRR=0.99, 95% CI=0.85-1.16, p-interaction=0.046; see Figure 1). While the interaction term was significant for MVPA when examining total sedentary time and mean sedentary bout duration and falls, none of the point estimates were significant suggesting no meaningful difference by MVPA strata. There was no clear evidence for effect modification of sedentary time or mean sedentary bout duration and incident falls by physical functioning.

In the sensitivity analyses that excluded women with low physical function (i.e., SPPB <4), results did not appreciably change (data not shown), indicating that women with poor physical function were not influencing the observed associations.

Falls experienced by women with the least sedentary time (those in Q1) were the least likely to require medical treatment and the least likely to result in a serious injury or fracture (Supplementary Table S1).

Discussion

Our main finding was that higher sedentary bout durations lead to more incident falls over 13-months in older women. Prior research has not examined whether the duration of sedentary bouts as a metric of patterns of sedentarism is associated with falls in older adults making our results novel. We did not find that total sedentary time was associated with falls in fully adjusted overall models, nor did we find that it was protective against falls. We did find that women with a history of 2 or more falls had the highest overall risk of falling, and that risk was strongly related to both sedentary time and mean sedentary bout durations. Our descriptive analysis of complications from falls showed that falls experienced by women with the lowest levels of sedentary time were the least likely to need medical attention or to result in fracture.

The results of adjusted models show that only those in the highest quartile had a significantly higher risk for falls, suggesting no evidence of a dose response effect. After adjustment for demographics, those in the highest quartile of sedentary time had a 26%

higher risk for falling relative to the lowest quartile but this was attenuated and became non-significant with adjustment for health conditions and behaviors (14% increased risk). These findings suggest that health variables may mediate associations between sedentary time and falls. We also did not observe a protective effect for sedentary time.

In Model 3, for both sedentary time and mean sedentary bout duration exposures, the further adjustment for MVPA did not change the observed effects. In models stratified by MVPA, the overall significant interactions suggested a stronger relationship between longer sedentary time and mean sedentary bout durations and falls among older women with lower MVPA. However, none of the IRRs for the quartiles were significant (as indicated by confidence intervals crossing the 1.0 threshold) indicating these could be chance findings or that our estimates may be too imprecise to identify where the variation by MVPA occurs. Additionally, our prior work reported no associations between high levels of MVPA and falls for older women;[34] women with poor physical functioning or a history of frequent falls had an increased fall risk only if they also had low MVPA levels. More research is needed to clarify the role of MVPA, if any, on the association between sedentary behavior and falls.

In our study of older women, we did not find evidence that physical function modified the association for sedentary time or bout duration with falls incidence. This was in contrast to a prior study reporting that older men with higher levels of accelerometer-measured sedentary time had an increased risk of questionnaire-reported falls but only among those with self-reported mobility limitations.[40] Unlike this prior study, we measured physical functioning using a performance-based test and falls prospectively using fall calendars which could have led us to different results.

In the effect modification analyses, the overall interaction of total sedentary time and falls when stratified by a history of 2 or more falls was borderline significant. Among those with a history of 2 or more falls, women engaging in 10.3 hours per day of sedentary time or more had a statistically significant 70% higher risk for falls than women with 8.3 hours or less of daily sedentary time. The risk was considerably higher than the effect observed among women in the highest sedentary time quartile with 0-1 falls in the past year. Likewise, women with history of frequent falls who had the highest mean sedentary bout durations had a 56% higher falls risk, which was greater than observed for their counterparts in the 0-1 falls stratum; the overall interaction did not achieve significance. These stronger effects pertain to a small group of older women who had a history of recurrent falls (592 women out of 5361) yet suggest that more research is needed on whether sedentary behavior is particularly relevant behavior to falls risk among this group.

