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Non-Exercise Physical Activity and Survival

English Longitudinal Study of Ageing

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Background: The activity patterns of older adults include more light/mild-intensity or "non-exercise" activity and less moderate- to vigorous-intensity activity. The health benefits of this type of activity pattern remain unclear.

Purpose: To examine dose–response associations between physical activity and survival using time-varying analysis to understand the importance of "non-exercise" activity for survival in older adults.

Methods: Participants (N=10,426) were drawn from The English Longitudinal Study of Ageing, a representative sample of men and women aged ≥50 years living in England. Participant data were linked with death records from the National Health Service registries from 2002 to 2011. Analyses were conducted in 2013. Cox proportional hazards models were used to estimate the risk of death according to time-varying estimates of physical activity.

Results: Over an average follow-up of 7.8 years (median follow-up, 8.5 years), there were 1,896 deaths. In models adjusted for comorbidities, psychosocial factors, smoking, and obesity, there was a dose–response association between time-varying physical activity and mortality, with the greatest survival benefit in vigorously active participants. However, participating in mild ("non-exercise")-intensity physical activity was also associated with a lower risk of all-cause mortality (hazard ratio [HR]=0.76, 95% CI=0.69, 0.83); cardiovascular mortality (HR=0.74, 95% CI=0.64, 0.85); and death by other causes (HR=0.67, 95% CI=0.58, 0.78). Time-varying models produced stronger, more robust estimates than models using a single measurement of physical activity at baseline.

Conclusions: Older adults gain health benefits from participating in regular "non-exercise" physical activity, although the greatest benefits are observed for more vigorous activity.

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Introduction

Evidence[1–3] suggests that regular physical activity (PA) is among the most important lifestyle factors for the maintenance of health. Inactivity ranks alongside tobacco, alcohol, and obesity as a leading cause of reduced healthy life expectancy.[4] Despite the importance of PA for health, there remains a paucity of evidence on the thresholds and patterns of PA necessary for health benefits in older populations. Current guidelines on PA for the elderly are largely based on data from the general population and recommend 150 minutes per week of moderate-intensity activity, 75 minutes per week of vigorous activity, or a combination of the two.[1] However, older participants are likely to accrue PA of mild or "non-exercise" intensity and the majority of the elderly population do not meet the current PA guidelines.[5,6]

Several studies[7–15] have shown beneficial effects of PA on survival in elderly cohorts, although owing to the differences in PA assessment/thresholds across studies, it is challenging to make direct comparisons on dose–response effects. For example, in a study[7] of people aged 70–88 years, being active was defined as taking part in at least 4 hours per week of PA, whereas others have categorized PA according to self-rated intensity of activity[12,14] or total PA energy expenditure.[13,15]

Some evidence[12,14] suggests that survival benefits can be achieved even at low levels of PA, although further work in large representative samples of the community is required to confirm these findings. Given the barriers to undertaking vigorous exercise, it is important to examine

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whether older adults can benefit from incorporating lighter "non-exercise" PA into their daily lives.

The aim of this study was to examine the prospective dose–response associations between PA and survival in a large representative community-dwelling sample of adults aged 50 years and older at baseline. Further, we aimed to explore whether the dose–response association differed between younger (age <70 years) and older (age ≥70 years) participants. To account for individual variation in PA over time, we made full use of successive assessments of PA by using a time-varying model. This is particularly relevant because many previous studies[16] have relied on PA measures from a single point (baseline) in time that might underestimate the true effect of PA on mortality by not accounting for changes in PA over follow-up.

Methods

Study Sample and Procedures

Participants were drawn from the English Longitudinal Study of Ageing (ELSA), an ongoing panel study that contains a nationally representative sample of the English population living in households.[17] The baseline ELSA cohort consists of men and women born on or before February 29, 1952. The ELSA sample was recruited from households that had previously participated in the Health Survey for England (HSE) in 1998, 1999, or 2001. HSE recruits participants using multistage, stratified probability sampling with postcode sectors selected at the first stage and household addresses selected at the second stage.

Interviews at baseline (2002–2003) were carried out with 11,391 individuals (5,186 men and 6,205 women); the overall response rate was 70% at the household level and 67% at the individual level. After the baseline interview, follow-up interviews took place at regular 2-year intervals in 2004–2005, 2006–2007, 2008–2009, and 2010–2011 and health examinations in 2004–2005 and 2008–2009.

