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Original Contribution

Associations of Accelerometry-Assessed and Self-Reported Physical Activity and Sedentary Behavior With All-Cause and Cardiovascular Mortality Among US Adults

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The US physical activity (PA) recommendations were based primarily on studies in which self-reported data were used. Studies that include accelerometer-assessed PA and sedentary behavior can contribute to these recommendations. In the present study, we explored the associations of PA and sedentary behavior with all-cause and cardiovascular disease (CVD) mortality in a nationally representative sample. Among the 2003–2006 National Health and Nutrition Examination Survey cohort, 3,809 adults 40 years of age or older wore an accelerometer for 1 week and self-reported their PA levels. Mortality data were verified through 2011, with an average of 6.7 years of follow-up. We used Cox proportional hazards models to obtain adjusted hazard ratios and 95% confidence intervals. After excluding the first 2 years, there were 337 deaths (32% or 107 of which were attributable to CVD). Having higher accelerometer-assessed average counts per minute was associated with lower all-cause mortality risk: When compared with the first quartile, the adjusted hazard ratio was 0.37 (95% confidence interval: 0.23, 0.59) for the fourth quartile, 0.39 (95% confidence interval: 0.27, 0.57) for the third quartile, and 0.60 (95% confidence interval: 0.45, 0.80) second quartile. Results were similar for CVD mortality. Lower all-cause and CVD mortality risks were also generally observed for persons with higher accelerometer-assessed moderate and moderate-to-vigorous PA levels and for self-reported moderate-to-vigorous leisure, household and total activities, as well as for meeting PA recommendations. Accelerometer-assessed sedentary behavior was generally not associated with all-cause or CVD mortality in fully adjusted models. These findings support the national PA recommendations to reduce mortality.

accelerometry; aerobic exercise; cohort study; leisure activity; light activity; strength training; transportation activity; walking

Abbreviations: AHR, adjusted hazard ratio; CVD, cardiovascular disease; MVPA, moderate-to-vigorous physical activity; NHANES, National Health and Nutrition Examination Survey; PA, physical activity.

Editor's note: *An invited commentary on this article appears on page 633.*

The burden of cardiovascular disease (CVD) in the United States continues into the 21st century, with coronary heart disease and stroke being the first and third leading causes of death, respectively (1). Physical activity (PA) is an amenable behavior that can prevent or postpone death from all causes or CVD (2). An extensive literature review of studies on PA and health (3) supported the first US governmental PA guidelines for adults in 2008 (4). Recommendations included muscle strengthening activities and at least 150 minutes/week of moderate aerobic activity, at least 75 minutes/week of vigorous aerobic activity, or an equivalent combination of the 2.

The US guidelines were based primarily on data from studies with self-reported PA. Using a nationally representative sample of US adults, we explored the associations of both accelerometer-assessed and self-reported PA and

sedentary behavior with the risks of all-cause and CVD mortality. We hypothesized that regardless of the assessment method, higher levels of PA would be associated with lower mortality risk, whereas higher levels of sedentary behavior would be associated with higher mortality risk, independent of each other. Our intent was to address critical gaps in our understanding of these associations by using 2 complementary assessment methods in order to inform public health guidelines and assist prevention strategies.

METHODS

Through in-person interviews and physical examinations, the National Health and Nutrition Examination Survey (NHANES) provides an assessment of the nutrition and health of the US population. The data used in the present study were collected in 2003–2006 because this data set is the most recently available set to include both accelerometer-assessed (model AM7164, ActiGraph, Pensacola, Florida) and self-reported PA. All participants provided written informed consent (5), and the analysis was approved by the University of North Carolina Institutional Review Board. Details on mortality, PA assessment (accelerometry and self-report), and other measures used in this study are described in Web Appendix 1 (available at http://aje.oxfordjournals.org/).

Study sample

We limited the sample to participants who were 40 years of age or older (n = 6,355) and excluded persons who were not eligible for mortality linkage because we were unable to match their NHANES record to the National Death Index (n = 7). Participants were asked whether a doctor or health professional ever told them that they had a history of angina, coronary heart disease, congestive heart failure, myocardial infarction, or stroke. Participants were classified as having prevalent CVD if they answered "yes" to any of these 5 questions and were further excluded (n = 1,214), although in sensitivity analyses, these participants were incorporated. To account for prevalent conditions that might affect PA levels and sedentary behavior, we excluded participants who died in the first 2 years of follow-up (n = 128). We also excluded those who either did not wear the accelerometer (n = 600) or whose accelerometer was found to not be in calibration upon return (n = 208) or was faulty (i.e., recording no counts) (n = 86). We further limited the cohort by excluding persons who did not provide adherent data (≥3 days of accelerometer wear for ≥8 hours/day over the week; n = 225). Lastly, we excluded those who were missing data on self-reported PA or any potential confounder left in our final models (n = 78), which resulted in a final sample size of 3,809.