The underlying mechansims for why prolonged sedentary patterns predict falls risk have not yet been systematically evaluated. It could be the case that taking more breaks from sedentary time provides lower extremity strengthening and better balance that improves physical function and could protect against falls. For example, in the Lifestyle Interventions and Independence of Elders (LIFE) Study, sedentary time was associated with an increase in risk for mobility disability longitudinally.[41] The results in our study indicate that sedentary time is likely relevant for fall- and injurious fall-prevention. It is well-established that structured physical activity can reduce the risk of falling and sustaining serious injuries.[42]

Studies are now needed to determine whether interventions that specifically aim to reduce sedentary time, such as by promoting frequent breaks from sitting and more bouts of standing and moving even if physical activity is not substantially altered, could be protective against falls.

Data on fall injuries from telephone interviews suggested that higher sedentary time puts women who fall at higher risk for needing a hospital admission, having serious injuries from their fall, and having a fracture related to their fall. Future research is needed to better characterize whether sedentary time is associated with injurious falls and fall-related hospitalization in studies that are powered to do so.

Strengths of our study include using an accelerometer to measure sedentary time, which enabled us to examine mean sedentary bout duration, and to consider the influence of accelerometer-measured MVPA on this association. Our outcome was based on careful surveillance for fall events using daily reporting of falls on calendars prospectively collected monthly over 1 year. Limitations include our measurement of sedentary time and patterns of sedentary time using accelerometers worn at the hip which are not as accurate at measuring sedentary patterns as when accelerometers are worn on the thigh.[43,44] Even with our prospective design, there could be reverse causation bias, for example among recurrent fallers, fear of falling could be leading to higher sedentary time. Future investigations could examine this potential mechanism.

Conclusions

This is the first known study to examine accelerometer assessments of sedentary time patterns and incident falls in older women, the group at highest risk of total and injurious falls. Our findings extend prior research by revealing that longer uninterrupted sedentary time patterns have an adverse association with falls in a large cohort of community-living older women. Women with history of frequent falls may be particularly vulnerable to prolonged sedentary patterns and high levels of total sedentary time. The American Geriatrics Society recommends multicomponent interventions including individually tailored exercise programs to reduce falls risk in those at high-risk for falling.[45] More prospective studies, including randomized trials, are needed to test whether decreasing overall sedentary time or interrupting prolonged bouts of sedentary time could reduce falls risk as an alternative health promoting strategy that could be added to current guidelines for fall prevention and healthy aging.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Decisions concerning study design, data collection and analysis, interpretation of results, preparation of the manuscript, and the decision to submit the manuscript for publication resided with committees comprising WHI investigators that included NHLBI representatives. The contents of the manuscript are solely the responsibility of the authors.