Analyses were conducted in 2013. Our analytic sample comprised 10,426 individuals, after the exclusion of participants who had not consented for the mortality data linkage and those with missing baseline values in any of the variables used in the analysis. Participants gave full informed consent to participate in the study, and ethical approval was obtained from the National Research Ethics Committee.

Physical Activity Assessment

Self-reported PA data were collected at baseline and all follow-up interviews using three questions on the frequency of participation in vigorous, moderate, and mild physical activities (more than once per week, once per week, one to three times per month, or hardly ever). Before answering, participants were shown examples of activities on a card to help them interpret different PA intensities.

Examples of mild activities included laundry and home repairs; moderate-intensity activity included gardening, cleaning the car, walking at moderate pace, dancing, and floor or stretching exercises; and vigorous intensity included running/jogging, swimming, cycling, aerobics/gym workout, tennis, and digging with a spade. PA was further categorized into four groups, as previously described[18]: inactive (no activity on a weekly basis); only mild activity at least once a week; at least moderate but no vigorous activity at least once a week; and any vigorous activity at least once a week. The PA questions were repeated every 2 years through follow-up, enabling assessment of changes in PA levels over time.

We used successive measurements of PA from the baseline and first three follow-up interviews (2002–2008) to construct a time-varying PA variable that was the main predictor in our analysis. The time-varying PA variable did not include PA data from the fourth follow-up interview (2010–2011) because that survey was completed in June 2011 and causes of death data were available up to February 2011. The physical activity measure has demonstrated excellent convergent validity in grading a plethora of psychosocial, physical, and biochemical risk factors.[18–20]

Mortality Follow-Up

Individual participant data were linked with death records from National Health Service registries for all consenting respondents (96.5% of the sample). Diagnoses for primary cause of death were recorded using the ICD-10. ICD-10 codes from I00 to I99 were used to classify cardiovascular deaths and ICD-10 codes from C00 to C97 to classify cancer deaths. Deaths were classified as "other" if not arising from causes related to cardiovascular disease (CVD) or cancer.

Covariates

Age, gender, marital status, and socioeconomic position (SEP) (i.e., education and household wealth) were measured. A binary variable (yes/no) was derived for each of the following self-reported doctor-diagnosed chronic diseases: hypertension, diabetes, heart disease, stroke, cancer, chronic obstructive pulmonary disease, and nervous and psychiatric problems. Smoking (current, previous, or non-smoker) and elevated depressive symptoms (defined as a score of ≥4 on the eight-item Centre of Epidemiological Studies Depression [CES-D] scale[21,22]) were also assessed.

Nurses collected anthropometric data (weight, height, waist circumference) during health examinations. Body weight was measured using Tanita electronic scales (Tokyo, Japan) without shoes and in light clothing, and height was measured using a stadiometer. BMI was calculated using the standard formula (weight [kilograms]/height [meters] squared). We categorized BMI into the following categories: <18.5, ≥18.5 to <25, ≥25 to <30, ≥30, and missing.

Waist circumference was recorded twice midway between the iliac crest and lower rib using a measuring tape. An average of the first two measurements was used provided these differed by no more than 3 cm; otherwise, a third reading was taken and the two closest results were used. We derived a variable of waist circumference with the following categories: <94 cm, ≥94 cm, ≥102 cm, and missing (in men) and <80 cm, ≥80 cm, ≥88 cm, and missing (in women).

We used multiple measurements of chronic diseases, elevated depressive symptoms, and smoking from the baseline and the first three follow-up interviews to derive time-varying variables that were used as covariates in our analysis. We also derived

time-varying BMI and waist circumference variables with the use of two measurements of BMI and waist circumference from the ELSA health examinations and one measurement of BMI and waist circumference from the HSE that was available for the ELSA respondents.

Statistical Analysis

We used Cox proportional hazards regression models to examine associations between PA and death. Months were the time scale for the follow-up, and for participants with no record of an event, the data were censored at February 2011. The proportional hazards assumption was examined using plots of the Nelson–Aalen cumulative hazard estimates. Because we aimed to explore whether the association between PA and survival varied between younger and older participants, we performed subgroup analyses according to two age categories, 50–69 years and ≥70 years.