Statistical analyses

To account for the differential probability of selection, all percentages and means were weighted to the 2000 census values using the 4-year sample weights provided by NHANES. The data were nested (i.e., screener, household interview, examination) so that nonresponse and poststratification adjustments were applied. Multivariable Cox proportional hazards models were used to determine the associations (e.g., time to event) of PA and sedentary behavior with mortality; accelerometer-assessed and self-reported associations were explored separately. Continuous measures of PA and sedentary behavior were included in the models in quartiles when possible; when the strata became small, we explored 3-level (tertiles or split at median with a 0 category) and 2-level (split at a meaningful cutpoint or at 0) categorizations. A linear test for trend was calculated by changing the exposure variable to an ordinal score and obtaining a P value for that variable. SAS, version 9.2 (SAS Institute, Inc., Cary, North Carolina) was used for all analyses and was accessed at a National Center for Health Statistics Research Data Center (http://www.cdc.gov/rdc/index.htm). Frequencies and means were calculated using the SURVEYFREQ and SURVEYMEAN procedures, respectively, to account for the weighted data. The Cox proportional hazard models were calculated using PHREG and accounted for all variables that comprised the weights in every model (age, race/ethnicity, and sex) (6).

All models were calculated several ways. First, we adjusted for potential confounders that were associated with at least 1 PA or sedentary behavior and 1 outcome measure, including age, sex, race/ethnicity, educational level, marital status, smoking status, employment, the need for special equipment to walk, arthritis, and cancer (model 1). Because including employment in some self-reported PA models violated the proportional hazard assumption, employment was also included as a cross-product with follow-up time in the models. The following variables did not confound any association by more than 10% and therefore were excluded from further consideration: household income, C-reactive protein concentration, total cholesterol level, and alcohol intake. Second, for accelerometer models only, we further adjusted for average daily accelerometer wear time coded continuously (model 1A). Third, models were further adjusted for other components of PA and sedentary behavior, always in the continuous form (model 2). For accelerometer models, we no longer adjusted for wear time. We controlled for the other components of PA or sedentary behavior under the assumption that these measures were acting as either mediators or confounders. For example, models exploring moderate-to-vigorous physical activity (MVPA) controlled for light PA and sedentary behavior. Similarly, models exploring sedentary behavior controlled for MVPA and light PA. Fourth, models were explored by further adjusting for potential mediators, including body mass index, diabetes, and hypertension (model 3). The proportional hazard assumption was tested using time-dependent covariates (7). Because including body mass index in these models violated the proportional hazard assumption in some models, body mass index was also included as a cross-product with follow-up time in the final models. Fifth, to conduct a sensitivity analysis, we used model 3 and included those participants with self-reported baseline CVD and explored associations of PA or sedentary behavior with all-cause mortality while controlling for self-reported CVD (n = 4,510).

RESULTS

Description of sample

Over an average of 6.7 years of follow-up (median, 6.8 years; interquartile range, 5.7–7.8), 337 deaths occurred, of which 107 (31.8%) were due to cardiovascular cause. Overall, 12 deaths due to external causes were censored (*International Classification of Diseases, 10th Revision*, codes V01–Y89). The mean age of the sample (all of whom were 40 years or older) was 55.3 years; 54.6% were female, 8.3% were Hispanic, 9.9% were non-Hispanic black, 77.4% were non-Hispanic white, and 4.4% were another race/ethnicity. Other descriptive characteristics of the sample are listed in Table 1.

Accelerometry data showed that the sample averaged 295.2 counts/minute (Table 2). The average level of MVPA was 20.1 minutes/day (using the cutpoints defined by Troiano et al. (8)), with approximately 29.4% occurring in MVPA bouts (defined in Web Appendix 1). Most MVPA minutes were from moderate activity, because the sample averaged only 0.7 minutes/day from vigorous activity. The average time for sedentary behavior was 505.9 minutes/day, with approximately 77.1% occurring in sedentary bouts (defined in Web Appendix 1).

At least some moderate-to-vigorous leisure activity was reported by 64.2% of the sample, with a mean time of 2.9 hours/week (Table 3). As part of their usual daily activities, approximately half of the sample reported mostly standing or walking without lifting or carrying (52.6%), whereas 24.5% reported heavier work, and 22.9% reported mostly sitting.

Accelerometer-assessed PA and mortality

For the association between all PA measures and all-cause mortality, compared with the initial model (model 1), further adjustment for average daily wear time (model 1A) did not meaningfully change model interpretations (Web Tables 1 and 2). Adjustment for other PA or sedentary behavior components (model 2) did attenuate light activity (using the cutpoints of Troiano et al. (8) and Matthews (9), respectively). Further adjustment for potential mediators (model 3) did not meaningfully change model interpretations (Table 4 and Web Table 2).

Focusing on model 3, we found that a lower all-cause mortality risk was observed for persons in all categories above the referent for average counts per minute (an indicator of average daily PA), moderate activity (8, 9), MVPA (8, 9), and bouts of MVPA (8, 9) (Table 4 and Web Table 2). Lower all-cause mortality risk was indicated but not significant for light activity (8) but not when defined using the cutpoints of Matthews (9). Lower all-cause mortality risk was indicated for those who engaged in enough PA to approximately meet the PA guidelines (adjusted hazard ratio (AHR) = 0.72, 95% confidence interval: 0.50, 1.05). When we divided persons who met PA guidelines into 2 groups (high and medium activity), we found that those in the highest group had the largest risk reduction (data not shown). When we included those with CVD in the analysis sample, the risk of all-cause mortality was similar to findings seen when excluding those with CVD (Web Table 3).