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REFERENCES

1. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med. 1988;319(26):1701–1707. doi: 10.1056/NEJM198812293192604 [PubMed: 3205267]
2. Hill K, Schwarz J, Flicker L, Carroll S. Falls among healthy, community-dwelling, older women: a prospective study of frequency, circumstances, consequences and prediction accuracy. Aust N Z J Public Health. 1999;23(1):41–48. doi: 10.1111/j.1467-842x.1999.tb01203.x [PubMed: 10083688]
3. Sattin RW. Falls among older persons: a public health perspective. Annu Rev Public Health. 1992;13:489–508. doi: 10.1146/annurev.pu.13.050192.002421 [PubMed: 1599600]
4. Bergen G, Stevens MR, Burns ER. Falls and Fall Injuries Among Adults Aged >/=65 Years - United States, 2014. MMWR Morb Mortal Wkly Rep. 2016;65(37):993–998. doi: 10.15585/mmwr.mm6537a2 [PubMed: 27656914]
5. Sleet DA, Moffett DB, Stevens J. CDC's research portfolio in older adult fall prevention: a review of progress, 1985-2005, and future research directions. J Safety Res. 2008;39(3):259–267. doi: 10.1016/j.jsr.2008.05.003 [PubMed: 18571566]
6. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. International Journal of Behavioral Nutrition and Physical Activity. 2017;14(1):75. 10.1186/s12966-017-0525-8
7. Kerr J, Takemoto M, Bolling K, et al. Two-Arm Randomized Pilot Intervention Trial to Decrease Sitting Time and Increase Sit-To-Stand Transitions in Working and Non-Working Older Adults. PloS one. 2016;11(1):e0145427–e0145427. 10.1371/journal.pone.0145427 [PubMed: 26735919]
8. Edwardson CL, Yates T, Biddle SJH, et al. Effectiveness of the Stand More AT (SMArT) Work intervention: cluster randomised controlled trial. BMJ. 2018;363:k3870. 10.1136/bmj.k3870 [PubMed: 30305278]
9. Dori ER, Melissa LA, Anne R, et al. Reducing Sitting Time in Obese Older Adults: The I-STAND Randomized Controlled Trial. Journal of Aging and Physical Activity. 2020:1–11. 10.1123/japa.2019-047010.1123/japa.2019-047010.1123/japa.2019-047010.1123/japa.2019-0470
10. de Rezende LF, Rey-Lopez JP, Matsudo VK, do Carmo Luiz O. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health. 2014;14(1):333. doi: 10.1186/1471-2458-14-333 [PubMed: 24712381]
11. Rosenberg DE, Bellettiere J, Gardiner PA, Villarreal VN, Crist K, Kerr J. Independent Associations Between Sedentary Behaviors and Mental, Cognitive, Physical, and Functional Health Among Older Adults in Retirement Communities. J Gerontol A Biol Sci Med Sci. 2016;71(1):78–83. doi: 10.1093/gerona/glv103 [PubMed: 26273024]
12. Sardinha LB, Santos DA, Silva AM, Baptista F, Owen N. Breaking-up sedentary time is associated with physical function in older adults. J Gerontol A Biol Sci Med Sci. 2015;70(1):119–124. doi: 10.1093/gerona/glu193 [PubMed: 25324221]
13. Copeland JL, Ashe MC, Biddle SJ, et al. Sedentary time in older adults: a critical review of measurement, associations with health, and interventions. Br J Sports Med. 2017;51(21):1539. doi: 10.1136/bjsports-2016-097210 [PubMed: 28724714]