We estimated unadjusted models that were sequentially adjusted for age, then gender and marital status, then SEP and time-varying chronic diseases. The fully adjusted models were additionally adjusted for time-varying smoking, elevated depressive symptoms, BMI, and waist circumference. For comparison reasons, in supplementary analyses, we estimated the same models using only the baseline measurements of PA and covariates.

Further, to ascertain that the association between PA and mortality was not confounded by physical disability, we also estimated the fully adjusted model only for participants who reported no mobility limitations at baseline. All analyses were conducted using SPSS, version 20 (SPSS Inc., Chicago IL).

Results

Participants defined as physically inactive were older, less likely to be married, less educated and poorer, and had higher prevalence of depressive symptoms, obesity, and existing disease (Table 1). Participants who reported any vigorous PA demonstrated the lowest prevalence of disease and risk factors.

Over an average follow-up of 7.8 years (median follow-up, 8.5 years), there were 1,896 all-cause deaths (671 from CVD; 596 from cancer; 629 from other). There was a dose–response association between PA and mortality (Table 2), which persisted after adjustment for all covariates, with the greatest survival benefit being observed in the vigorously active participants. However, participating in mild-intensity PA was also associated with a lower risk of all-cause mortality (hazard ratio [HR]=0.76, 95% CI=0.69, 0.83); CVD mortality (HR=0.74, 95% CI=0.65, 0.85); and death by other causes (HR=0.67, 95% CI=0.58, 0.78). Only vigorous PA was associated with lower risk of cancer mortality (HR=0.65, 95% CI=0.52, 0.81).

In supplementary analyses using only baseline PA exposure (Table S1), we observed a similar pattern of results, although the effect estimates were generally smaller and less robust with larger CIs. In further sensitivity analyses (Table S2), the mild PA group was assigned as the reference category. Interestingly, both moderate and vigorous PA offered significant protection for all outcomes compared with mild PA, whereas increased risk was observed in the inactive participants.

In further analyses, the sample was stratified according to age into younger (<70 years) and older (≥70 years) age groups. Again, robust dose–response associations were observed for PA and survival in both age groups (Tables 3 and 4), and the association between mild-intensity PA and survival persisted.

In sensitivity analyses that excluded participants with any mobility limitations at baseline (n=4,432), we observed similar results to those of the main analyses: HR for mild PA=0.72, 95% CI=0.56, 0.92; HR for moderate PA=0.57, 95% CI=0.46, 0.70; and HR for vigorous PA=0.50, 95% CI=0.39, 0.64.

Discussion

The aim of this study was to examine dose–response associations between PA and survival over 8 years of follow-up using a time-varying estimate of PA. The key strength of this study was the use of a large representative sample drawn from the community. We observed robust dose–response associations between PA and survival, even after adjusting for a wide range of sociodemographic and clinical risk factors. A key novel finding was the association between mild-intensity "non-exercise" PA and survival.

These results are consistent with recent data[12,14] that have also demonstrated beneficial effects of light activity on survival in older adults. Although causal associations cannot be inferred from our data, longitudinal studies of community samples have several advantages in that they are more representative and can be followed over longer periods of time without the risk of contamination effects, which are a concern in controlled trials with extended follow-up.

In the present study, we aimed to minimize possible confounding by controlling for key covariables (including age, gender, marital status, SEP, smoking, depressive symptoms, and obesity) and reduce the risk of reverse causality by adjusting for comorbidities. We have previously demonstrated associations between PA and several biomarkers in ELSA,[19] which supports the biological plausibility of our findings and further reinforces the likelihood of causality.

A second aim of this study was to investigate the effects of long-term PA exposure on survival, as previous studies have generally relied on single measures taken at baseline. Some previous studies[7,13,14] have suggested that an increase in PA during follow-up has beneficial effects

Table 1. Baseline characteristics of 10,426 women and men aged ≥50 years, *n* (%) unless otherwise noted

