Accelerometer-Measured Physical Activity and Mortality in Women Aged 63 to 99

Michael J. LaMonte, PhD, MPH,[a] David M. Buchner, MD, MPH,[b] Eileen Rillamas-Sun, PhD,[c] Chongzhi Di, PhD,[c] Kelley R. Evenson, PhD, MS,[d] John Bellettiere, PhD, MPH,[e] Cora E. Lewis, MD, MSPH,[f] I-Min Lee, MD, ScD,[g] Lesly F. Tinker, PhD,[b] Rebecca Seguin, PhD,[h] Oleg Zaslovsky, PhD,[i] Charles B. Eaton, MD, MS,[j] Marcia L. Stefanick, PhD,[k] and Andrea Z. LaCroix, PhD, MPH[e]

OBJECTIVES: To prospectively examine associations between accelerometer-measured physical activity (PA) and mortality in older women, with an emphasis on light-intensity PA.

DESIGN: Prospective cohort study with baseline data collection between March 2012 and April 2014.

SETTING: Women's Health Initiative cohort in the United States.

PARTICIPANTS: Community-dwelling women aged 63 to 99 (N = 6,382).

MEASUREMENTS: Minutes per day of usual PA measured using hip-worn triaxial accelerometers, physical functioning measured using the Short Physical Performance Battery, mortality follow-up for a mean 3.1 years through September 2016 (450 deaths).

RESULTS: When adjusted for accelerometer wear time, age, race-ethnicity, education, smoking, alcohol, self-rated health, and comorbidities, relative risks (95% confidence intervals) for all-cause mortality across PA tertiles were 1.00 (referent), 0.86 (0.69, 1.08), 0.80 (0.62, 1.03) trend $P = .07$, for low light; 1.00, 0.57 (0.45, 0.71), 0.47 (0.35, 0.61) trend $P < .001$, for high light; and, 1.00, 0.63 (0.50, 0.79), 0.42 (0.30, 0.57) trend $P < .001$, for moderate-to-vigorous PA (MVPA). Associations remained significant for high light-intensity PA and MVPA ($P < .001$) after further adjustment for physical function. Each 30-min/d increment in light-intensity (low and high combined) PA and MVPA was associated, on average, with multivariable relative risk reductions of 12% and 39%, respectively ($P < .01$). After further simultaneous adjusting for light intensity and MVPA, the inverse associations remained significant (light-intensity PA: RR = 0.93, 95% CI = 0.89–0.97; MVPA: RR = 0.67, 95% CI = 0.58–0.78). These relative risks did not differ between subgroups for age or race and ethnicity (interaction, $P \geq .14$, all).

CONCLUSION: When measured using accelerometers, light-intensity and MVPA are associated with lower mortality in older women. These findings suggest that replacing sedentary time with light-intensity PA is a public health strategy that could benefit an aging society and warrants further investigation. **J Am Geriatr Soc 2017.**

Key words: aging; women's health; physical activity; epidemiology; longevity

From the [a]Department of Epidemiology and Environmental Health, University at Buffalo, Buffalo, New York; [b]Department of Kinesiology and Community Health, University of Illinois, Urbana-Champaign, Illinois; [c]Fred Hutchinson Cancer Research Center, Seattle, Washington; [d]Department of Epidemiology, University of North Carolina, Chapel Hill, North Carolina; [e]Department of Family Medicine and Public Health, University of California, San Diego, San Diego, California; [f]Department of Medicine, University of Alabama, Birmingham, Alabama; [g]Departments of Epidemiology and Medicine, Harvard University, Boston, Massachusetts; [h]Department of Nutritional Sciences, Cornell University, Ithaca, New York; [i]Department of Epidemiology, University of Washington, Seattle, Washington; [j]Department of Family Medicine and Epidemiology, Alpert School of Medicine, Brown University, Providence, Rhode Island; and [k]Department of Medicine, Stanford University, Stanford, California.

Address correspondence to Michael J. LaMonte, Department of Epidemiology and Environmental Health, School of Public Health and Health Professions, University at Buffalo—SUNY, 270 Farber Hall, 3435 Main St. Buffalo, NY 14214. E-mail: mlamonte@buffalo.edu

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Age-related deterioration in health is associated with a reduction in physical activity (PA).[1,2] U.S.[3] and international[4] guidelines on PA and public health recommend that healthy older adults perform at least 2.5 h/wk of moderate-intensity or 1.25 h/wk of vigorous-intensity aerobic PA for health benefits, a target that few older U.S. adults meet,[5] often because they are not capable of engaging in moderate- to vigorous-intensity PA (MVPA). Substantially lower all-cause mortality risk is associated with relatively high MVPA levels (3–5 times guideline recommended) assessed using questionnaires.[6,7] The extent to which this extends to older adults is unclear. Typically, self-reported activity explains only 10% to 20% of the variance in device-measured PA.[8] PA misclassification is large in older

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adults,[9] especially for light-intensity PA, which these individuals commonly perform but is currently not recommended for public health. Use of accelerometers to measure PA is novel in prospective studies on older adults and provides the ability to calibrate the effect of PA much better than with self-report, especially for light-intensity PA.

Only a few studies have reported on accelerometer-measured PA and health outcomes, typically all-cause mortality, specifically in older adults.[10–12] These studies have classified PA using accelerometer cutpoints derived from younger populations, which can result in misclassification in older adults[13] because the energy costs of PA are greater for older people. More data are needed to understand whether associations between PA and mortality are similar for younger-old and older-old adults and whether chronic disease burden or functional limitations attenuate any PA benefit. We examined associations between mortality and accelerometer-measured PA using age-relevant intensity cutpoints in older women of various ethnicities.

METHODS

Study Population

Women in the present study were enrolled in the Objective Physical Activity and Cardiovascular Health (OPACH) Study, a prospective investigation of accelerometer-measured PA and cardiovascular disease in women aged 63 to 99 ancillary to the Women's Health Initiative (WHI). Details regarding implementation of the WHI[14] and OPACH[15] studies have been published. During 2012–13, 7,875 women consented to participate in the WHI Long Life Study, which included in-home examinations[15] comprised of health questionnaires, anthropometric measurements, and a physical function test (Short Physical Performance Battery (SPPB[16]). A subset of 7,048 women consented to participate in the OPACH study and received an accelerometer, wear instructions, and a sleep log.[15] After the wear interval, accelerometers and logs were mailed to the WHI coordinating center. Of the 6717 (95.3%) women who returned their accelerometer, 6,489 (96.5%) had usable data for analysis.

Accelerometer Measurement

Participants were asked to wear a triaxial accelerometer (GT3X+, ActiGraph, Pensacola, FL) on their hip for 7 consecutive days during waking and sleeping hours except when bathing or swimming. Acceleration data from the 3 planes was processed using ActiLife software version 6 using 15-second epochs and the normal filter and then integrated in a vector magnitude (VM).[15] The VM counts were averaged and reported as mean total PA, an indicator of total PA volume. The VM counts also were categorized into intensity-specific PA levels as low light-intensity PA (19–225 counts/15 s), high light-intensity PA (226–518 counts/15 s), and MVPA (≥519 counts/15 s) using cutpoints derived from the OPACH calibration study[17] (Supplemental Table S1).