Generally, findings were similar when limiting the outcome to CVD mortality (Table 4 and Web Table 2). However, for the measure that approximated meeting PA recommendations, the association was attenuated (AHR = 0.89, 95% confidence interval: 0.47, 1.66; Table 4). The number of deaths was too small to explore the highest levels of meeting recommendations (i.e., high activity).

Accelerometer-assessed sedentary behavior and mortality

Associations of sedentary time or percent of day spent engaging in sedentary behavior with all-cause or CVD mortality from models 1 and 1A were not sustained after further adjustment for light PA and MVPA (model 2) and for potential mediators (model 3) (Table 4 and Web Table 1). When we evaluated sedentary bouts, we found that in the fully adjusted models (model 3), compared with persons the lowest quartile, those in the second quartile had lower risks of all-cause mortality (AHR = 0.63, 95% confidence interval: 0.41, 0.96) and CVD mortality (AHR = 0.46, 95% confidence interval: 0.21, 1.00). When we included those with CVD in the analysis sample, we found that sedentary behavior and sedentary bouts were not significantly associated with all-cause or CVD mortality (Web Table 3). However, compared with persons in the lowest quartile for percentage of the day spent engaging in sedentary behavior, those in the second quartile had a lower risk of all-cause mortality (AHR = 0.66, 95% confidence interval: 0.44, 0.99).

Self-reported PA and mortality

Initial models were adjusted for potential confounders (model 1), explored by adding other components of PA (model 2), and finally further adjusted for potential mediators (model 3). Generally, the results from the 3 variations of these models were similar for all-cause mortality (Table 5, Web Table 4 for hours per week, and Web Table 5 for metabolic equivalent-hours per week). In the fully adjusted model (model 3), self-reported moderate-to-vigorous household (highest level), moderate leisure, moderate-to-vigorous leisure, walking, and aerobic activities were all associated with a lower risk of all-cause mortality compared with the reference category of no time spent engaging in these activities (Table 5). Being in the highest 2 tertiles of total reported PA was also associated with a lower risk of all-cause mortality.

Those who met PA recommendations had a lower risk of all-cause mortality than did those who did not meet the recommendations. Persons who reported that their usual daily activities were mostly standing, walking, lifting, or heavier work had a lower risk of all-cause mortality than did those who reported mostly sitting. Transportation activity, vigorous leisure activity, muscle strengthening, and screen time were not significantly associated with all-cause mortality, although the adjusted hazard ratio was lower for those who reported muscle strengthening and vigorous leisure activity and for those in the second tertile for screen

Table 1. Descriptive Characteristics of Adults 40 Years of Age or Older Included in the Analyses (n = 3,809), National Health and Nutrition Examination Survey, 2003–2006

Descriptive Characteristic	No.	Weighted % (SE)	Weighted Mean (SE)	No. Missing
Age, years				0
40–49	1,152	37.7 (1.4)		
50–59	861	30.8 (1.0)		
60–69	888	17.1 (0.7)		
≥70	908	14.4 (0.9)		
Sex				0
Male	1,824	45.4 (1.0)		
Female	1,985	54.6 (1.0)		
Race/ethnicity				0
Non-Hispanic white	2,058	77.4 (2.2)		
Non-Hispanic black	778	9.9 (1.3)		
Hispanic	838	8.3 (1.2)		
Other	135	4.4 (0.6)		
Educational level				0
Less than high school	1,083	15.5 (1.1)		
High school graduate/GED	923	26.1 (0.8)		
Greater than high school	1,803	58.3 (1.4)		
Household income, $				206
0–14,999	512	8.1 (0.6)		
15,000–34,999	1,059	22.2 (0.9)		
35,000–64,999	988	29.6 (1.5)		
≥65,000	1,044	40.1 (2.2)		
Employment				
Yes	2,012	64.1 (1.3)		0
Marital status				0
Married	2,351	67.2 (1.3)		
Need special equipment to walk				0
Yes	328	6.6 (0.6)		
Body mass index[a]				0
Underweight (0–18.4)	42	1.2 (0.2)		
Normal (18.5–24.9)	1,007	27.7 (1.1)		
Overweight (25.0–29.9)	1,439	36.4 (1.0)		
Obese class I (30.0–34.9)	807	20.8 (0.7)		
Obese class II or III (≥35.0)	514	13.9 (0.7)		
Cigarette smoking status				0
Never	1,853	49.0 (1.1)		
Former	1,189	30.4 (1.0)		
Current	767	20.6 (1.0)		
≥12 alcoholic drinks/year				206
Yes	2,458	71.8 (1.6)		
C-reactive protein, mg/dL				113
<0.3	2,208	62.1 (1.1)		
≥0.3	1,488	37.9 (1.1)		
Arthritis				
Yes	1,312	32.3 (1.0)		0