14. Thibaud M, Bloch F, Tournoux-Facon C, et al. Impact of physical activity and sedentary behaviour on fall risks in older people: a systematic review and meta-analysis of observational studies. Eur Rev Aging Phys Act. 2012;9(1):5–15. doi: 10.1007/s11556-011-0081-1
15. Bea JW, Thomson CA, Wallace RB, et al. Changes in physical activity, sedentary time, and risk of falling: The Women's Health Initiative Observational Study. Prev Med. 2017;95:103–109. doi: 10.1016/j.ypmed.2016.11.025 [PubMed: 27932054]
16. Prince SA, LeBlanc AG, Colley RC, Saunders TJ. Measurement of sedentary behaviour in population health surveys: a review and recommendations. PeerJ. 2017;5:e4130. doi: 10.7717/peerj.4130 [PubMed: 29250468]
17. LaMonte MJ, Lee IM, E R-S, et al. Comparison of questionnaire and device measures of physical activity and sedentary behavior in a multi-ethnic cohort of older women. J Meas Phys Behav. 2019;2(2):82–93. doi: 10.1123/jmpb.2018-0057
18. Healy GN, Winkler EA, Owen N, Anuradha S, Dunstan DW. Replacing sitting time with standing or stepping: associations with cardio-metabolic risk biomarkers. Eur Heart J. 2015;36(39):2643–2649. doi: 10.1093/eurheartj/ehv308 [PubMed: 26228867]
19. Jefferis BJ, Merom D, Sartini C, et al. Physical Activity and Falls in Older Men: The Critical Role of Mobility Limitations. Med Sci Sports Exerc. 2015;47(10):2119–2128. doi: 10.1249/MSS.0000000000000635 [PubMed: 25668406]
20. Cauley JA, Harrison SL, Cawthon PM, et al. Objective measures of physical activity, fractures and falls: the osteoporotic fractures in men study. J Am Geriatr Soc. 2013;61(7):1080–1088. doi: 10.1111/jgs.12326 [PubMed: 23855842]
21. Scott D, Johansson J, Gandham A, Ebeling PR, Nordstrom P, Nordstrom A. Associations of accelerometer-determined physical activity and sedentary behavior with sarcopenia and incident falls over 12 months in community-dwelling Swedish older adults. Journal of Sport and Health Science. 2020. 10.1016/j.jshs.2020.01.006
22. LaCroix AZ, Rillamas-Sun E, Buchner D, et al. The Objective Physical Activity and Cardiovascular Disease Health in Older Women (OPACH) Study. BMC Public Health. 2017;17(1):192. doi: 10.1186/s12889-017-4065-6 [PubMed: 28193194]
23. Design of the Women's Health Initiative clinical trial and observational study. The Women's Health Initiative Study Group. Control Clin Trials. 1998;19(1):61–109. doi: 10.1016/s0197-2456(97)00078-0 [PubMed: 9492970]
24. Anderson GL, Manson J, Wallace R, et al. Implementation of the Women's Health Initiative study design. Ann Epidemiol. 2003;13(9 Suppl):S5–17. doi: 10.1016/s1047-2797(03)00043-7 [PubMed: 14575938]
25. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol. 1994;49(2):M85–M94. doi: 10.1093/geronj/49.2.m85 [PubMed: 8126356]
26. Choi L, Liu Z, Matthews CE, Buchowski MS. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. 2011;43(2):357–364. doi: 10.1249/MSS.0b013e3181ed61a3 [PubMed: 20581716]
27. Migueles JH, Cadenas-Sanchez C, Ekelund U, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. Sports Med. 2017;47(9):1821–1845. doi: 10.1007/s40279-017-0716-0 [PubMed: 28303543]
28. Migueles JH, Cadenas-Sanchez C, Ekelund U, et al. Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. Sports Medicine. 2017;47(9):1821–1845. 10.1007/s40279-017-0716-0 [PubMed: 28303543]
29. Evenson KR, Wen F, Herring AH, et al. Calibrating physical activity intensity for hip-worn accelerometry in women age 60 to 91 years: The Women's Health Initiative OPACH Calibration Study. Prev Med Rep. 2015;2:750–756. doi: 10.1016/j.pmedr.2015.08.021 [PubMed: 26527313]