Accelerometer wear was identified using information from the sleep logs and a computer-based automated algorithm,[18] and non-wear was identified using a standard protocol.[19] Sleep time was excluded using data from sleep logs. To be included in the present analysis, we required at least 4 days with 10 or more hours per day of awake wear time (convention for compliant wear), resulting in a sample size of 6,382 women.

Mortality Ascertainment

Mortality surveillance was completed annually through mailed outcomes questionnaires augmented by National Death Index searches, proxy queries, obituaries, and hospital records to identify deaths.[20] The primary outcome was all-cause mortality through September 30, 2016. Cardiovascular disease (CVD) and cancer mortality were secondary outcomes. Trained physicians reviewed death certificates and other medical records to adjudicate cause of death. *International Classification of Diseases, Tenth Revision*, codes I00–09 and I60–69 identified CVD and C00–97 identified cancer as the underlying causes of death.

Statistical Analysis

Time to event was accrued from the first day of accelerometer monitoring to the date of death, loss to follow-up, or September 30, 2016, whichever came first. Hazard ratios were estimated from Cox regression analysis as measures of the relative risk (RR) with 95% confidence intervals (CI) for mortality according to PA levels. Models included progressive adjustment for potential confounders, beginning with accelerometer awake wear time and age (Model 1) and then adding race and ethnicity, education, smoking, alcohol, age at menopause, self-rated general health, and number of comorbidities (Model 2). Physical function, available in 5,479 (86%) participants, was an assumed mediator of the association between PA and mortality and was added last (Model 3). Although mean accelerometer-measured total PA was slightly higher in women with (336.8 min/d) than without (327.2 min/d) physical function scores (P < .001), mean age (78.7 vs 78.7, P = .90), awake wear time (14.8 vs 14.8 h/d, P = .83), and all-cause mortality (21.9 vs 27.1 per 1,000 person-years, P = .74) were not different. Tertiles of total and intensity-specific PA were modeled, and tests for linear trend were conducted across median values of categorical PA. For continuous PA, relative risks per 30-min/d increment were estimated. Linearity of the association was confirmed using restricted cubic spline regression[21] (Supplemental Figure S1). Tests for interaction were conducted by adding the cross-product term for continuous PA according to the subgroup of interest to the Cox regression models. The proportional hazards assumption was examined graphically by plotting survival according to PA categories and modeling mortality as a function of the interaction between PA and follow-up. No appreciable violations were noted.

Population attributable risk (PAR) of all-cause mortality was estimated for the lowest tertile of total PA and for current smoking, presence of one or more comorbidities, and presence of very low physical function (SPPB <5) to quantify the influence that controlling these mortality determinants could theoretically have in the source population of our cohort. PAR was computed as $P_c(1–1/RR_{adj})$, where P_c is the prevalence of a risk factor among decedents, and RR_{adj} is the multivariable RR for mortality associated with the risk factor.[22] The potential effect of subclinical morbidity at baseline was examined by discarding the first 6 months of follow-up and stratifying the association between PA and mortality simultaneously on age and comorbidity at baseline. *P*-values are for two-sided hypotheses tested at alpha .05.

RESULTS

At baseline, the cohort had a mean age of 78.6, body mass index (BMI) of 28.1 kg/m^2 (29.6% had BMI ≥30.0 kg/m^2), 1.6 comorbid conditions (21.2% had ≥3), and a mean physical function score of 8.2 out of a possible 12 (Table 1); 49.4% were white, 33.7% black, and 16.9% Hispanic. Of the mean 334.1 min/d of total PA, low light-intensity PA accounted for 56.1%, high-light-intensity PA for 29.0%, and MVPA for 14.9%. Correlations between the PA measures and with age are shown in Supplementary Table S2. All baseline characteristics, except age at menopause, were significantly associated with total PA (Table 1) and all-cause mortality (Supplementary Table S3).

We documented 450 all-cause deaths (154 CVD, 87 cancer) during a mean 3.1-year (range 0.5–4.5 years) follow-up interval. Crude all-cause mortality rates (per 1,000 person-years) declined across incremental tertiles of total PA (lowest 38.2; highest, 9.4), low light-intensity PA (lowest 30.8, highest 14.8), high light-intensity PA (lowest 38.7, highest 10.4) and MVPA (lowest 41.9, highest 7.6) (Table 2). Inverse patterns were also observed for CVD and cancer mortality. Age- and race- and ethnicity-specific all-cause death rates according to total PA are shown in Supplementary Figure S2. Except for age 60 to 69, in which mortality was low irrespective of PA, associations with total PA were inverse for awake wear time–adjusted mortality in women aged 70 to 79, 80 to 89, and 90 and older. Age- and awake wear time–adjusted mortality declined across PA tertiles in white and black women, whereas in Hispanic women the numbers of deaths were small, and the pattern was less clear. After controlling for awake wear time, age, and the other covariables, strong inverse associations with all-cause mortality were observed for total PA (RRs = 1.00, 0.68, 0.49, trend $P < .001$), high light PA (RRs = 1.00, 0.57, 0.47, trend $P < .001$), and MVPA (RRs = 1.00, 0.63, 0.42, trend $P < .001$) (Table 2). Low light-intensity PA was inversely, although nonsignificantly, associated with mortality (RRs = 1.00, 0.86, 0.80, trend P = .07). Further adjustment for physical function attenuated these associations, which remained significant for total PA, high light-intensity PA, and MVPA (all $P < .001$). Results were similar for CVD mortality. For cancer mortality, there was a significant age- and wear time–adjusted inverse association with MVPA ($P = .02$). After multivariable adjustment, although there was a suggestion of inverse associations between each PA exposure and cancer mortality, none were statistically significant.

Table 3 shows multivariable RRs for all-cause mortality associated with a 30-min/d increment in total PA, light-intensity PA (low and high combined), and MVPA. Each 30-min/d increment in total PA, light-intensity PA and MVPA was associated, on average, with statistically significant 12%, 12% and 39% lower mortality risk, respectively. When further simultaneously adjusting for light-intensity PA and MVPA, significant inverse associations remained (light-intensity PA: RR = 0.93; MVPA: RR = 0.67). Associations between each PA exposure and mortality generally were consistent across subgroup categories, and interaction tests were nonsignificant, with one exception. Associations between MVPA and mortality were stronger in women with lower (SPPB ≤8, RR = 0.56) than higher physical function (SPPB >8, RR = 0.77; interaction $P = .009$).

To further understand the influence of PA intensity on mortality risk, we examined light-intensity PA and MVPA simultaneously in a multivariable model estimating the RRs associated with each intensity at the same amount of energy expenditure (five metabolic equivalent (MET)-h/wk). Energy expenditure was calculated by multiplying the accelerometer measured time (h/wk) by the median measured MET value (1 MET = 3.0 mL of oxygen uptake/kg per min) observed in our calibration study[17] for light-intensity PA (2.0 METs) and MVPA (3.8 METs). This approach allows determination of whether mortality risks differ according to PA intensity when holding constant the amount of PA. For each 5 MET-hr/wk in light PA (equivalent to about 30 min/d of slow walking), the multivariable RR of mortality was 0.69 (95% CI: 0.56, 0.87; ß coefficient, -0.359) and for MVPA (equivalent to about 15 min/d of brisk walking) was 0.35 (95% CI: 0.24, 0.52; ß coefficient, -1.042). The difference between regression coefficients was significant ($\chi^2_{df\ 1} = 7.0$, $P = .008$), indicating that although light-intensity PA and MVPA were inversely associated with all-cause mortality, the relative risk reduction associated with MVPA was significantly greater than for the same amount of light-intensity PA.