Table continues

Table 1. Continued

Descriptive Characteristic	No.	Weighted % (SE)	Weighted Mean (SE)	No. Missing
Hypertension				0
No	860	26.0 (1.0)		
Prehypertension	887	25.6 (1.2)		
Yes	2,062	48.4 (1.3)		
Diabetes mellitus				0
No	2,424	71.6 (1.0)		
Prediabetes	825	17.6 (0.8)		
Yes	560	10.8 (0.7)		
Cancer or malignancy				0
No	3,373	88.6 (0.6)		
Nonmelanoma skin cancer	112	3.3 (0.3)		
Any other type of cancer	324	8.1 (0.5)		
Age, years	3,809		55.3 (0.4)	0
Body mass index[a]	3,809		28.8 (0.2)	0
Total cholesterol, mg/dL	3,684		208.0 (0.9)	125
C-reactive protein, mg/dL	3,696		0.4 (0.02)	113

Abbreviations: GED, general education development certificate; SE, standard error.
[a] Weight (kg)/height (m)^2.

Table 2. Weighted Means and Percentages of Accelerometer-Assessed Physical Activity and Sedentary Behavior (n = 3,809), National Health and Nutrition Examination Survey, 2003–2006

Accelerometer Measure	Definition in Counts per Minute	No.	Weighted Mean (SE)	Weighted % (SE)
Average counts per minute		3,809	295.2 (3.1)	
Physical activity using Troiano et al. (8) cutpoint, minutes/day		3,809		
Light	100–2,019		332.9 (2.0)	
Moderate	2,020–5,998		19.4 (0.5)	
Vigorous	≥5,999		0.7 (0.1)	
Moderate-to-vigorous	≥2,020		20.1 (0.6)	
Moderate-to-vigorous bouts[a]	≥2,020		5.9 (0.3)	
Physical activity using Matthews (9) cutpoint, minutes/day		3,809		
Light	100–759		258.6 (1.3)	
Moderate-to-vigorous (lifestyle)[b]	≥760		102.1 (1.5)	
Moderate-to-vigorous bouts[a] (lifestyle)[b]	≥760		37.0 (1.0)	
Moderate (lifestyle)	760–2,019		82.0 (1.1)	
Sedentary behavior using Matthew et al. (36) cutpoint, minutes/day				
Sedentary behavior	<100	3,809	505.9 (3.2)	
Sedentary bouts[c]	<100	3,809	389.9 (3.8)	
Accelerometer assessed physical activity				
High activity		356		11.1 (0.8)
Medium activity		718		22.2 (1.1)
Not meeting recommendations		2,735		66.7 (1.4)

Abbreviation: SE, standard error.
[a] A moderate-to-vigorous physical activity bout was defined as ≥10 minutes of consecutive moderate-to-vigorous physical activity, with allowance for interruptions for up to 20% of the time below the threshold and <5 consecutive minutes below the threshold.
[b] Lifestyle refers to a lower moderate to vigorous physical activity definition that includes activities that may not be aerobic.
[c] Sedentary bouts were defined as having ≥30 minutes with at least 80% of the minutes falling below the sedentary threshold, allowing for <5 consecutive minutes above the threshold.

Table 3. Weighted Means and Percentages of Self-Reported Physical Activity and Sedentary Behavior in the Past Month ($n = 3,809$), National Health and Nutrition Examination Survey, 2003–2006

Self-Reported Physical Activity and Sedentary Behavior Measures	No.	Weighted Mean (SE)	Weighted % (SE)
Transportation activity	3,809		
Hours/week		0.6 (0.1)	
MET-hours/week		2.2 (0.3)	
Moderate-to-vigorous household activity	3,809		
Hours/week		2.8 (0.2)	
MET-hours/week		12.6 (0.9)	
Moderate leisure activity	3,809		
Hours/week		2.1 (0.1)	
MET-hours/week		7.9 (0.4)	
Vigorous leisure activity	3,809		
Hours/week		0.8 (0.0)	
MET-hours/week		6.3 (0.3)	
Total moderate-to-vigorous leisure activity	3,809		
Hours/week		2.9 (0.1)	
MET-hours/week		14.2 (0.5)	
Walking	3,809		
Hours/week		1.0 (0.0)	
MET-hours/week		3.4 (0.2)	
Aerobic exercise	3,809		
Hours/week		2.1 (0.1)	
MET-hours/week		10.9 (0.4)	
Total physical activity	3,809		
Hours/week		6.3 (0.3)	
MET-hours/week		29.1 (1.1)	
Screen time	3,805		
Hours/day		3.0 (0.0)	
MET-hours/day		3.3 (0.1)	
Transportation activity	392		8.7 (0.7)
Moderate-to-vigorous household activity	2,420		71.7 (1.4)
Moderate leisure activity	1,989		58.7 (1.1)
Vigorous leisure activity	888		28.3 (1.2)
Total moderate-to-vigorous leisure activity	2,206		64.2 (1.2)
Walking	1,317		39.8 (1.0)
Aerobic exercise	2,030		59.5 (1.2)
Meet physical activity recommendation			
Yes, high activity	830		25.1 (1.2)
Yes, medium activity	450		13.0 (0.8)
No	2,529		61.9 (1.1)
Strengthening			
≥2 times/week	660		19.2 (1.1)
1 time/week	232		6.9 (0.8)
None	2,917		73.9 (1.5)
Usual daily activities			
Carrying, lifting light loads, or heavy work	842		24.5 (1.2)
Mostly standing or walking without carrying or lifting	2,090		52.6 (1.0)
Mostly sitting	872		22.9 (1.0)

Abbreviations: MET, metabolic equivalent; SE, standard error.