30. Diaz KM, Howard VJ, Hutto B, et al. Patterns of Sedentary Behavior and Mortality in U.S. Middle-Aged and Older Adults: A National Cohort Study. Annals of internal medicine. 2017;167(7):465–475. 10.7326/M17-0212 [PubMed: 28892811]
31. Bellettiere J, Healy GN, LaMonte MJ, et al. Sedentary Behavior and Prevalent Diabetes in 6,166 Older Women: The Objective Physical Activity and Cardiovascular Health Study. J Gerontol A Biol Sci Med Sci. 2019;74(3):387–395. doi: 10.1093/gerona/gly101 [PubMed: 29726906]
32. Bellettiere J, LaMonte MJ, Evenson KR, et al. Sedentary behavior and cardiovascular disease in older women: The Objective Physical Activity and Cardiovascular Health (OPACH) Study. Circulation. 2019;139(8):1036–1046. doi: 10.1161/CIRCULATIONAHA.118.035312 [PubMed: 31031411]
33. Shiroma EJ, Freedson PS, Trost SG, Lee IM. Patterns of accelerometer-assessed sedentary behavior in older women. JAMA. 2013;310(23):2562–2563. [PubMed: 24346993]
34. Buchner DM, Rillamas-Sun E, Di C, et al. Accelerometer-Measured Moderate to Vigorous Physical Activity and Incidence Rates of Falls in Older Women. J Am Geriatr Soc. 2017;65(11):2480–2487. 10.1111/jgs.14960 [PubMed: 28755415]
35. Rillamas-Sun E, LaCroix A, Bell CL, Ryckman K, Ockene JK, Wallace RB. The Impact of Multimorbidity and Coronary Disease Comorbidity on Physical Function in Women Aged 80 Years and Older: The Women's Health Initiative. J Gerontol A Biol Sci Med Sci. 2016;71 (Suppl 1):54–61. doi: 10.1093/gerona/glv059
36. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. N Engl J Med. 1995;332(9):556–561. doi: 10.1056/NEJM199503023320902 [PubMed: 7838189]
37. Willett WC, Howe GR, Kushi LH. Adjustment for total energy intake in epidemiologic studies. Am J Clin Nutr. 1997;65(4 Suppl):1220S–1228S. doi: 10.1093/ajcn/65.4.1220S [PubMed: 9094926]
38. Pavasini R, Guralnik J, Brown JC, et al. Short Physical Performance Battery and all-cause mortality: systematic review and meta-analysis. BMC medicine. 2016;14(1):215. 10.1186/s12916-016-0763-7 [PubMed: 28003033]
39. R Core Team. R: A language and environment for statistical computing. 2013; www.R-project.org, 2014.
40. Jefferis BJ, Merom D, Sartini C, et al. Physical Activity and Falls in Older Men: The Critical Role of Mobility Limitations. Med Sci Sports Exerc. 2015. doi: 10.1249/MSS.0000000000000635
41. Mankowski RT, Anton SD, Axtell R, et al. Device-Measured Physical Activity As a Predictor of Disability in Mobility-Limited Older Adults. J Am Geriatr Soc. 2017;65(10):2251–2256. doi: 10.1111/jgs.15037 [PubMed: 28799216]
42. El-Khoury F, Cassou B, Charles MA, Dargent-Molina P. 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. 2013;347:f6234. doi: 10.1136/bmj.f6234 [PubMed: 24169944]
43. Lyden K, Kozey Keadle SL, Staudenmayer JW, Freedson PS. Validity of two wearable monitors to estimate breaks from sedentary time. Med Sci Sports Exerc. 2012;44(11):2243–2252. doi: 10.1249/MSS.0b013e318260c477 [PubMed: 22648343]
44. Barreira TV, Zderic TW, Schuna JM Jr., Hamilton MT, Tudor-Locke C Free-living activity counts-derived breaks in sedentary time: Are they real transitions from sitting to standing? Gait Posture. 2015;42(1):70–72. doi: 10.1016/j.gaitpost.2015.04.008 [PubMed: 25953504]
45. Panel on Prevention of Falls in Older Persons, American Geriatrics Society, British Geriatrics Society. Summary of the Updated American Geriatrics Society/British Geriatrics Society clinical practice guideline for prevention of falls in older persons. J Am Geriatr Soc. 2011;59(1):148–157. doi: 10.1111/j.1532-5415.2010.03234.x [PubMed: 21226685]