In the public health context, the PAR was estimated to quantify the theoretical proportion of deaths in the source population that might be averted, assuming a causal association, if women improved their PA level beyond that of the lowest tertile (Table 4). PAR also was estimated for current smoking, 1 or more prevalent comorbidities, and very low physical function (SPPB score <5). Overall, the PAR was 29.8% for prevalent comorbidity, 23.5% for low total PA, 9.0% for low physical function, and 1.3% for current smoking. In women aged 80 and older, corresponding values were 21.2%, 23.3%, 8.7%, and 1.0%.

Sensitivity analyses showed that, after discarding deaths during the first 6 months of follow-up, multivariable associations for total PA, light-intensity PA, and MVPA with each mortality endpoint were similar to those in the primary analysis (Supplementary Table S4). To further evaluate the influence of prevalent disease at baseline, we simultaneously stratified these associations according to age and number of comorbidities (Supplementary Table S5). Inverse associations were observed for each PA exposure in women younger than 80 and those aged 80 and older regardless of number of comorbidities, except for light-intensity PA in women younger than 80 with 3 or more comorbidities, for which the sample size was small.

DISCUSSION

The novel aspect of this large prospective study was use of accelerometers to measure usual daily PA in community-dwelling older women. The results support the hypothesis

Table 1. Baseline Characteristics of All Women and According to Tertile of Total Physical Activity (PA)

Characteristic	All	Tertile of Total PA			P-Value for Trend
		1 (low)	2	3 (high)	
N	6,382	2,127	2,128	2,127	
PA, min/d, mean ± SD					
Total	334.1 ± 98.9	227.6 ± 46.9	331.1 ± 24.2	443.4 ± 57.2	<.001
Low light	187.5 ± 51.1	139.6 ± 31.3	189.9 ± 21.1	233.1 ± 40.9	<.001
High light	96.9 ± 36.1	62.2 ± 20.2	95.6 ± 16.9	132.8 ± 26.9	<.001
Moderate to vigorous	49.7 ± 34.4	25.8 ± 16.9	45.6 ± 23.6	77.6 ± 36.5	<.001
Follow-up, years, mean ± SD	3.1 ± 0.7	3.0 ± 0.8	3.2 ± 0.7	3.2 ± 0.7	.01
Age, mean ± SD	78.6 ± 6.7	80.7 ± 6.5	78.6 ± 6.6	76.8 ± 6.4	<.001
Age, %					
60–69	10.3	5.7	9.8	15.2	<.001
70–79	40.1	32.2	41.1	46.9	
80–89	45.5	55.1	45.2	36.3	
≥90	4.1	7.0	3.9	1.6	
Accelerometer wear time, h/d, mean ± SD	14.8 ± 1.4	14.2 ± 1.4	14.8 ± 1.2	15.4 ± 1.2	<.001
Age at menopause, mean ± SD	48.2 ± 6.3	48.0 ± 6.5	48.2 ± 6.3	48.2 ± 6.3	.51
BMI, kg/m^2, mean ± SD	28.1 ± 5.6	29.7 ± 6.0	28.1 ± 5.3	26.4 ± 4.9	<.001
BMI, kg/m^2, %					
<18.5 (underweight)	1.4	0.8	1.2	2.0	<.001
18.5–24.9 (normal)	30.9	20.9	28.7	42.7	
25.0–29.9 (overweight)	36.1	34.3	38.9	35.0	
≥30.0 (obese)	29.6	40.6	29.0	19.2	
Race and ethnicity					
White	49.4	58.2	47.7	42.2	<.001
Black	33.7	30.7	35.8	34.6	
Hispanic	16.9	11.1	16.5	23.3	
Education, %					
≤High school	20.2	20.3	19.9	20.4	<.001
Some college	39.2	42.5	39.1	35.9	
≥College graduate	40.7	37.2	41.0	43.7	
Current smoker	2.6	3.4	2.4	1.8	.001
Alcohol, drinks per week in past 3 months					
0	34.3	38.8	33.4	30.5	<.001
<1	40.1	41.6	41.2	37.6	
≥1	25.6	19.6	25.4	31.9	
Self-rated general health, %					
Excellent	8.9	5.1	9.1	12.7	<.001
Very good	37.2	30.2	37.7	43.5	
Good	45.2	51.6	45.6	38.4	
Fair	8.3	12.2	7.3	5.3	
Poor	0.4	0.9	0.2	0.1	
SPPB score, mean ± SD (n = 5,479) (range 0-12)					<.001
SPPB score, % (n = 5,479)	8.2 ± 2.5	7.2 ± 2.7	8.4 ± 2.3	8.9 ± 2.2	<.001
0–4	9.0	17.2	6.3	4.0	
5–8	41.9	48.5	43.7	34.1	
9–12	49.0	34.4	50.1	61.9	
Number of comorbidities, mean ± SD[a]	1.6 ± 1.3	1.9 ± 1.4	1.6 ± 1.2	1.4 ± 1.1	<.001
Number of comorbidities, %[a]					
0	16.9	11.8	16.3	22.6	<.001
1–2	58.9	55.9	59.9	60.8	
≥3	21.2	29.1	20.5	13.9	

[a]Coronary heart disease, stroke, cancer, diabetes mellitus, hip fracture, osteoarthritis, depression, chronic obstructive pulmonary disease, cognitive impairment, frequent falls.

SD = standard deviation; BMI = body mass index; SPPB = Short Physical Performance battery test of physical functioning[16], range 0-12 (missing n=903).

that higher levels of accelerometer-measured PA, even when below the moderate-intensity threshold recommended in current guidelines,[3,4] are associated with lower all-cause and CVD mortality in women aged 63 to 99. Our findings expand on previous studies showing that higher self-reported PA reduces mortality in adults aged 60 and older,[6,23] specifically in older women,[23] and at less than recommended amounts.[6,23,24] Moreover, our findings challenge the conclusion of recent meta-analyses that MVPA, measured by to self-report, is required to offset mortality risk in adults.[6,7] Two principal observations underscore the present results.