	Physical inactivity (*n*=1,067)	Mild physical activity (*n*=1,540)	Moderate physical activity (*n*=4,958)	Vigorous physical activity (*n*=2,861)	*p*-value[a]
Age (years; M [SD])	71.0 (11.3)	68.3 (11.0)	64.6 (9.6)	61.7 (8.4)	**<0.001**
Female	557 (52.2)	1,047 (68.0)	2,653 (54.0)	1,418 (49.6)	**<0.001**
Married	584 (54.7)	868 (56.4)	3,416 (68.9)	2,096 (73.3)	**<0.001**
University degree/a-level	157 (14.7)	239 (15.5)	1,426 (28.8)	1,125 (39.3)	**<0.001**
Wealthiest tertile (≥£201,010)	191 (18.0)	296 (19.2)	1,731 (35.0)	1,264 (44.2)	**<0.001**
Current smoker	210 (19.7)	343 (22.3)	914 (18.4)	377 (13.2)	**<0.001**
BMI >30[b]	274 (32.8)	446 (32.7)	1,165 (25.4)	519 (19.5)	**<0.001**
Waist circumference ≥102 cm (in men)/88 cm (in women)[b]	406 (51.6)	605 (52.5)	1,627 (42.4)	742 (32.7)	**<0.001**
Elevated depressive symptoms (≥4 CES-D symptoms)	366 (34.3)	397 (25.8)	676 (13.6)	243 (8.5)	**<0.001**
Heart disease	252 (24.0)	297 (19.3)	548 (11.1)	215 (8.0)	**<0.001**
Stroke	135 (13.0)	94 (6.1)	161 (3.2)	53 (1.9)	**<0.001**
Hypertension	509 (48.0)	724 (47.0)	1,872 (38.8)	867 (30.3)	**<0.001**
Diabetes	138 (13.0)	176 (11.4)	340 (6.9)	122 (4.3)	**<0.001**
Cancer	90 (8.4)	115 (7.5)	290 (5.8)	160 (5.6)	**<0.001**
Psychiatric problems	84 (7.9)	137 (8.9)	358 (7.2)	198 (6.9)	0.090
COPD	147 (14.0)	158 (10.3)	288 (5.8)	96 (3.4)	**<0.001**

Note: Boldface indicates significance.
[a]*p*-values were generated using chi-square, Kruskal–Wallis, and ANOVA tests for categorical, ordinal, and continuous covariates, respectively.
[b]The estimates of BMI and waist circumference were based on 9,463 and 8,041 individuals, respectively, with non-missing values.
CES-D, Centre of Epidemiological Studies Depression scale; COPD, chronic obstructive pulmonary disease.

on survival, and others[10] have shown that becoming or remaining sedentary is significantly associated with increased mortality risk in comparison with remaining physically active.

A key strength of the present study was the availability of repeated assessments of PA and other important covariables such as chronic disease, enabling construction of a time-varying model. Consistent with a recent study[23] from the Framingham cohort, our data support the notion that a single assessment of PA underestimates the true effects, as we observed stronger, more robust estimates in the time-varying model.

Mild "non-exercise" activities are generally defined as activity between 1.5 and 3 METs,[24] such as housework and light ambulatory activity, but an individual that only participates in such activities would not currently meet the PA guidelines. The protective effects of mild activity that we have observed may be linked to the displacement of sedentary time, as prolonged sitting may carry its own health risks independent of PA.[25,26]

Replacing 30 minutes per day of sedentary time with equal amounts of mild PA was associated with better physical health in a sample of older adults.[27] This might be biologically plausible but could also be explained by differences in the perception of PA intensity[28,29] in that milder activities in older adults might actually elicit a similar level of exertion to moderate activity in younger participants. Given that the present PA guideline does not appear to be achievable for the majority of older adults, it would be desirable if older participants could benefit from incorporating milder PA into their daily lives. Thus, our findings carry an important public health message.

The pattern of association between PA and cancer death was slightly different in that only vigorous activity was deemed protective. This might be explained by the fact we did not differentiate between specific types of cancers, which is relevant as PA has been most consistently associated with protection against breast, prostate, and colon cancers.[1]

Table 2. Hazard ratios (95% CIs) for time-varying physical activity and survival in the overall sample (N=10,426)