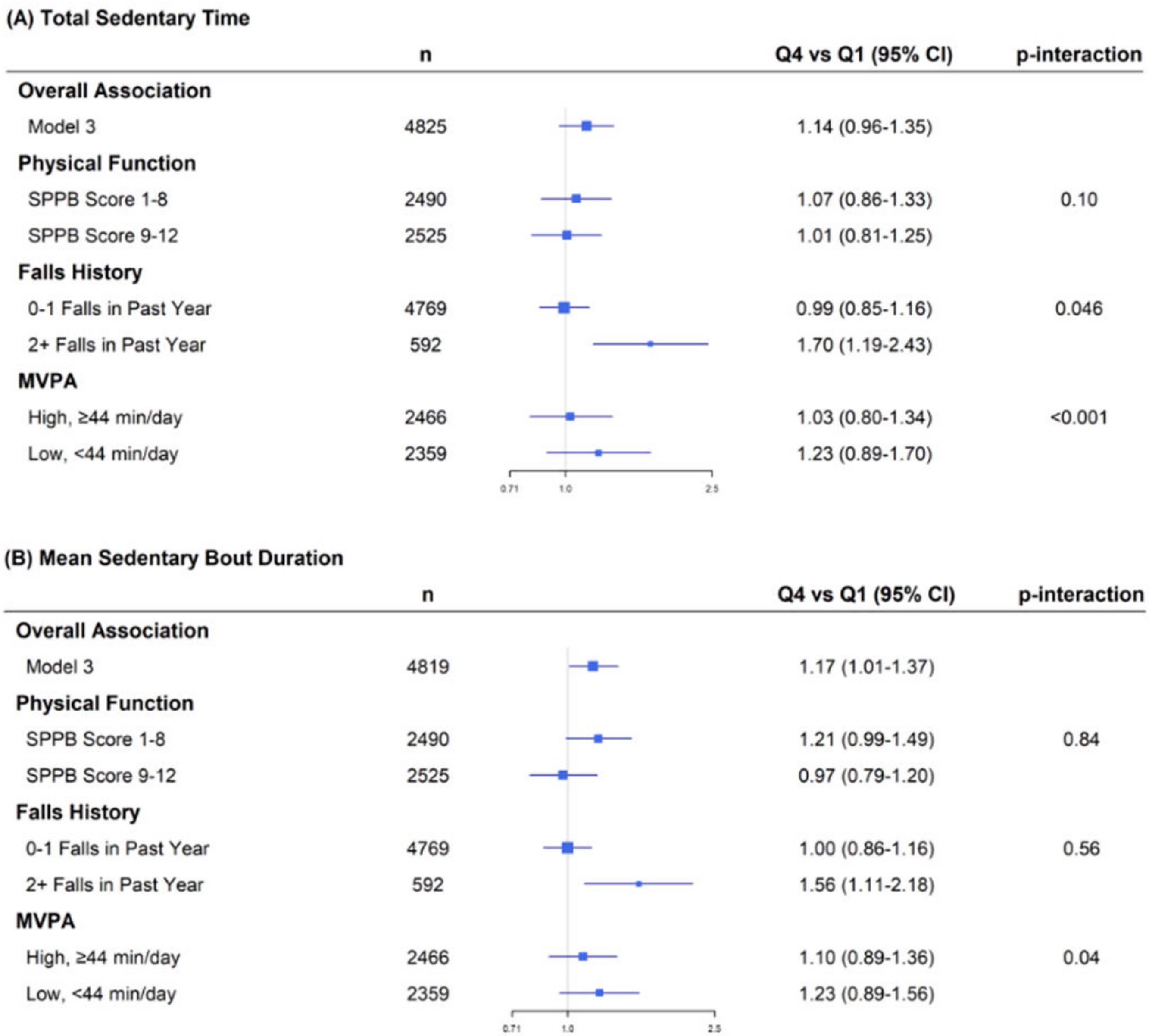

Figure 1.

Adjusted incidence rate ratios (95% confidence intervals) of falls by accelerometer-measured sedentary time and mean sedentary bout duration stratified by Short Physical Performance Battery (SPPB) scores, past falls history, and accelerometer moderate-to-vigorous physical activity (MVPA)

Table 1:

Demographic characteristics by accelerometer measured quartiles of sedentary time