First, absolute rates of all-cause and CVD mortality were at least 50% lower in cohort members in the middle tertile of each PA exposure than in those in the lowest

Table 2. Risk of All-Cause, Cardiovascular Disease (CVD), and Cancer Mortality According to Physical Activity (PA) Level (N = 6,382)

	Physical Activity Tertile			
	1 (low)	2	3 (high)	P-Trend
All-Cause Mortality				
Total PA, deaths (rate[a])	259 (38.2)	124 (17.8)	67 (9.4)	
RR (95% CI)[b]	1.00	0.58 (0.47–0.73)	0.38 (0.28–0.51)	<.001
RR (95% CI)[c]	1.00	0.68 (0.54–0.85)	0.49 (0.37–0.66)	<.001
RR (95% CI)[d] (N = 5479)	1.00	0.73 (0.57–0.93)	0.56 (0.41–0.76)	<.001
Low light intensity PA, deaths (rate[a])	211 (30.8)	135 (19.3)	104 (14.8)	
RR (95% CI)[b]	1.00	0.77 (0.61–0.95)	0.69 (0.54–0.89)	.002
RR (95% CI)[c]	1.00	0.86 (0.69–1.08)	0.80 (0.62–1.03)	.07
RR (95% CI)[d] (N = 5479)	1.00	0.91 (0.71–1.15)	0.87 (0.66–1.14)	.28
High light intensity PA, deaths (rate[a])	263 (38.7)	113 (16.2)	74 (10.4)	
RR (95% CI)[b]	1.00	0.49 (0.39–0.62)	0.36 (0.28–0.48)	<.001
RR (95% CI)[c]	1.00	0.57 (0.45–0.71)	0.47 (0.35–0.61)	<.001
RR (95% CI)[d] (N = 5479)	1.00	0.61 (0.47–0.78)	0.57 (0.42–0.76)	<.001
MVPA, deaths (rate[a])	280 (41.9)	116 (16.6)	54 (7.6)	
RR (95% CI)[b]	1.00	0.54 (0.43–0.67)	0.31 (0.23–0.42)	<.001
RR (95% CI)[c]	1.00	0.63 (0.50–0.79)	0.42 (0.30–0.57)	<.001
RR (95% CI)[d] (N = 5479)	1.00	0.66 (0.51–0.84)	0.46 (0.33–0.65)	<.001
CVD Mortality				
Total PA, deaths (rate[a])	97 (14.3)	43 (6.2)	14 (1.9)	
RR (95% CI)[b]	1.00	0.56 (0.39–0.81)	0.23 (0.13–0.41)	<.001
RR (95% CI)[c]	1.00	0.64 (0.44–0.94)	0.29 (0.16–0.53)	<.001
RR (95% CI)[d] (N = 5479)	1.00	0.66 (0.44–1.01)	0.34 (0.18–0.64)	<.001
Low light intensity PA, deaths (rate[a])	82 (11.9)	41 (5.9)	31 (4.4)	
RR (95% CI)[b]	1.00	0.61 (0.42–0.89)	0.55 (0.35–0.85)	.003
RR (95% CI)[c]	1.00	0.69 (0.47–1.02)	0.64 (0.41–0.99)	.03
RR (95% CI)[d] (N = 5479)	1.00	0.78 (0.51–1.18)	0.72 (0.44–1.18)	.16
High light intensity PA, deaths (rate[a])	100 (14.7)	37 (5.3)	17 (2.4)	
RR (95% CI)[b]	1.00	0.44 (0.30–0.65)	0.24 (0.14–0.39)	<.001
RR (95% CI)[c]	1.00	0.50 (0.34–0.74)	0.30 (0.17–0.51)	<.001
RR (95% CI)[d] (N = 5479)	1.00	0.49 (0.32–0.76)	0.33 (0.18–0.59)	<.001
MVPA, deaths (rate[a])	99 (14.8)	39 (5.6)	16 (2.2)	
RR (95% CI)[b]	1.00	0.57 (0.39–0.53)	0.31 (0.18–0.53)	<.001
RR (95% CI)[c]	1.00	0.68 (0.45–0.99)	0.42 (0.24–0.75)	.001
RR (95% CI)[d] (N = 5479)	1.00	0.68 (0.44–1.05)	0.43 (0.23–0.81)	.005
Cancer Mortality				
Total PA, deaths (rate[a])	42 (6.2)	23 (3.3)	22 (3.1)	
RR (95% CI)[b]	1.00	0.62 (0.37–1.05)	0.68 (0.39–1.19)	.13
RR (95% CI)[c]	1.00	0.71 (0.42–1.19)	0.85 (0.47–1.51)	.48
RR (95% CI)[d] (N = 5479)	1.00	0.68 (0.38–1.20)	0.76 (0.41–1.43)	.34
Low light intensity PA, deaths (rate[a])	34 (4.9)	32 (4.6)	21 (2.9)	
RR (95% CI)[b]	1.00	1.05 (0.64–1.72)	0.76 (0.43–1.35)	.38
RR (95% CI)[c]	1.00	1.13 (0.69–1.87)	0.82 (0.46–1.48)	.57
RR (95% CI)[d] (N = 5479)	1.00	0.98 (0.57–1.69)	0.79 (0.42–1.46)	.47
High light intensity PA, deaths (rate[a])	38 (5.6)	27 (3.9)	22 (3.1)	
RR (95% CI)[b]	1.00	0.79 (0.48–1.29)	0.69 (0.39–1.21)	.18
RR (95% CI)[c]	1.00	0.90 (0.54–1.49)	0.87 (0.49–1.54)	.61
RR (95% CI)[d] (N = 5479)	1.00	0.76 (0.43–1.34)	0.87 (0.47–1.59)	.59
MVPA, deaths (rate[a])	43 (6.4)	30 (4.3)	14 (1.9)	
RR (95% CI)[b]	1.00	0.83 (0.51–1.34)	0.45 (0.23–0.85)	.02
RR (95% CI)[c]	1.00	0.95 (0.58–1.56)	0.59 (0.30–1.15)	.15
RR (95% CI)[d] (N = 5479)	1.00	0.92 (0.54–1.58)	0.59 (0.29–1.21)	.18

[a]Crude death rate per 1,000 person-years.
[b]Adjusted for awake accelerometer wear time (h/d) and age (years).
[c]Adjusted for awake accelerometer wear time (h/d), age (years), race and ethnicity (white, black, Hispanic), education (≤high school, some college, ≥college), current smoking (no, yes), alcohol intake in past 3 months (none, <1, ≥1 drinks/week), age at menopause, self-rated general health (excellent, very good, good, fair, poor), and number of comorbid conditions (0–10, continuous).
[d]Adjusted for above covariables plus Short Physical Performance Battery score (0–12, continuous) (n = 5,479 (384 total deaths, 128 CVD deaths, 75 cancer deaths).
RR = relative risk; CI = confidence interval; MVPA = moderate to vigorous PA.