	Cases (*n*)	Person-years	Model 1	Model 2	Model 3	Model 4	Model 5
All-cause mortality							
Physical inactivity	466	6,959	1.00	1.00	1.00	1.00	1.00
Mild physical activity	449	11,236	0.54 (0.49, 0.59)	0.66 (0.61, 0.73)	0.72 (0.65, 0.78)	0.73 (0.67, 0.80)	0.76 (0.69, 0.83)
Moderate physical activity	742	39,408	0.25 (0.23, 0.27)	0.44 (0.40, 0.48)	0.47 (0.43, 0.51)	0.50 (0.46, 0.55)	0.54 (0.49, 0.59)
Vigorous physical activity	239	23,523	0.13 (0.12, 0.15)	0.34 (0.30, 0.38)	0.36 (0.32, 0.41)	0.40 (0.36, 0.45)	0.44 (0.39, 0.50)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
CVD mortality							
Physical inactivity	190	6,959	1.00	1.00	1.00	1.00	1.00
Mild physical activity	173	11,236	0.49 (0.43, 0.57)	0.64 (0.55, 0.74)	0.69 (0.59, 0.79)	0.71 (0.61, 0.82)	0.74 (0.64, 0.85)
Moderate physical activity	229	39,408	0.19 (0.17, 0.22)	0.38 (0.33, 0.44)	0.41 (0.35, 0.47)	0.44 (0.41, 0.54)	0.48 (0.41, 0.55)
Vigorous physical activity	79	23,523	0.11 (0.09, 0.13)	0.34 (0.28, 0.42)	0.37 (0.31, 0.46)	0.42 (0.34, 0.51)	0.46 (0.38, 0.57)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Cancer mortality							
Physical inactivity	88	6,959	1.00	1.00	1.00	1.00	1.00
Mild physical activity	123	11,236	0.83 (0.69, 1.00)	0.94 (0.78, 1.13)	1.01 (0.84, 1.22)	1.02 (0.84, 1.23)	1.02 (0.85, 1.24)
Moderate physical activity	283	39,408	0.53 (0.45, 0.63)	0.76 (0.64, 0.90)	0.78 (0.65, 0.92)	0.82 (0.69, 0.98)	0.86 (0.72, 1.03)
Vigorous physical activity	102	23,852	0.32 (0.26, 0.39)	0.55 (0.45, 0.68)	0.55 (0.45, 0.68)	0.60 (0.48, 0.74)	0.65 (0.52, 0.81)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Other mortality							
Physical inactivity	188	6,959	1.00	1.00	1.00	1.00	1.00
Mild physical activity	153	11,236	0.45 (0.39, 0.52)	0.58 (0.51, 0.67)	0.63 (0.54, 0.73)	0.64 (0.55, 0.74)	0.67 (0.58, 0.78)
Moderate physical activity	230	39,408	0.17 (0.15, 0.20)	0.35 (0.30, 0.40)	0.37 (0.32, 0.43)	0.41 (0.35, 0.47)	0.44 (0.38, 0.51)
Vigorous physical activity	58	23,523	0.07 (0.06, 0.09)	0.23 (0.18, 0.29)	0.26 (0.20, 0.32)	0.29 (0.23, 0.36)	0.31 (0.25, 0.40)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Note: Boldface indicates significance. Model 1 is the unadjusted association. Model 2 is adjusted for age. Model 3 is additionally adjusted for gender, marital status, and socioeconomic position (total net household wealth and education). Model 4 is additionally adjusted time-varying doctor-diagnosed self-reported chronic diseases (i.e., hypertension, diabetes, heart disease, stroke, cancer, psychiatric problems, and chronic obstructive pulmonary disease). Model 5 is additionally adjusted the following time-varying covariates: elevated depressive symptoms, smoking, and obesity (BMI and waist circumference).
CVD, cardiovascular disease.

Table 3. Physical activity and survival in 7,008 women and men aged 50–69 years, HR (95% CI) unless otherwise noted