Table 4. Adjusted[a] Hazard Ratios for the Association of All-Cause and Cardiovascular Disease Mortality With Accelerometer-Assessed Physical Activity[b] and Sedentary Behavior[c] (n = 3,809), National Health and Nutrition Examination Survey, 2003–2006

Accelerometer Measure	All-Cause Mortality				CVD Mortality			
	No. of Deaths	HR	95% CI	*P* Value	No. of Deaths	HR	95% CI	*P* Value
Average counts/minute				<0.0001				0.005
≥355.4 (highest quartile)	26	0.37	0.23, 0.59		7	0.35	0.15, 0.84	
255.7–355.3	36	0.39	0.27, 0.57		12	0.42	0.22, 0.81	
178.5–255.6	70	0.60	0.45, 0.80		19	0.49	0.29, 0.83	
≤178.4 (lowest quartile)	193	1.00			69	1.00		
Light physical activity, minutes/day				0.17				0.57
≥392.4 (highest quartile)	35	0.73	0.48, 2.08		11	0.90	0.44, 1.84	
324.4–392.3	51	0.70	0.35, 1.47		14	0.68	0.36, 1.26	
257.7–324.3	79	0.89	0.22, 1.05		28	1.06	0.65, 1.72	
≤257.6 (lowest quartile)	160	1.00			54	1.00		
Moderate physical activity, minutes/day				<0.0001				0.002
≥24.5 (highest quartile)	30	0.46	0.29, 0.72		11	0.58	0.27, 1.23	
11.1–24.4	33	0.42	0.28, 0.64		5	0.19	0.07, 0.50	
3.8–11.0	65	0.56	0.41, 0.77		21	0.49	0.29, 0.85	
≤3.7 (lowest quartile)	197	1.00			70	1.00		
Vigorous physical activity, minutes/day				0.93				0.95
≥0.1	38	1.02	0.71, 1.47		11	0.98	0.50, 1.92	
0	287	1.00			96	1.00		
Moderate-to-vigorous physical activity, minutes/day				<0.0001				0.001
≥25.1 (highest quartile)	30	0.44	0.28, 0.69		11	0.48	0.23, 1.03	
11.2–25.0	33	0.41	0.27, 0.62		5	0.18	0.07, 0.46	
3.9–11.1	64	0.56	0.41, 0.76		21	0.49	0.28, 0.84	
≤3.8 (lowest quartile)	198	1.00			70	1.00		
Moderate-to-vigorous physical activity bouts[d], minutes/day				0.02				0.02
≥8.4	34	0.71	0.49, 1.03		11	0.68	0.35, 1.30	
0.1–8.3	28	0.61	0.41, 0.91		[e]	0.26	0.09, 0.71	
0	263	1.00			92	1.00		
≥150 minutes/week of moderate or ≥75 minutes/week of vigorous or equivalent combination				0.09				0.71
Yes	37	0.72	0.50, 1.05		13	0.89	0.47, 1.66	
No	288	1.00			94	1.00		
Sedentary, minutes/day				0.64				0.52
≥588.4 (highest quartile)	128	0.97	0.65, 1.44		48	1.44	0.71, 2.90	
497.7–588.3	81	0.86	0.58, 1.27		26	1.03	0.50, 2.12	
413.5–497.6	74	1.05	0.71, 1.55		21	1.12	0.54, 2.31	
≤413.4 (lowest quartile)	42	1.00			12	1.00		
Sedentary bouts[f], minutes/day				0.13				0.08
≥518.4 (highest quartile)	150	0.75	0.48, 1.16		55	0.96	0.46, 2.04	
380.7–518.3	80	0.67	0.44, 1.01		25	0.69	0.33, 1.42	
265.0–380.6	53	0.63	0.41, 0.96		13	0.46	0.21, 1.00	
≤264.9 (lowest quartile)	42	1.00			14	1.00		

Table continues

Table 4. Continued

Accelerometer Measure	All-Cause Mortality				CVD Mortality			
	No. of Deaths	HR	95% CI	*P* Value	No. of Deaths	HR	95% CI	*P* Value
Percent of day in sedentary behavior				0.29				0.24
≥67.7 (highest quartile)	171	0.85	0.48, 1.53		58	1.10	0.41, 2.99	
60.1–67.6	72	0.72	0.44, 1.18		26	0.86	0.37, 2.01	
51.4–60.0	49	0.71	0.45, 1.14		12	0.53	0.22, 1.26	
≤51.3 (lowest quartile)	33	1.00			11	1.00		

Abbreviations: CI, confidence interval; CVD, cardiovascular disease; HR, hazard ratio.

[a] Presented here are data from the full models (model 3), which were adjusted for age (40–49, 50–59, 60–69, ≥70 years), sex, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, other), educational level (less than high school, high school graduate/general education development certificate, or more than high school), married (yes vs. no), cigarette smoking (never, former, or current), interaction between current employment and follow-up time, need special equipment to walk (yes vs. no), arthritis (yes vs. no), cancer (no, nonmelanoma skin cancer, or any other type of cancer), body mass index (underweight, normal, overweight, obese class I, or obese class II/III), interaction between body mass index categories and follow-up time, hypertension (no, prehypertension, or yes), and diabetes (no, prediabetes, or yes). Full models were also adjusted for other physical activity/sedentary behavior components, which varied by exposure. Light physical activity was adjusted for sedentary and moderate-to-vigorous physical activity; moderate physical activity was adjusted for sedentary, light, and vigorous activity; vigorous physical activity was adjusted for sedentary, light, and moderate activity; moderate-to-vigorous physical activity (including bouts) was adjusted for sedentary and light activity; ≥150 minutes/week of moderate or ≥75 minutes/week of vigorous or equivalent combination was adjusted for sedentary and light activity; sedentary behavior (including bouts and percent) was adjusted for light and moderate-to-vigorous physical activity; and average counts per minute were not adjusted for other physical activity/sedentary behavior components.

[b] Evaluated using the cutpoints of Troiano et al. (8).

[c] Evaluated using the cutpoints of Matthews et al. (36).

[d] A moderate-to-vigorous physical activity bout was defined as ≥10 minutes of consecutive moderate-to-vigorous physical activity, with allowance for interruptions for up to 20% of the time below the threshold and <5 consecutive minutes below the threshold

[e] The number of deaths for this category was based on small counts and not considered reliable.

[f] Sedentary bouts were defined as having ≥30 minutes with at least 80% of the minutes falling below the sedentary threshold, allowing for <5 consecutive minutes above the threshold.

time. When we included those with CVD in the analysis sample, in fully adjusted models (model 3), the all-cause mortality results were generally similar (Web Table 6 for hours per week and Web Table 7 for metabolic equivalent-hours per week).

Findings were similar when limiting the outcome to CVD mortality, with a few exceptions (Table 5). First, CVD mortality associations with carrying, lifting light loads, and heavy work (AHR = 0.77, 95% confidence interval: 0.42, 1.41) and with mostly standing, walking without carrying, or lifting (AHR = 0.67, 95% confidence interval: 0.43, 1.05) were attenuated as compared with mostly sitting (referent). Second, the adjusted hazard ratio was higher for muscle strengthening 1 time/week compared with no reported muscle strengthening for CVD mortality (AHR = 1.77, 95% confidence interval: 0.75, 4.18) but not for all-cause mortality (AHR = 0.61, 95% confidence interval: 0.30, 1.25).

DISCUSSION

In a US population-based sample of adults, we found that the average intensity of PA (measured as average total counts per minute) showed a dose-response reduction in all-cause and CVD mortality risk. This supports findings from a prior study of 302 adults aged 70–82 years in which investigators assessed free-living activity energy expenditure using doubly labeled water and also found a lower risk of all-cause mortality (10). However, their assessment of energy expenditure could not provide guidance on contributions of the various PA intensities to mortality risk.

Regarding intensity, we found that accelerometer-assessed moderate PA, MVPA, and bouts of MVPA were generally associated with lower all-cause and CVD mortality, which supported our hypotheses. According to the self-reported findings, leisure and household activities, as well as reporting a generally active day (compared with mostly sitting), contributed to these reductions. Based on the accelerometer data, few participants engaged in vigorous activity, making it difficult to adequately explore this activity category. These findings concur with the results from a cohort study among men 71 years of age or older (mean age at baseline, 79 years) who wore an accelerometer for 1 week (SenseWear Pro Armband, APC Cardiovascular, Cheshire, United Kingdom) (11). Investigators in that study reported a higher risk among those in the lowest quartile of moderate (AHR = 1.58, 95% confidence interval: 1.10, 2.27) and light (AHR = 1.57, 95% confidence interval: 1.08, 2.29) activity compared with persons in the highest or most active quartile. These findings are also supported by results from several studies among patients with peripheral arterial disease (12) and chronic heart failure (13, 14) and among pacemaker recipients (15).

Table 5. Adjusted[a] Hazard Ratios for the Associations of All-Cause and Cardiovascular Disease Mortality With Self-Reported Physical Activity and Sedentary Behavior (n = 3,809), National Health and Nutrition Examination Survey, 2003–2006

Self-Reported Physical Activity and Sedentary Behavior Measures	All-Cause Mortality				CVD Mortality			
	No. of Deaths	HR	95% CI	*P* Value	No. of Deaths	HR	95% CI	*P* Value
Transportation activity, hours/week				0.88				0.42
≥3.6	13	1.02	0.58, 1.80		6	1.64	0.70, 3.82	
0.1–3.6	22	1.12	0.72, 1.74		9	1.30	0.65, 2.61	
0	290	1.00	Referent		92	1.00	Referent	
Moderate-to-vigorous household activity, hours/week				0.02				0.02
≥2.0	65	0.65	0.48, 0.88		16	0.44	0.25, 0.78	
0.1–1.9	91	0.85	0.65, 1.11		31	0.84	0.53, 1.34	
0	169	1.00	Referent		60	1.00	Referent	
Moderate leisure activity, hours/week				0.0002				0.03
≥2.3	67	0.65	0.48, 0.87		18	0.51	0.30, 0.88	
0.1–2.2	47	0.55	0.40, 0.76		17	0.64	0.37, 1.10	
0	211	1.00	Referent		72	1.00	Referent	
Vigorous leisure activity, hours/week				0.06				0.16
≥0.1	30	0.69	0.46, 1.02		8	0.58	0.27, 1.13	
0	295	1.00	Referent		99	1.00	Referent	
Moderate-to-vigorous leisure activity, hours/week				0.002				0.03
≥3.0	63	0.63	0.47, 0.85		16	0.47	0.26, 0.83	
0.1–2.9	68	0.67	0.50, 0.89		24	0.73	0.45, 1.18	
0	194	1.00	Referent		67	1.00	Referent	
Walking, hours/week				0.0003				0.002
≥1.7	43	0.64	0.46, 0.90		8	0.32	0.15, 0.67	
0.1–1.6	27	0.50	0.33, 0.75		9	0.48	0.24, 0.97	
0	255	1.00	Referent		90	1.00	Referent	
Aerobic exercise, hours/week				0.006				0.02
≥2.4	59	0.68	0.50, 0.92		13	0.42	0.23, 0.77	
0.1–2.3	55	0.67	0.49, 0.91		20	0.74	0.44, 1.23	
0	211	1.00	Referent		74	1.00	Referent	
Total physical activity, hours/week[b]				0.006				0.005
≥5.5 (highest tertile)	81	0.64	0.48, 0.86		22	0.45	0.27, 0.76	
1.2–5.4	87	0.73	0.56, 0.96		27	0.58	0.36, 0.94	
≤1.1 (lowest tertile)	157	1.00	Referent		58	1.00	Referent	
Screen time, hours/day				0.15				0.80
≥3.6 (highest tertile)	140	1.01	0.78, 1.31		44	0.90	0.57, 1.41	
2.1–3.5	66	0.77	0.57, 1.04		24	0.85	0.51, 1.42	
≤2.0 (lowest tertile)	118	1.00	Referent		39	1.00	Referent	
Meet physical activity recommendations				0.02				0.008
Meet	70	0.72	0.54, 0.96		17	0.47	0.27, 0.82	
Not meet	255	1.00	Referent		90	1.00	Referent	
Muscle strengthening, times/week				0.13				0.27
2 or more	35	0.75	0.52, 1.07		11	0.77	0.40, 1.46	
1	8	0.61	0.30, 1.25		6	1.77	0.75, 4.18	
0	282	1.00	Referent		90	1.00	Referent	

Table continues

Table 5. Continued

Self-Reported Physical Activity and Sedentary Behavior Measures	All-Cause Mortality				CVD Mortality			
	No. of Deaths	HR	95% CI	*P* Value	No. of Deaths	HR	95% CI	*P* Value
Usual daily activities				<0.0001				0.22
Carrying, lifting light loads, heavy work	44	0.52	0.36, 0.74		17	0.77	0.42, 1.41	
Mostly standing, walking without carrying, or lifting	160	0.60	0.47, 0.78		51	0.67	0.43, 1.05	
Mostly sitting	121	1.00	Referent		39	1.00	Referent	

Abbreviations: CI, confidence interval; CVD, cardiovascular disease; HR, hazard ratio.

[a] Presented here are data from the full models (model 3), which were adjusted for age (40–49, 50–59, 60–69, ≥70 years), sex, race/ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, other), educational level (less than high school, high school graduate/general education development certificate, or more than high school), married (yes vs. no), cigarette smoking (never, former, or current), interaction between current employment and follow-up time, need special equipment to walk (yes vs. no), arthritis (yes vs. no), cancer (no, nonmelanoma skin cancer, or any other type of cancer), body mass index (underweight, normal, overweight, obese class I, or obese class II/III), interaction between body mass index categories and follow-up time, hypertension (no, prehypertension, or yes), and diabetes (no, prediabetes, or yes). Full models were also adjusted for other physical activity/sedentary behavior components, which varied by exposure. Transportation activity was adjusted for total activity minus transportation activity and screen time; moderate-to-vigorous household activity was adjusted for total activity minus moderate-to-vigorous household activity and screen time; moderate leisure activity was adjusted for total activity minus moderate leisure activity and screen time; vigorous leisure activity was adjusted for total activity minus vigorous leisure activity and screen time; moderate-to-vigorous leisure was activity adjusted for total activity minus moderate-to-vigorous leisure activity and screen time; walking was adjusted for total activity minus walking and screen time; aerobic exercise adjusted for total activity minus aerobic exercise and screen time; total physical activity was adjusted for screen time; screen time was adjusted for total physical activity; meeting physical activity guidelines was adjusted for total activity minus aerobic exercise and screen time; muscle strengthening was adjusted for screen time; and usual daily activities were not adjusted for other physical activity/sedentary behavior components.

[b] Total hours per week is a combination of transportation, household, moderate leisure, and vigorous leisure activities.

Our hypotheses were not confirmed for sedentary behavior because we did not generally find consistent associations with mortality that were independent of other components of PA for either accelerometer-assessed sedentary behavior or self-reported screen time. Our findings are in contrast to those from earlier analyses from 2003–2004 of NHANES participants 50 years of age or older who were followed until 2006, in which higher levels of sedentary time were associated with higher all-cause mortality risk (16, 17). Because of the short follow-up time, the studies may be affected by reverse causality. Our study included more participants (e.g., participants enrolled in 2005–2006), had a longer follow-up period, controlled for light activity in addition to MVPA, and excluded persons with CVD, as well as those who died in the first 2 years of follow-up. In the previously mentioned cohort study of men 71 years of age or older, when using fully adjusted models, researchers also found that only persons in the highest quartile of sedentary time had a higher risk of all-cause (AHR = 1.79, 95% confidence interval: 1.19, 2.70) and CVD (AHR = 1.71, 95% confidence interval: 0.99, 2.97) mortality compared with those in the lowest quartile (11). However, they controlled estimates for self-reported PA rather than for other PA components assessed using the SenseWear Armband.

In line with results from prior studies that relied on self-report (18), our results showed that walking was associated with lower risks of all-cause and CVD mortality. This finding is also in agreement with results from a study of adults with impaired glucose tolerance who wore a pedometer at 2 time points (19). Both a higher baseline number of average daily steps and positive changes in the number of steps over the first year of follow-up were associated with a lower risk of CVD events.

Participants who self-reported meeting the muscle strengthening recommendation of at least twice per week had a nonsignificant reduction in all-cause mortality (AHR = 0.72, 95% confidence interval: 0.52, 1.07). Furthermore, we found that meeting the 2008 PA guidelines for aerobic activity (4), as indicated via the questionnaire, was associated with lower all-cause and CVD mortality risks. These findings support those from other national studies in which similar questions have been explored (20, 21). We operationalized a similar duration definition for meeting recommendations as assessed using accelerometry and also found an indication for lower all-cause mortality risk. However, it is important to emphasize that the PA guidelines were based primarily on self-reported data, and therefore our definitions for similar times from the accelerometer and questionnaire are not equivalent measures.

In the present study, we did not statistically compare the self-reported questionnaire findings with the accelerometry findings (22). The NHANES questionnaire on PA comprised questions designed for surveillance purposes and thus did not provide information that would allow us to directly calculate all time spent in sedentary, light, moderate, or vigorous PA during the same week the accelerometer was worn. Although the 2 assessment methods overlapped, each provided unique information (23). Future studies should explore how both assessment approaches can be integrated to provide a more comprehensive understanding of PA, sedentary behavior, and their associations with mortality.

Limitations

Previous studies have indicated lower all-cause and CVD mortality risks associated with higher levels of self-reported PA (18, 24–29) and lower levels of sedentary behavior (30–33). The unique contribution of the present study was the addition of accelerometer-assessed PA and sedentary behavior in conjunction with self-reported measures. However, this specific accelerometer has several limitations, including the fact that it undercounts some activities, such as bicycling and weight lifting, and cannot broadly classify counts into types of activities or postures, thus likely misclassifying motionless standing as sedentary behavior. The device also misses other activities, such as swimming, because the monitor is not waterproof and participants were told to remove it for water-based activities. The accelerometer was worn for 1 week; it is not known if this time period is too short to reflect long-term patterns of behavior.

We explored 2 definitions of light and moderate intensity from the accelerometer, with the lower cutpoint including more lifestyle activities and the higher cutpoint focused more on walking and running. Because cutpoint definitions are imperfect, it may be that the light activity definition spanning to the moderate intensity threshold of Troiano et al. (8) may inadvertently include some moderate activity. In contrast, the light activity definition spanning to the moderate intensity threshold of Matthews (9) may inadvertently exclude some light activity (that will be classified as moderate) and thus be too conservative.

When exploring potential selection bias, we found that compared with participants who were included, those who were 40 years of age or older and excluded from the analysis for any reason ($n = 2{,}546$) were more likely ($P < 0.01$) to be older, male, non-Hispanic white, unemployed, unmarried, or a former smoker and to have less than a high school education, have a lower household income, be less likely to report consuming 12 or more alcoholic drinks/year, need special equipment to walk, have a C-reactive protein concertation of 0.3 mg/dL or higher, or have either arthritis, hypertension, diabetes, or cancer. Those who were excluded were also more likely to self-report sitting, not doing strengthening exercises, and not meeting PA recommendations compared with those who were included in the analysis. The percentages in each body mass index category were generally similar.

Conclusion

Because the results from the present study are generalizable among US adults 40 years of age or older, they support the fact that meeting the national PA guidelines for aerobic activity reduces all-cause mortality. We also found that generally persons with higher moderate PA or MVPA levels had lower all-cause and CVD mortality risks. After adjustment for MVPA, light activity, and other potential confounders, no consistent associations were generally found between sedentary behavior (in average time, bouts, or percent of day) and mortality. Because PA levels among adults remain low (34), particularly among those who have already been diagnosed CVD (35), continued efforts are needed to shift population levels of PA to improve the health of Americans.

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