Table 3. Risk of All-Cause Mortality Associated with 30-Min/D Increment in Physical Activity (PA) in the Overall Cohort and Cohort Subgroups

Cohort Group	Total PA Relative Risk (95% CI)[a]	Light intensity PA[b]	MVPA
		Relative Risk (95% CI)[a]	
Overall (N = 6,382; 450 deaths)	0.88 (0.85–0.92)	0.88 (0.85–0.92)	0.61 (0.54–0.71)
		0.93 (0.89–0.97)[c]	0.67 (0.58–0.78)[c]
Age			
<80 (n = 3,211; 90 deaths)	0.91 (0.85–0.98)	0.93 (0.84–1.01)	0.68 (0.52–0.88)
		0.98 (0.89–1.08)[c]	0.69 (0.53–0.92)[c]
≥80 (n = 3,171; 360 deaths)	0.87 (0.84–0.91)	0.88 (0.84–0.92)	0.60 (0.51–0.71)
		0.92 (0.87–0.96)[c]	0.67 (0.56–0.79)[c]
Interaction, *P*-value	.67	.74	.73
Race and ethnicity			
White (n = 3,150; 320 deaths)	0.89 (0.85–0.93)	0.89 (0.86–0.94)	0.60 (0.51–0.71)
		0.94 (0.89–0.99)[c]	0.64 (0.54–0.76)[c]
Black (n = 2,151; 96 deaths)	0.85 (0.79–0.92)	0.85 (0.77–0.92)	0.53 (0.38–0.74)
		0.90 (0.82–0.99)[c]	0.63 (0.45–0.91)[c]
Hispanic (n = 1,081; 34 deaths)	0.91 (0.81–1.03)	0.89 (0.77–1.04)	0.88 (0.62–1.24)
		0.90 (0.77–1.05)[c]	0.96 (0.67–1.37)[c]
Interaction, *P*-value	.32	.14	.38
Body mass index, kg/m^2			
<30 (n = 4,492; 336 deaths)	0.87 (0.83–0.91)	0.87 (0.83–0.92)	0.62 (0.54–0.73)
		0.91 (0.87–0.96)[c]	0.69 (0.59–0.81)[c]
≥30 (n = 1,890; 114 deaths)	0.88 (0.81–0.95)	0.89 (0.81–0.97)	0.53 (0.38–0.75)
		0.94 (0.86–1.03)[c]	0.58 (0.41–0.82)[c]
Interaction, *P*-value	.86	.64	.29
Short Physical Performance Battery score (n = 5479, 384 deaths)			
≤8 (n = 2,792; 279 deaths)	0.88 (0.84–0.92)	0.89 (0.84–0.94)	0.56 (0.46–0.69)
		0.94 (0.89–0.99)[c]	0.61 (0.49–0.75)[c]
>8 (n = 2,687; 105 deaths)	0.92 (0.85–0.98)	0.92 (0.85–1.01)	0.77 (0.61–0.96)
		0.95 (0.87–1.03)[c]	0.79 (0.63–1.00)[c]
Interaction, *P*-value	.10	.16	.009

[a]Adjusted for awake accelerometer wear time, age, race and ethnicity, education, smoking, alcohol, age at menopause, number of comorbid conditions, and self-assessed general health status as defined in Table 2 footnote.
[b]Combined minutes per day of low and high light intensity PA.
[c]Light intensity PA and moderate to vigorous PA (MVPA) mutually adjusted for one another.
CI = confidence interval; PA = Physical Activity.

Table 4. Population Attributable Risk (PAR) of All-Cause Mortality According to Selected Cohort Characteristics

Characteristic	Prevalence, % In Cohort	Prevalence, % In Decedents	RR (95% CI)[a]	PAR (%) (95% CI)[b]
All (N = 6,382; 450 deaths)				
Low total physical activity	33.3	57.6	1.69 (1.38–2.01)	23.5 (14.3–31.8)
Current smoker	2.6	3.1	1.72 (1.01–2.95)	1.3 (−0.4–2.9)
≥1 comorbidities	83.1	92.0	1.48 (1.05–2.09)	29.8 (3.4–49.0)
Low physical function (SPPB score <5)	9.0	23.4	1.62 (1.26–2.09)	9.0 (3.6–13.9)
Aged ≥80 (n = 3,171; 360 deaths)				
Low total physical activity	41.7	59.7	1.64 (1.31–2.06)	23.3 (12.4–32.9)
Current smoker	1.5	2.2	1.80 (0.89–3.65)	1.0 (−0.6–2.5)
≥1 comorbidities	86.9	91.7	1.30 (0.89–1.91)	21.2 (−11.8–44.4)
Low physical function (SPPB score <5)	14.4	25.1	1.53 (1.17–2.00)	8.7 (2.4–14.6)

[a]Adjusted for awake accelerometer wear-time, age, race and ethnicity, education, alcohol, age at menopause, self-rated general health, and the other characteristics in the table.
[b]Calculated using the following formula[22]: $P_c(1–1/RR_{adj})$, where P_c is the prevalence of a risk factor among decedents and RR_{adj} is the multivariable adjusted[a] relative risk (RR) for mortality associated with the specified risk factor.
CI = confidence interval; SPPB = Short Physical Performance Battery.

tertile. This is particularly impressive when considering the small mean differences between these tertiles of 50 min/d for low light-intensity PA, 33 min/d for high light-intensity PA, and 20 min/d for MVPA. Use of accelerometers enhanced accurate quantification of such small differences in usual daily PA, which is not possible using questionnaire assessments. Small increases in daily PA, which older adults can achieve,[25] could have a substantial effect on mortality in later life. Even in the oldest cohort members, ages 80-89 and ≥90 years, absolute rates of all-cause mortality were 44% and 15% lower, respectively, when comparing the middle and lowest total PA tertile. Furthermore, absolute rates of all-cause rates of mortality were 40% lower in black and white women in the middle tertile of PA than in those in the lowest tertile. After controlling for relevant mortality predictors, relative risk reductions in all-cause mortality associated with 30 min/d of total PA, light-intensity PA, and MVPA were evident in women ≥80 years, and in both white and black women. The benefit of small amounts of daily PA at less-than-guideline-recommended moderate intensity may reach a broad age and racial and ethnic distribution of the aging U.S. population.

Second, we used age-specific accelerometer intensity cutpoints to define light-intensity PA and MVPA. Our accelerometer measures reinforce previous self-reported data[24] in showing that older women spend the majority of daily PA in light-intensity PA. Previous findings are inconsistent regarding self-reported light-intensity PA and mortality, some showing no association[26] and others showing protection.[24] Results of the present study provide clear evidence of lower risks of all-cause and CVD mortality associated with light-intensity PA and MVPA measured using accelerometers. Low light-intensity PA was inversely associated with all-cause and CVD mortality and, impressively, is defined as accelerometer count levels (19–225 counts/ 15 s) just slightly higher than those defining sedentary behavior (<19).[17] Even in women aged 80 and older with 3 or more comorbidities at baseline, 30 min/d of light-intensity PA (low and high combined) and MVPA was associated with multivariable risk reductions in all-cause mortality of 10% and 43%, respectively. Because multimorbidity affects more than 80% of adults aged 85 and older and is associated with substantial disease burden,[27,28] this is a remarkable observation that suggests that small amounts of light-intensity PA could confer meaningful mortality benefit in a high-risk subset of older women. For those able and interested in doing MVPA, results indicate that the benefit could be greater.

Accelerometer studies in the National Health and Nutrition Examination Study (NHANES) have had mixed results regarding light-intensity PA and mortality.[12,29,30] In these investigations, hip-worn uniaxial accelerometers were used, and light-intensity PA was defined as 100 to 2019 vertical axis counts/minute and MVPA as 2,020 or more vertical axis counts/minute. MVPA was significantly associated with lower multivariable mortality risk when controlling for light-intensity PA,[12,29,30] but only two of these studies observed significantly lower mortality associated with light-intensity PA when controlling for MVPA.[12,30] In this regard, Schmid et al. [12] observed a 13% lower mortality risk associated with 30-min/d of light-intensity PA in adults aged 65 and older, consistent with the 8% lower risk for the same duration of light-intensity PA we observed in women aged 63 to 99.