		Wear-time Adjusted Minutes Per Day Sedentary (Quartiles)				
Characteristic	**Total**	**Q1 (<496 mins)**	**Q2 (496-<557 mins)**	**Q3 (557-<618 mins)**	**Q4 (≥618 mins)**	**p-value**
N (%)	**5545**	**1378 (24.9)**	**1385 (25.0)**	**1398 (25.2)**	**1384 (25.0)**	
Demographic						
Age, years, mean (SD)	78.8 (6.7)	76.6 (6.2)	78.2 (6.7)	79.2 (6.6)	81.0 (6.4)	<0.001
Age Category, n (%)						<0.001
63 - 74 years	1695 (30.6)	585 (42.5)	455 (32.9)	388 (27.8)	267 (19.3)	
75 - 79 years	1061 (19.1)	291 (21.1)	278 (20.1)	268 (19.2)	224 (16.2)	
80 - 84 years	1594 (28.8)	348 (25.3)	385 (27.8)	404 (28.9)	457 (33.0)	
85+ years	1195 (21.6)	154 (11.2)	267 (19.3)	338 (24.2)	436 (31.5)	
Race/Ethnicity, n (%)						<0.001
White	2797 (50.4)	546 (39.6)	655 (47.3)	720 (51.5)	876 (63.3)	
Black	1821 (32.8)	498 (36.1)	469 (33.9)	474 (33.9)	380 (27.5)	
Hispanic/Latina	927 (16.7)	334 (24.2)	261 (18.8)	204 (14.6)	128 (9.3)	
College Graduate, n (%)	2247 (40.8)	584 (42.4)	589 (42.8)	539 (39.0)	535 (38.9)	0.05
Health Behavior or Status						
Alcohol Use, n (%)						<0.001
Non-drinker	1908 (37.3)	414 (32.2)	454 (35.2)	503 (39.3)	537 (42.8)	
Less than 1 per week	1741 (34.1)	416 (32.3)	450 (34.9)	445 (34.8)	430 (34.3)	
1 or more drinks per week	1463 (28.6)	457 (35.5)	387 (30.0)	331 (25.9)	288 (23.0)	
Moderate or Severe Body Pain, n (%)	1696 (33.2)	338 (26.5)	418 (32.5)	445 (34.7)	495 (39.5)	<0.001
Uses Sleep Aid ≥1-2xs/wk, n (%)	870 (17.1)	185 (14.5)	240 (18.7)	231 (18.1)	214 (17.2)	0.02
BMI, kg/m2, mean (SD)	28.1 (5.7)	26.3 (4.9)	27.4 (5.3)	28.5 (5.7)	30.1 (6.1)	<0.001
BMI Categories, n (%)						<0.001
<25 kg/m2	1796 (32.6)	639 (46.6)	491 (35.8)	388 (27.9)	278 (20.3)	
25 - <30 kg/m2	1983 (36.0)	471 (34.4)	508 (37.0)	541 (38.9)	463 (33.8)	
≥30 kg/m2	1724 (31.3)	260 (19.0)	373 (27.2)	461 (33.2)	630 (46.0)	
Number of Chronic Conditions[a], n (%)						<0.001
Zero	1102 (19.9)	363 (26.4)	286 (20.7)	239 (17.2)	214 (15.5)	
One	2063 (37.3)	559 (40.6)	530 (38.3)	521 (37.5)	453 (32.8)	
Two	1433 (25.9)	308 (22.4)	354 (25.6)	387 (27.9)	384 (27.8)	
Three or more	931 (16.8)	146 (10.6)	214 (15.5)	242 (17.4)	329 (23.8)	
SPPB Score (Range 0-12), mean (SD)	8.3 (2.5)	9.0 (2.2)	8.7 (2.2)	8.2 (2.5)	7.2 (2.7)	<0.001
SPPB Score Categorized, n (%)						<0.001
1 - 8	2502 (49.7)	485 (37.8)	567 (44.9)	645 (51.2)	805 (65.8)	
9 - 12	2528 (50.3)	799 (62.2)	696 (55.1)	614 (48.8)	419 (34.2)	

Characteristic	Total	Wear-time Adjusted Minutes Per Day Sedentary (Quartiles) Q1 (<496 mins)	Q2 (496-<557 mins)	Q3 (557-<618 mins)	Q4 (≥618 mins)	p-value
Accelerometer-measured sedentary minutes, mean (SD)	555 (90)	437 (48)	527 (17)	587 (17)	666 (38)	
Accelerometer-measured mean sedentary bout duration in minutes, mean (SD)	7.4 (2.7)	5.1 (0.9)	6.4 (1.0)	7.5 (1.3)	10.3 (3.3)	
Accelerometer-measured MVPA minutes, mean (SD)	51.0 (34.5)	83.2 (37.6)	55.0 (28.0)	40.4 (22.3)	25.8 (17.2)	

Note: Total sedentary minutes included adjustment for wear time while awake by standardizing residuals. Chi-square test for categorical variables; trend test for continuous variables.

Abbreviations: BMI = Body Mass Index, MVPA = Moderate-to-Vigorous Physical Activity, Q = quartile, SD = standard deviation, SPPB = Short Physical Performance Battery

[a]From 10 conditions: cardiovascular disease, cerebrovascular disease, cancer, diabetes, osteoporosis, depression, chronic obstructive pulmonary disease, cognitive impairment, hearing loss, and urinary incontinence

Table 2:

Falls incidence and incidence rate ratios by quartiles of accelerometer-measured sedentary time.

	Accelerometer-measured sedentary time quartiles (Q)[*]				
	Q1 (lowest)	**Q2**	**Q3**	**Q4 (highest)**	**p-trend[***]**
Total sedentary time[**]					
Number of Falls	1200	1354	1342	1568	
Falls rate[****]	76.3	87.0	87.4	105.8	
Model 1[a,z]	1.0 (ref)	1.10 (0.96-1.25)	1.05 (0.92-1.20)	1.26 (1.10-1.44)	0.01
Model 2[b,z]	1.0 (ref)	1.06 (0.93-1.21)	1.05 (0.91-1.20)	1.11 (0.96-1.29)	0.58
Model 3[c,z]	1.0 (ref)	1.07 (0.93-1.24)	1.07 (0.91-1.25)	1.14 (0.96-1.35)	0.65
Mean sedentary bout duration					
Number of Falls	1162	1268	1307	1724	
Falls rate[****]	76.4	83.0	83.9	112.6	
Model 1[a,z]	1.0 (ref)	1.03 (0.90-1.17)	0.98 (0.86-1.12)	1.24 (1.09-1.42)	<0.001
Model 2[b,z]	1.0 (ref)	1.04 (0.91-1.20)	1.01 (0.88-1.16)	1.16 (1.01-1.33)	0.01
Model 3[c,z]	1.0 (ref)	1.05 (0.92-1.21)	1.02 (0.88-1.17)	1.17 (1.01-1.37)	0.01

Abbreviations: CI = confidence interval, Q = quartile, SD = standard deviation

[a]Adjusted for age, race/ethnicity, and education. Total sedentary time also adjusted for wear time. Total sedentary time n=5509; Mean sedentary bout duration n=5501.

[b]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, and chronic conditions. Total sedentary time also adjusted for wear time. Total sedentary time n=4825; Mean sedentary bout duration n=4819.

[c]Adjusted for age, race/ethnicity, education, vision, body pain, alcohol use, sleep aid use, body mass index, chronic conditions, and MVPA. Total sedentary time also adjusted for wear time. Total sedentary time n=4825; Mean sedentary bout duration n=4819.

[*]Quartile (Q) cutpoints: sedentary time Q1 = 195 - 496, Q2 = 497-556, Q3 = 557-617, Q4 = ≥618; mean sedentary bout duration Q1 = 2.6-5.5, Q2 = 5.6-6.7, Q3 = 6.8-8.3, Q4 = ≥8.4.

[**]Total sedentary time was adjusted for awake wear time using the residuals method.

[***]P-trend values are from cox regression models that include total sedentary time and mean sedentary bout duration as a continuous variable.

[****]Crude falls rate per 1000 person-months.

[z]Data are IRR (95% CI)