	Cases (*n*)	Person-years of follow-up	Model 1	Model 2	Model 3	Model 4	Model 5
All-cause mortality							
Physical inactivity	99	3,722	1.00	1.00	1.00	1.00	1.00
Mild physical activity	100	6,455	0.52 (0.42, 0.62)	0.55 (0.45, 0.67)	0.64 (0.53, 0.78)	0.68 (0.56, 0.82)	0.73 (0.60, 0.88)
Moderate physical activity	215	28,036	0.28 (0.24, 0.33)	0.31 (0.27, 0.37)	0.39 (0.33, 0.46)	0.44 (0.37, 0.53)	0.50 (0.42, 0.60)
Vigorous physical activity	102	19,292	0.18 (0.15, 0.22)	0.21 (0.17, 0.26)	0.27 (0.22, 0.33)	0.32 (0.26, 0.40)	0.38 (0.31, 0.47)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
CVD mortality							
Physical inactivity	36	3,722	1.00	1.00	1.00	1.00	1.00
Mild physical activity	28	6,455	0.43 (0.30, 0.60)	0.46 (0.32, 0.65)	0.57 (0.40, 0.82)	0.62 (0.43, 0.88)	0.67 (0.47, 0.96)
Moderate physical activity	44	28,036	0.18 (0.13, 0.24)	0.20 (0.14, 0.27)	0.28 (0.21, 0.39)	0.35 (0.25, 0.49)	0.40 (0.29, 0.57)
Vigorous physical activity	20	19,292	0.10 (0.07, 0.16)	0.13 (0.08, 0.19)	0.20 (0.13, 0.30)	0.27 (0.18, 0.41)	0.32 (0.21, 0.50)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Cancer mortality							
Physical inactivity	27	3,722	1.00	1.00	1.00	1.00	1.00
Mild physical activity	42	6,455	0.78 (0.56, 1.09)	0.84 (0.60, 1.16)	0.91 (0.66, 1.28)	0.95 (0.68, 1.32)	0.99 (0.71, 1.39)
Moderate physical activity	127	28,036	0.58 (0.44, 0.77)	0.65 (0.49, 0.86)	0.70 (0.53, 0.94)	0.75 (0.56, 1.01)	0.83 (0.61, 1.12)
Vigorous physical activity	59	19,292	0.40 (0.29, 0.54)	0.46 (0.34, 0.63)	0.50 (0.37, 0.69)	0.55 (0.39, 0.76)	0.62 (0.45, 0.87)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.001**
Other mortality							
Physical inactivity	36	3,722	1.00	1.00	1.00	1.00	1.00
Mild physical activity	30	6,455	0.40 (0.28, 0.55)	0.43 (0.31, 0.60)	0.51 (0.37, 0.72)	0.56 (0.40, 0.78)	0.62 (0.44, 0.87)
Moderate physical activity	44	28,036	0.15 (0.11, 0.20)	0.17 (0.13, 0.23)	0.23 (0.17, 0.31)	0.28 (0.20, 0.38)	0.32 (0.23, 0.44)
Vigorous physical activity	23	19,292	0.08 (0.06, 0.12)	0.10 (0.07, 0.14)	0.14 (0.09, 0.21)	0.19 (0.12, 0.28)	0.23 (0.15, 0.36)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Note: Boldface indicates significance. Model 1 is the unadjusted association. Model 2 is adjusted for age. Model 3 is adjusted for Model 2 and gender, marital status, and socioeconomic position (total net household wealth and education). Model 4 is adjusted for Model 3 and time-varying doctor-diagnosed self-reported chronic diseases (i.e., hypertension, diabetes, heart disease, stroke, cancer, psychiatric problems, and chronic obstructive pulmonary disease). Model 5 is adjusted for Model 4 and the following time-varying covariates: elevated depressive symptoms, smoking, and obesity (BMI and waist circumference).
CVD, cardiovascular disease; HR, hazard ratio.

Table 4. Physical activity and survival in 3,418 women and men aged ≥70 years, HR (95% CI) unless otherwise noted

	Cases (*n*)	Person-years of follow-up	Model 1	Model 2	Model 3	Model 4	Model 5
All-cause mortality							
Physical inactivity	367	3,237	1.00	1.00	1.00	1.00	1.00
Mild physical activity	349	4,780	0.59 (0.53, 0.65)	0.68 (0.62, 0.76)	0.72 (0.66, 0.80)	0.74 (0.67, 0.82)	0.76 (0.69, 0.84)
Moderate physical activity	527	11,371	0.37 (0.33, 0.40)	0.48 (0.43, 0.53)	0.49 (0.44, 0.54)	0.52 (0.47, 0.57)	0.54 (0.49, 0.60)
Vigorous physical activity	137	4,231	0.29 (0.25, 0.33)	0.44 (0.38, 0.51)	0.43 (0.37, 0.50)	0.47 (0.40, 0.54)	0.50 (0.42, 0.58)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
CVD mortality							
Physical inactivity	154	3,237	1.00	1.00	1.00	1.00	1.00
Mild physical activity	145	4,780	0.55 (0.47, 0.64)	0.66 (0.56, 0.77)	0.69 (0.59, 0.81)	0.71 (0.60, 0.83)	0.73 (0.62, 0.86)
Moderate physical activity	185	11,371	0.31 (0.27, 0.36)	0.43 (0.37, 0.50)	0.44 (0.37, 0.51)	0.46 (0.39, 0.54)	0.49 (0.42, 0.58)
Vigorous physical activity	59	4,231	0.30 (0.24, 0.37)	0.49 (0.39, 0.61)	0.48 (0.39, 0.61)	0.52 (0.41, 0.65)	0.56 (0.45, 0.71)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Cancer mortality							
Physical inactivity	61	3,237	1.00	1.00	1.00	1.00	1.00
Mild physical activity	81	4,780	0.91 (0.72, 1.14)	0.93 (0.74, 1.17)	1.00 (0.79, 1.25)	0.99 (0.78, 1.24)	1.00 (0.79, 1.26)
Moderate physical activity	156	11,371	0.72 (0.59, 0.89)	0.75 (0.61, 0.93)	0.74 (0.60, 0.91)	0.75 (0.62, 0.95)	0.81 (0.65, 1.01)
Vigorous physical activity	43	4,231	0.55 (0.41, 0.73)	0.58 (0.44, 0.78)	0.53 (0.40, 0.72)	0.57 (0.42, 0.77)	0.61 (0.45, 0.83)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Other mortality							
Physical inactivity	152	3,237	1.00	1.00	1.00	1.00	1.00
Mild physical activity	123	4,780	0.50 (0.43, 0.59)	0.62 (0.53, 0.73)	0.66 (0.56, 0.77)	0.66 (0.56, 0.78)	0.69 (0.58, 0.81)
Moderate physical activity	186	11,371	0.29 (0.25, 0.33)	0.41 (0.35, 0.48)	0.43 (0.36, 0.50)	0.46 (0.39, 0.54)	0.48 (0.41, 0.57)
Vigorous physical activity	35	4,231	0.18 (0.14, 0.24)	0.33 (0.25, 0.43)	0.34 (0.26, 0.45)	0.37 (0.28, 0.49)	0.38 (0.29, 0.50)
p-value for linear trend			**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Note: Boldface indicates significance. Model 1 is the unadjusted association. Model 2 is adjusted for age. Model 3 is adjusted for Model 2 and gender, marital status, and socioeconomic position (total net household wealth and education). Model 4 is adjusted for Model 3 and time-varying doctor-diagnosed self-reported chronic diseases (i.e., hypertension, diabetes, heart disease, stroke, cancer, psychiatric problems, and chronic obstructive pulmonary disease). Model 5 is adjusted for Model 4 and the following time-varying covariates: elevated depressive symptoms, smoking, and obesity (BMI and waist circumference).

CVD, cardiovascular disease; HR, hazard ratio.

Our study has some limitations. Chronic disease was based on self-report of physician diagnosis, although previous work[30] has demonstrated the validity of this measure in ELSA. Self-reported PA was crudely assessed, albeit the same questions were consistently used at each follow-up assessment. For this reason, and because self-reported PA in older adults has been shown to overestimate actual activity and underestimate its true effects on mortality in older adults,[15] our study may have considerably underestimated the strength of associations between PA and survival.

Because the physical activity questionnaire was relatively crude and did not inquire about PA time, but only frequency, it was challenging to derive any meaningful data on "volume." However, our data suggest that the vigorously active participants did in fact record the greatest volume of activity, as 84.2% and 79.1% of this group also recorded mild or moderate activity, respectively, more than once a week.

Thus, the greater benefits seen in the vigorous PA group may, in part, have been derived from a higher total volume of PA. The interpretation of HR estimates in the presence of time-dependent covariates is potentially more complex than its non–time-dependent counterpart, although our results were comparable using the different approaches.

In summary, we observed robust, multivariate-adjusted dose–response associations between time-varying PA and survival in a large representative sample of community-dwelling older adults over 10 years of follow-up. A key novel finding was the association between mild-intensity PA and survival. These data suggest that optimal health benefits can be achieved through more vigorous–intensity PA. Older adults may also gain survival benefit from participation in lower-intensity activity that is below the threshold set by the present PA guidelines.

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PD performed the analysis with full access to the data, and takes responsibility for the integrity and accuracy of the results. MH drafted the manuscript. All authors contributed to the concept and design of study and critical revision of the manuscript.

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Appendix

Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.1016/j.amepre.2014.05.044.