Low total PA in later life has relevance to all-cause mortality reduction similar to that of multimorbidity, as suggested by the PARs of approximately 23% and 29%, respectively, in the older women studied here. If women became active beyond those in the lowest tertile or if multimorbidity were eliminated, all-cause deaths would decrease by about 1 in 4, assuming causal associations. PAR, although a theoretical estimate, brings into context the force an exposure exerts on population health, which depends on the amount of exposure and the strength of its association with mortality.[31] PAR would be low for characteristics that are not common (e.g., smoking in the present cohort). Because the population prevalence of low PA and its associated mortality risk is high,[32] the potential population effect for delaying mortality in later life through increases in PA is considerable.

The major strength and novelty of our study is accelerometer PA measurement in a multiethnic cohort of women of a wide range of older ages and functional and general health status. The high proportion (89%) of WHI Long Life Study participants who participated in OPACH, the high proportion of accelerometers returned (95%), and the high proportion (92%) of women meeting the wear time criteria reduce the likelihood that self-selection influenced the study results. Use of triaxial accelerometers allowed detection of movement in three planes, whereas studies using uniaxial devices detect movement in a single plane (as in NHANES), which could be less sensitive to movement patterns and intensities of daily life[33] among older adults.[17] Accelerometer intensity thresholds were determined in a sex- and age-relevant calibration study,[17] which is novel in epidemiological investigations.[34]

Subclinical disease at baseline could have influenced study findings. The consistency of results after discarding deaths during early follow-up and stratifying according to age (<80 vs ≥80), physical functioning, and multimorbidity reduces the likelihood that this is the primary explanation for our results. PA intensity was defined on an absolute scale. Because of the age-related decline in aerobic capacity,[35] even lighter-intensity PA defined on an absolute scale may reflect a higher relative intensity in an older adult than in a younger. Subgroup analyses, particularly in Hispanic women, may have had limited statistical power, which should be considered when interpreting those results. Although the present results do not extend directly to men, they are consistent with those of previously published studies.[12]

In conclusion, when measured using accelerometers, higher levels of light-intensity PA, below the guideline-recommended MVPA threshold,[3,4] are associated with lower all-cause and CVD mortality in a multiethnic cohort of women aged 63 to 99. The mortality benefit of light-intensity PA and MVPA appears to extend to all subgroups examined—obese, aged 80 and older, with multimorbidity, and with low physical function. With continued growth in numbers of older women,[36] the high prevalence of inactivity in this group,[9] and the large amount of daily time spent in light-intensity activities,[24] these findings support greater emphasis on the benefits of light-intensity PA in future PA recommendations for our aging population. Further investigation is needed of the health benefits of increasing light-intensity PA by reducing time spent sedentary.

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Short List of WHI Investigators

Program Office, National Heart, Lung, and Blood Institute, Bethesda, MD: Jacques Rossouw, Shari Ludlam, Dale Burwen, Joan McGowan, Leslie Ford, and Nancy Geller; Clinical Coordinating Center, Fred Hutchinson Cancer Research Center, Seattle, WA: Garnet Anderson, Ross Prentice, Andrea LaCroix, and Charles Kooperberg; Investigators and Academic Centers, Brigham and Women's Hospital, Harvard Medical School, Boston, MA: JoAnn E. Manson; MedStar Health Research Institute/ Howard University, Washington, DC: Barbara V. Howard; Stanford Prevention Research Center, Stanford, CA: Marcia L. Stefanick; The Ohio State University, Columbus, OH: Rebecca Jackson; University of Arizona, Tucson/ Phoenix, AZ: Cynthia A. Thomson; University at Buffalo, Buffalo, NY: Jean Wactawski-Wende; University of Florida, Gainesville/Jacksonville, FL: Marian Limacher; University of Iowa, Iowa City/Davenport, IA: Robert Wallace; University of Pittsburgh, Pittsburgh, PA: Lewis Kuller; School of Medicine, Wake Forest University, Winston-Salem, NC: Sally Shumaker

WHI Memory Study: School of Medicine, Wake Forest University, Winston-Salem, NC: Sally Shumaker.

For a full list of all investigators who have contributed to WHI science, see www.whi.org/researchers/Documents%20%20Write%20a%20Paper/WHI%20Investigator%20Long%20List.pdf

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Sponsor's Role: 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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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1. Accelerometer PA levels and examples of corresponding activity tasks and intensity levels.

Table S2. Spearman correlations[a] between physical activity measures and age (N = 6,382).

Table S3. Baseline characteristics according to all-cause mortality status (N = 6,382). Data are mean ±SD, or %.

Table S4. Sensitivity analysis on risk of all-cause, CVD, and cancer mortality associated with a 30-minute/day increment in physical activity after discarding deaths (28 all-cause; 12 CVD; 8 cancer) during the first 6 months of follow-up.

Table S5. Sensitivity analysis on risk of all-cause mortality associated with a 30-minute/day increment in physical activity with simultaneous stratification on age and number of comorbidities (N = 6382, 450 deaths).

Figure S1. Multivariable-adjusted restricted cubic spline[21] dose-response function between total physical activity and all-cause mortality (N = 6,382).

Figure S2. All-cause death rates by age and racial-ethnic groups according to total physical activity levels.

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FIGURE LEGENDS

Supplemental Figure S1. Multivariable-adjusted restricted cubic spline[21] dose-response function between total physical activity and all-cause mortality (N=6,382). Knots at the 5th (2.9 hr/d), 50th (5.5 hr/d), and 95th (8.4 hr/d) percentiles; reference is the 10th (3.5 hr/d) percentile. Model adjusted for awake accelerometer wear time, age, race-ethnicity, education, current smoking, alcohol intake, age at menopause, self-rated health status and number of comorbidities.

The exposure-response function is linear fully across the range of total PA exposure for which exposure frequency is sufficiently high (see histogram below dose-response curve). Linear trend, $p <.001$; non-linearity, $p = .18$.

Supplemental Figure S2. All-cause death rates by age and racial-ethnic groups according to total physical activity levels.

Age-specific rates are adjusted for awake accelerometer wear-time. Racially-ethnically specific rates are adjusted for age and awake wear-time. Number of deaths for tertiles 1, 2, and 3, respectively are 2, 4, and 5 for ages 60-69; 42, 18, and 19 for ages 70-79; 181, 87, and 39 for ages 80-89; 34, 15, and 4 for ages 90+; 191, 84, and 45 for whites; 55, 33, and 8 for blacks; and, 13, 7, and 14 for Hispanics.

Table S1. Accelerometer PA levels and examples of corresponding activity tasks and intensity levels.

	VM counts/15 sec	**Corresponding Activity Task**	**Corresponding MET[a] Intensity**
Low Light PA	19-225	Wash/dry dishes	1.6-2.2
High Light PA	226-518	Slow walking (1.5 mph, level)	2.3-2.9
MVPA	≥519	Brisk walking (2.0-2.5 mph, level)	≥3.0

From Evenson et al. [17]

VM, vector magnitude; MET, metabolic equivalent.

[a]Assumes 1 MET = 3.0 ml O_2 uptake/kg body mass/minute, as typically observed in older adults.[17]

Table S2. Spearman correlations[a] between physical activity measures and age (N = 6,382).

	LLPA	HLPA	MVPA	Age[b]
Total PA[c]	0.80	0.89	0.65	-0.25
LLPA[c]		0.57	0.17	-0.12
HLPA[c]			0.61	-0.16
MVPA[c]				-0.38

LLPA, low light physical activity; HLPA, high light physical activity; MVPA, moderate-to-vigorous physical activity.

[a]Correlations between PA measures are adjusted for age and accelerometer wear time.

[b]Correlations with age are adjusted for accelerometer wear time.

P <.001 for all correlations.

Table S3. Baseline characteristics according to all-cause mortality status (N = 6,382). Data are mean ±SD, or %.

Characteristic	Decedent	Survivor	P-value	Deaths (Rate/1000 PY)	Age-adjusted RR (95% CI)
N (%)	450 (7.1)	5,932 (92.9)			
Total PA (min/d)	274.0 ± 93.2	338.6 ± 97.9	<.001		
Low light PA (min/d)	170.0 ± 52.8	188.8 ± 50.7	<.001		
High light PA (min/d)	74.9 ± 35.0	98.6 ± 35.7	<.001		
MVPA (min/d)	29.2 ± 26.9	51.2 ± 50.3	<.001		
Follow-up (years)	2.1 ± 1.0	3.2 ± 0.6	<.001		
Age (years)	83.5 ± 5.7	78.3 ± 6.6	<.001		
60-69	2.4	10.8	<.001	11 (5.4)	1.00 (ref)
70-79	17.6	41.8		79 (9.2)	1.60 (0.85, 3.01)
80-89	68.2	43.8		307 (32.6)	5.77 (3.16, 10.53)
≥90	11.8	3.6		53 (63.4)	11.53 (6.02, 22.08)
Accelerometer wear time (hr/d)	14.5 ± 1.4	14.8 ± 1.4	.01		0.85 (0.79, 0.91)
Age at menopause (years)	48.5 ± 6.0	48.1 ± 6.4	.278		0.99 (0.98, 1.01)
BMI (kg/m^2)	27.3 ± 5.8	28.2 ± 5.6	.002		
<18.5 (underwt)	2.1	1.3	.001	9 (32.2)	1.14 (0.58, 2.23)
18.5-24.9 (normal)	38.6	30.3		165 (26.7)	1.00 (ref)
25.0-29.9 (overwt)	32.7	36.4		140 (19.7)	0.82 (0.66, 1.02)
≥30 (obese)	26.6	32.0		114 (18.1)	0.97 (0.76, 1.23)
Race-ethnicity			<.001		
White	71.1	47.7		320 (31.2)	1.00 (ref)
Black	21.3	34.6		96 (13.9)	0.88 (0.69, 1.13)
Hispanic	7.6	17.7		34 (9.1)	0.57 (0.39, 0.82)
Education			.054		
High school or less	22.7	20.1		102 (24.5)	1.00 (ref)
Some college	42.0	38.9		189 (23.1)	1.01 (0.79, 1.29)
College or more	35.3	41.1		159 (18.8)	0.79 (0.62, 1.02)
Current smoker			.452		
No	96.9	97.5		436 (21.4)	1.00 (ref)
Yes	3.1	2.5		14 (27.1)	2.04 (1.19, 3.48)
Alcohol, drinks past 3 mo			<.001		
None	43.6	35.6		196 (27.7)	1.00 (ref)
<1 per week	35.8	40.5		161 (19.5)	0.72 (0.59, 0.89)
≥1 per week	20.7	25.9		93 (16.9)	0.59 (0.46, 0.75)
SPPB score (n=5479)	6.7 ± 2.8	8.3 ± 2.5	<.001		
0-4	23.4	7.9	<.001	90 (57.9)	1.00 (ref)
5-8	49.2	41.4		189 (24.9)	0.59 (0.46, 0.77)
9-12	27.3	50.7		105 (11.6)	0.33 (0.25, 0.45)

Self-rated general health			<.001		
Excellent	4.0	9.4		18 (9.4)	1.00 (ref)
Very good	26.7	37.9		120 (15.3)	1.45 (0.88, 2.38)
Good	50.0	44.8		225 (24.2)	2.22 (1.37, 3.59)
Fair	17.8	7.6		80 (48.2)	4.14 (2.48, 6.90)
Poor	1.6	0.3		7 (82.2)	9.95 (4.16, 23.83)
Number of comorbidities	2.3 ± 1.5	1.6 ± 1.2	<.001		
0	8.0	17.6	<.001	36 (9.9)	1.00 (ref)
1-2	54.0	62.5		243 (18.8)	1.57 (1.11, 2.23)
≥3	38.0	19.9		171 (40.0)	2.87 (1.99, 4.12)

RR, relative risk; CI, confidence interval; PY, person-years.

Number of comorbidities (range 0-10) include presence or absence of the following: coronary heart disease, stroke, cancer, diabetes, hip fracture, osteoarthritis, depression, COPD, cognitive impairment, frequent falls.

SPPB score, short physical performance battery test of physical functioning[16] (range = 0-12), N=5,479, 384 deaths.

Table S4. Sensitivity analysis on risk of all-cause, CVD, and cancer mortality associated with a 30-minute/day increment in physical activity after discarding deaths (28 all-cause; 12 CVD; 8 cancer) during the first 6 months of follow-up.

	Total PA RR (95% CI)[a]	**Light PA** RR (95% CI)[a]	**MVPA** RR (95% CI)[a]
All-cause death (N=6,354; 422 deaths)	0.88 (0.86, 0.92)	0.89 (0.85, 0.93) [b]0.94 (0.89, 0.98)	0.59 (0.51, 0.68) [b] 0.64 (0.55, 0.74)
CVD death (N=6,354; 142 deaths)	0.84 (0.79, 0.90)	0.83 (0.77, 0.89) [b] 0.87 (0.81, 0.95)	0.54 (0.42, 0.71) [b] 0.64 (0.49, 0.85)
Cancer death (N=6,354; 79 deaths)	0.97 (0.89, 1.05)	0.97 (0.88, 1.07) [b] 1.00 (0.91, 1.11)	0.79 (0.59, 1.04) [b] 0.79 (0.59, 1.05)

RR, relative risk; CI, confidence interval.

[a]Adjusted for awake accelerometer wear-time, age, race-ethnicity, education, smoking, alcohol, age at menopause, number of comorbid conditions, and self-assessed general health status as defined in Table 2 footnote.

Light PA is the combined minutes/day in low light PA and high light PA.

[b]Light PA and MVPA are mutually adjusted for one another.

Table S5. Sensitivity analysis on risk of all-cause mortality associated with a 30-minute/day increment in physical activity with simultaneous stratification on age and number of comorbidities (N=6382, 450 deaths).

	Total PA RR (95% CI)[b]	**Light PA** [a] RR (95% CI)[b]	**MVPA** [a] RR (95% CI)[b]
Age <80 years (N=3211; 90 deaths)			
No. comorbidities			
0-1 (N=1898; 36 deaths)	0.91 (0.80, 1.03)	0.91 (0.78, 1.06)	0.75 (0.51, 1.11)
2 (N=788; 26 deaths)	0.89 (0.77, 1.02)	0.89 (0.76, 1.06)	0.65 (0.40, 1.03)
3+ (N=525; 28 deaths)	0.97 (0.85, 1.11)	1.01 (0.86, 1.18)	0.63 (0.36, 1.09)
Age ≥80 years (N=3171; 360 deaths)			
No. comorbidities			
0-1 (N=1471; 123 deaths)	0.89 (0.84, 0.96)	0.90 (0.83, 0.97)	0.67 (0.53, 0.85)
2 (N=872; 94 deaths)	0.81 (0.75, 0.89)	0.81 (0.73, 0.89)	0.52 (0.37, 0.74)
3+ (N=828; 143 deaths)	0.89 (0.84, 0.96)	0.90 (0.84, 0.97)	0.57 (0.42, 0.78)

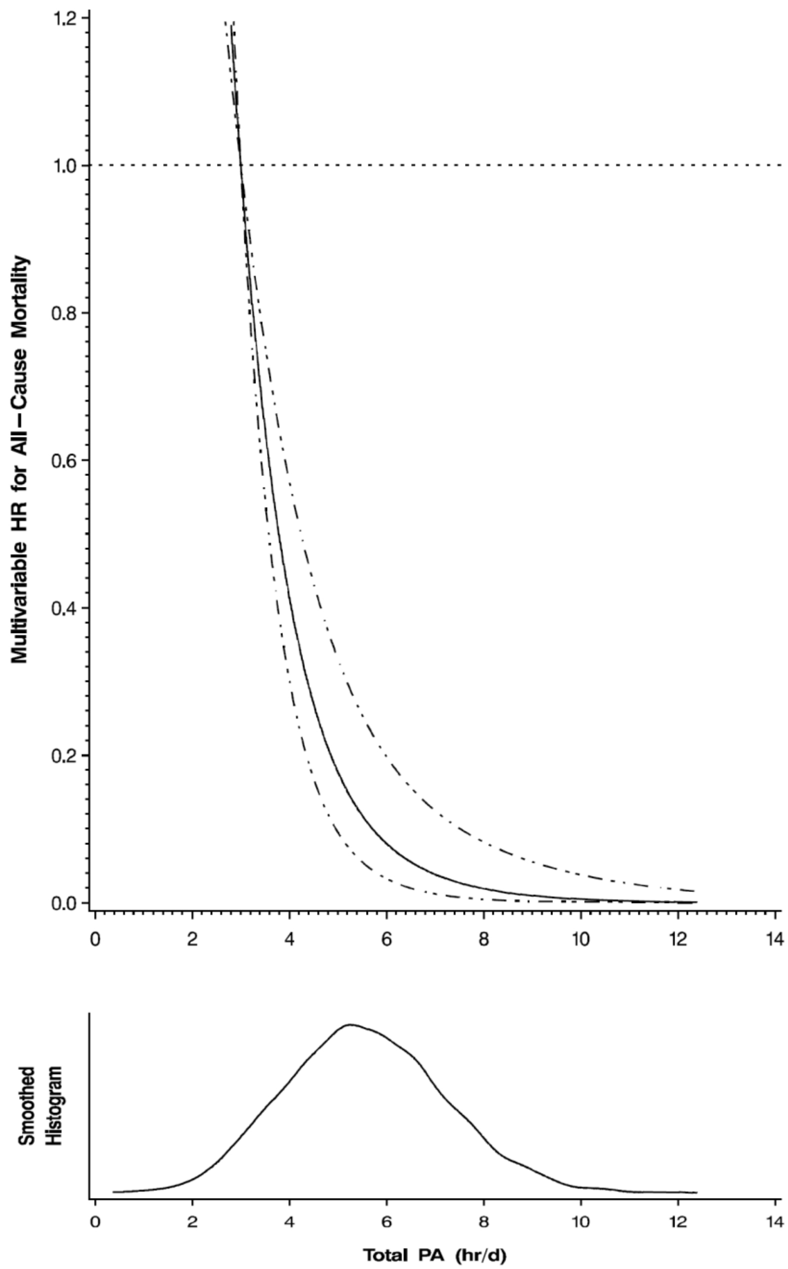
RR, relative risk; CI, confidence interval.

Light PA is the combined minutes/day in low light PA and high light PA.

[a] Light PA and MVPA are mutually adjusted for one another.

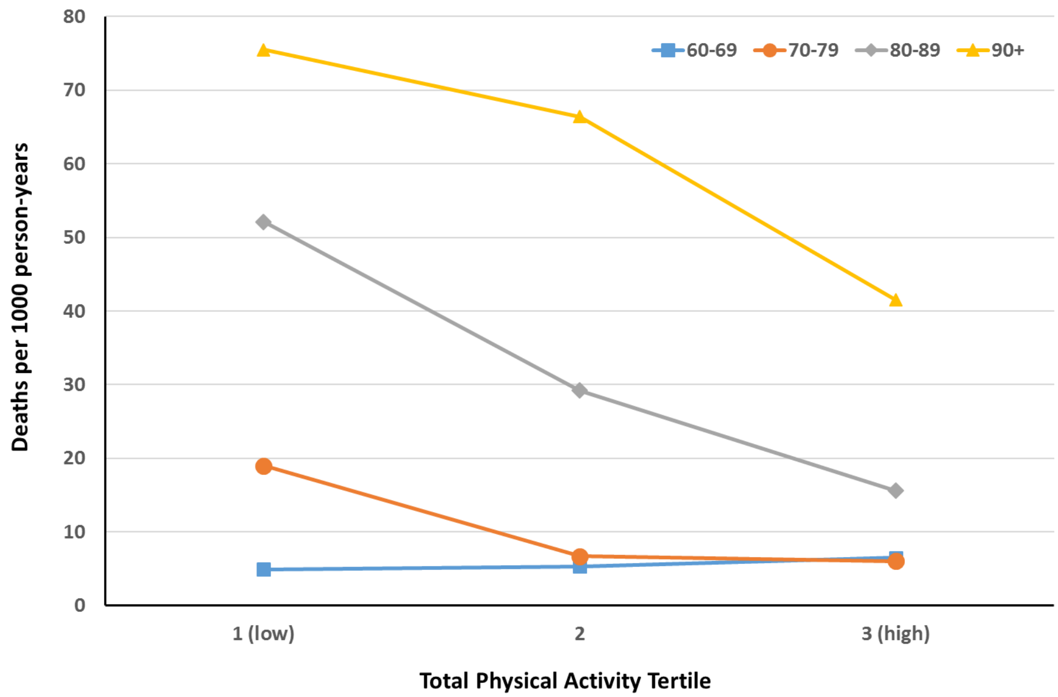
[b] Adjusted for awake accelerometer wear-time, age, race-ethnicity, education, smoking, alcohol, age at menopause, number of comorbid conditions, and self-assessed general health status as defined in Table 2 footnote.

Supplemental Figure S1.



Supplemental Figure S2.

Age Subgroups:



Race-ethnicity subgroups: