Volume of Light Versus Moderate-to-Vigorous Physical Activity: Similar Benefits for All-Cause Mortality?

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Background—It is unclear whether the greater benefits of moderate-to-vigorous physical activity (PA) over light PA are attributed to the higher-intensity PA or simply the greater volume of PA accumulated per unit time for moderate-to-vigorous PA. We examined this question using estimates of the *volume* of light and moderate-to-vigorous PA in relation to all-cause mortality.

Methods and Results—We used National Health and Nutrition Examination Survey 2003–2006 accelerometer records in adults (≥40 years; n=4840) and mortality data collected through 2011 (n=700 deaths). We estimated intensity-specific PA volume using activity counts (AC) accumulated in light (100–759 AC/min), moderate-to-vigorous PA (≥760 AC/min), and total PA (≥100 AC/min). We examined quartiles of each exposure using Cox proportional hazard models (hazard ratios [95% confidence interval) adjusted for demographic and behavioral risk factors, health status, and body mass index. Mortality risk was less across increasing quartiles of light PA volume (AC×1000) when compared with the least quartile (AC ≤61.8); the least risk occurred in the upper quartile of light PA, AC >98.5 (hazard ratios=0.69, 95% confidence interval: 0.47, 1.00, *P* trend ≤0.05). The benefits for mortality risk were greater across quartiles of moderate-to-vigorous PA and reached a hazard ratio of 0.28 (95% confidence interval: 0.17, 0.46, *P* trend ≤0.05) for AC >187.9, when compared with the referent group (AC ≤50.8). Results examining various combinations of light and moderate-to-vigorous intensity-specific volumes demonstrated the strong influence of total activity on mortality risk.

Conclusions—In this population, increasing light PA was associated with less mortality, but at an approximately equal volume of PA, moderate-to-vigorous PA appeared to have greater benefits. **(*J Am Heart Assoc*. 2018;7:e008815. DOI: 10.1161/JAHA.118.008815.)**

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Physical inactivity—defined as not achieving physical activity (PA) guidelines—accounts for as much as 6% to 10% of the incidence of type 2 diabetes mellitus, coronary heart disease, and cancer[1]—conditions that collectively account for nearly half of all deaths.[2] It is therefore not surprising that the United States and other countries have endorsed PA guidelines for health. The general recommendation is that adults should engage in adequate moderate-to-vigorous PA, with moderate-intensity activities defined as those with an energy cost of 3 to 5.9 metabolic equivalents, and vigorous intensity activities as those expending 6 or more metabolic equivalents.[3–5] The Physical Activity Guidelines for Americans specifically suggest that adults can meet the recommendation by achieving a minimum overall volume of PA activity by accumulating 150 min/wk of moderate-intensity activity or 75 min/wk of vigorous intensity activity or an equivalent combination of the 2 intensities. This is consistent with the idea that an equal volume (ie, duration×intensity) of moderate or vigorous intensity physical activity rather than intensity per se is associated with substantial health benefits.[4] Although this recommendation emphasizes the importance of the volume of moderate-intensity PA for better health, it is unclear whether even lower intensity physical activities (nonsedentary light-intensity activities, <3 metabolic equivalents) also confer similar health benefits.

Accelerometer-based studies demonstrate the mortality benefits for the duration (hours per day) of light and moderate-to-vigorous intensity activity; most studies suggest a stronger association for greater-intensity activity.[6–11] For example,

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Clinical Perspective

What Is New?

- This study examines whether the stronger benefits associated with moderate-to-vigorous PA are simply because of the greater volume of activity accumulated per unit of time as compared with light-intensity activity.
- Total volume of PA rather than intensity seems to be the key driver in reducing the risk for all-cause mortality.
- The difference in mortality benefits associated with moderate-to-vigorous PA are only modest in comparison to light PA after accounting for the volume of PA.

What Are the Clinical Implications?

- Our study can provide valuable information for practitioners working with individuals who can benefit from regular participation in PA.
- These findings add flexibility for clinical practice when providing individuals with options for combining activities of different intensities (eg, light and moderate-to-vigorous PA).
- Our results are particularly relevant for practitioners working with inactive segments of the population, whose preferences may rely on light PA when starting an exercise program.

Matthews et al found that a 1 h/d increase of light-intensity activity was associated with 16% less mortality, whereas a 1 h/d increase of moderate-to-vigorous activity was associated with 40% less mortality.[9] However, these studies focused only on PA duration; they did not account for the greater volume of energy expended per hour for moderate-to-vigorous intensity activity. Thus, it is unclear whether the stronger associations for moderate-to-vigorous activity are simply because of the greater volume of activity accumulated per unit of time in moderate or vigorous activity when compared with light-intensity activity.

The benefits of an equivalent volume of moderate- or vigorous-intensity activity is generally accepted; however, whether an equal volume of light-intensity activity confers benefits similar to those associated with higher-intensity activity of the same volume is still an open question. Here, we sought to test the hypothesis that equal volumes of light and moderate-to-vigorous intensity activity have similar mortality benefits using device-based measures of PA from the National Health and Nutrition Examination Survey (NHANES) 2003–2006 cycles with mean mortality follow-up of 6.6 years.

Methods

Study Population

The data, analytic methods, and study materials will not be made available to other researchers for purposes of reproducing the results or replicating the procedure. This study used publicly available accelerometer data for the US population from the 2003–2006 NHANES cycles. The NHANES includes several health behavior indicators including PA; it is based on a complex, multistage, probability sampling design of all ages in order to reflect the health status of the US population. Mortality was ascertained using information available from the National Death Index through December 31, 2011. The study population was restricted to adults aged ≥40 years (N=6355 respondents). The NHANES study was approved by the National Center for Health Statistics Research Ethics Review Board, and all participants were required to provide signed consent for participation.

PA Measures

PA was measured with a uniaxial accelerometer (AM-7164; ActiGraph) and a standard 7-day measurement protocol[12]; participants were instructed to wear the monitor at the waist at all times except for bathing and sleep. The devices were initialized to collect activity counts (AC) in 1-minute epochs. Accumulated AC provide an accurate estimate of the duration and intensity of body movement at the waist and were summed across the whole day to assess total PA volume.[13] Using established cut points, we summed the accumulated volume of activity as AC in nonsedentary light (100<AC<760) and moderate-to-vigorous activity (≥760 AC). We also summed nonsedentary total activity counts (TAC; AC >100). These cut points provide useful approximations of time spent in light and moderate-to-vigorous activity in a variety of free-living studies.[14–16] After screening the activity data for nonwear time,[12] 4840 subjects had at least 1 valid day of accelerometer data (wear ≥10 h/d).

Covariates

Consistent with our previous work with this data set,[9] we included a number of covariates in our modeling of the association between PA and mortality. These included age (years), sex, race-ethnicity (non-Hispanic white, non-Hispanic black, Hispanic, or other), education (less than high school, high school diploma, or high school or more), alcohol consumption (never, former, or current), smoking status (never, former, or current), body mass index (in kg/m^2: <25, 25–29.9, or ≥30), and self-reported diagnosis (yes/no) of diabetes mellitus, coronary artery disease, stroke, cancer, and reduced mobility (difficulty in walking a quarter mile or up 10 stairs).

Statistical Analysis

To accommodate expected nonlinear relationships between PA and mortality, the distributions of AC in light, AC in moderate-to-vigorous PA, and TAC or total PA, were classified by quartiles. The data distributions resulted in quartile cutoffs of 61.8, 80.5, and 98.5 AC×1000 for accumulated counts in light PA, 50.8, 110.2, and 187.9 AC×1000 for moderate-to-vigorous PA, and 122.3, 197.9, and 283.1 AC×1000 for total PA.

Our primary analysis used Cox proportional hazard models to estimate hazard ratios (HR) and 95% confidence intervals (HR [95% CI]) for mortality when adjusted for all covariates. We first examined the distributions of light- and moderate-to-vigorous PA across each stratum of covariates. To examine main effects using the respective bottom quartile as the referent group (ie, bottom quartiles, ≤61.8 AC for light PA, ≤50.8 AC for moderate-to-vigorous PA; and ≤122.3 AC for total PA), Cox proportional hazard models were computed separately for light, moderate-to-vigorous PA, and total PA quartiles. To examine the relative benefits of various combinations of light and moderate-to-vigorous PA volumes, we then computed additional Cox proportional models for the joint associations of light and moderate-to-vigorous PA quartiles. The referent group for these analyses was defined by the least PA quartiles for both light and for moderate-to-vigorous PA, with ≤61.8 AC for light PA and ≤50.8 AC for moderate-to-vigorous PA. The HRs associated with these joint combinations were plotted against total PA volume (average total PA; TAC) accumulated by each joint combination of quartiles.

Supplemental analyses included a more detailed examination of accelerometer compliance (wear time) and distributions of sedentary, light, moderate-to-vigorous, and total PA across quartiles of light and moderate-to-vigorous PA (Table S1). The distributions of activity (Table S2) and death records (Table S3) were also examined by joint quartiles of light- and moderate-to-vigorous PA. Sensitivity analyses were conducted to account for possible reverse causality by replicating our fully adjusted models and excluding participants with <1 and 2 years of follow-up. We tested and confirmed the proportional hazards assumption for all our key exposures (light, moderate-to-vigorous PA, and total PA). All analyses were conducted using SAS 9.3v® and SUDAAN® to incorporated sample weights and adjust for the complex survey design. For descriptive statistics, we used Proc Descript (continuous variables) and Proc Crosstab (categorical variables) while the associations between mortality and PA were assessed using Proc Survival.

Results

A total of 4840 adults (49.7% male; 55.0% non-Hispanic white; 35.8% obese) aged 40 years and older had complete data and were followed over a period of 6.6 years, during which 700 deaths occurred. Participants had an average of 13.8 h/d, and 5.8 days of monitor wear, 8.2 h/d sedentary, 4.1 hours in light PA, and 1.3 h/d in moderate-to-vigorous PA (note that these are accumulated duration with no bout criteria). Overall, the least active quartiles of either light- or moderate-to-vigorous PA had greater proportions of participants who were obese, non-Hispanic white, less educated, and with chronic diseases (diabetes mellitus, cancer, and others) (Table 1).

Table 1. Weighted US Proportions (Standard Error) for Covariates by Quartiles of Light and Moderate-to-Vigorous PA

	Light PA				Moderate-to-Vigorous PA			
	Q1 (n=1159)	Q2 (n=1215)	Q3 (n=1236)	Q4 (n=1230)	Q1 (n=1174)	Q2 (n=1217)	Q3 (n=1229)	Q4 (n=1220)
	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)	% (SE)
Sex (male)	54.5 (2.4)	50.1 (1.8)	44.7 (2.2)	38.7 (1.6)	34.4 (1.6)	36.9 (1.9)	44.4 (1.5)	63.1 (1.5)
Ethnicity (non-Hispanic white)	80.2 (1.8)	80.3 (2.3)	77.8 (2.0)	72.3 (3.3)	81.7 (1.9)	75.7 (2.9)	76.3 (2.4)	77.3 (2.4)
BMI status (obese)	41.8 (1.9)	33.9 (1.9)	36.5 (1.8)	32.9 (1.7)	38.9 (1.7)	44.5 (1.6)	36.5 (2.0)	27.1 (1.4)
Education (<high school)	21.2 (1.8)	13.8 (1.8)	17.2 (1.5)	18.4 (1.3)	29.2 (2.6)	17.3 (1.2)	13.7 (1.4)	14.1 (1.4)
Alcohol consumption (current)	54.1 (2.3)	64.0 (2.0)	63.5 (2.3)	64.7 (2.5)	41.1 (2.5)	59.6 (1.9)	66.1 (2.7)	72.4 (2.1)
Smoking habits (current)	18.0 (1.6)	19.6 (1.9)	23.5 (1.8)	22.4 (1.6)	18.3 (1.5)	24.1 (2.1)	20.9 (1.1)	20.7 (1.2)
Diabetes mellitus (yes)	22.8 (1.6)	11.6 (1.6)	11.5 (0.9)	8.0 (0.8)	28.1 (1.9)	15.1 (1.1)	10.6 (0.9)	4.5 (0.8)
Stroke (yes)	9.6 (1.2)	2.9 (0.6)	2.5 (0.4)	2.1 (0.4)	12.0 (1.4)	3.4 (0.5)	2.5 (0.5)	1.0 (0.3)
Chronic heart failure (yes)	22.3 (1.7)	10.3 (1.0)	8.7 (1.3)	5.7 (0.7)	29.1 (1.8)	11.0 (1.5)	7.5 (1.0)	4.0 (0.6)
Reduced mobility (yes)	19.2 (1.4)	14.5 (1.6)	10.3 (1.2)	8.6 (0.9)	30.0 (1.4)	14.7 (1.2)	9.5 (1.2)	4.1 (0.7)
Cancer/malignancy (yes)	17.7 (1.4)	15.0 (1.2)	11.1 (0.9)	9.1 (0.8)	24.6 (1.5)	13.4 (1.4)	10.9 (1.0)	7.6 (1.0)

Light PA Quartiles: Q1—first Quartile (AC ≤61.8); Q2—second Quartile (61.8<AC≤80.5); Q3—third Quartile (80.5<AC≤98.5); Q4—fourth Quartile (AC >98.5). Moderate-to-Vigorous PA Quartiles: Q1—first Quartile (AC ≤50.8); Q2—second Quartile (50.8<AC≤110.2); Q3—third Quartile (110.2<AC≤187.9); Q4—fourth Quartile (AC >187.9). Weighted mean (standard error) age for quartiles 1–4 of Light PA were 62.5 (0.6), 57.1 (0.4), 55.3 (0.6), and 53.6 (0.2) years of age, respectively; Weighted mean (standard error) age for quartiles 1–4 of Moderate-to-Vigorous PA were 69.9 (0.6), 58.0 (0.5), 54.2 (0.4), and 50.6 (0.4) years of age, respectively. AC indicates activity counts; BMI, body mass index; PA, physical activity; SE, standard error.

Table 2. Proportional HR for Main Effects of Total, Light, and Moderate-to-Vigorous PA

		Model 1	Model 2	Model 3	Model 4
	N	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
Light PA					
AC ≤61.8	1159	1.00 (REF)	1.00 (REF)	1.00 (REF)	1.00 (REF)
61.8<AC≤80.5	1215	0.32 (0.26, 0.40)	0.49 (0.40, 0.61)	0.59 (0.46, 0.74)	0.72 (0.56, 0.91)
80.5<AC≤98.5	1236	0.22 (0.17, 0.30)	0.42 (0.32, 0.56)	0.52 (0.40, 0.68)	0.77 (0.59, 1.02)
AC >98.5	1230	0.14 (0.10, 0.21)	0.33 (0.22, 0.48)	0.40 (0.28, 0.56)	0.69 (0.47, 1.00)
P value (trend)		<0.001	<0.001	<0.001	0.009
Moderate-to-vigorous PA					
AC ≤50.8	1174	1.00 (REF)	1.00 (REF)	1.00 (REF)	1.00 (REF)
50.8<AC≤110.2	1217	0.22 (0.17, 0.30)	0.38 (0.28, 0.51)	0.48 (0.37, 0.63)	0.54 (0.42, 0.70)
110.2<AC≤187.9	1229	0.08 (0.06, 0.11)	0.17 (0.13, 0.24)	0.25 (0.19, 0.33)	0.29 (0.22, 0.39)
AC >187.9	1220	0.06 (0.04, 0.10)	0.15 (0.09, 0.26)	0.24 (0.15, 0.40)	0.28 (0.17, 0.46)
P value (trend)		<0.001	<0.001	<0.001	<0.001
Total PA					
AC ≤122.3	1166	1.00 (REF)	1.00 (REF)	1.00 (REF)	
122.3<AC≤197.9	1221	0.21 (0.17, 0.26)	0.37 (0.29, 0.48)	0.48 (0.38, 0.59)	
197.9<AC≤283.1	1235	0.09 (0.07, 0.13)	0.21 (0.15, 0.29)	0.30 (0.23, 0.40)	
AC >283.1	1218	0.06 (0.04, 0.10)	0.17 (0.10, 0.29)	0.26 (0.16, 0.44)	
P value (trend)		<0.001	<0.001	<0.001	

Model 1—with main exposures only (ie, model with quartiles of light PA, moderate-to-vigorous PA, or total PA). Model 2—Model 1 plus age and sex. Model 3—Model 2 plus ethnicity, BMI status, education, alcohol consumption, diabetes mellitus, stroke, chronic heart failure, reduced mobility, and cancer/malignancy. Model 4—Model 3 plus mutual adjustment for either light physical activity or moderate-to-vigorous physical activity. AC indicates activity counts; BMI, body mass index; CI, confidence interval; HR, hazard ratio; PA, physical activity; REF, referent group.

We first examined the mortality associations separately for the volumes of light- and moderate-to-vigorous intensity activity, as well as total activity (Table 2). Significantly less mortality risk was noted for greater light-intensity activity volume before and after adjusting for covariates and moderate-to-vigorous activity. In fully adjusted models, participants in the greatest light-intensity category (>98.5 AC×1000) had 31% less risk (HR=0.69 [95% CI, 0.47–1.00]) than those with less than 61.8 AC×1000.

Greater moderate-to-vigorous activity was also inversely associated with mortality risk after adjustment for covariates and light activity. Notably, the second quartile of moderate-to-vigorous PA (50.8 to ≤110.2 AC/1000) had roughly the same volume of PA as the greatest quartile of light activity (noted above); and was associated with 46% less risk (HR=0.54 [95% CI, 0.42–0.70]) compared with the least quartile of moderate-to-vigorous PA. Greater volume of moderate-to-vigorous activity was associated with even lower mortality risk. It is important to note that because of the large differences in the distributions of PA volume accumulated in light and moderate-to-vigorous PA, there was limited overlap in terms of equal volume of PA in the quartiles for each intensity of PA. The strength of associations for total PA was comparable to those for moderate-to-vigorous activity.

Given the significant mortality benefits for both light and moderate-to-vigorous intensity PA, we next explored the combined influence of both intensities, by jointly classifying PA exposure. In all comparisons, the referent group was the least in light- and moderate-to-vigorous activity. Among those with the least moderate-to-vigorous activity (≤50.8 AC×1000), greater amounts of light PA were associated with 30% to 40% less mortality risk. In contrast, among those with the least light activity (≤61.8 AC×1000), greater moderate-to-vigorous PA was associated with a 60% to 90% less mortality risk; however, CI were wide for the most active group (Table 3). In general, the greatest reductions in risk were associated with a greater volume of both light- and moderate-to-vigorous PA. This suggests that the total volume of PA (light and moderate-to-vigorous) was important for risk reduction. In sensitivity analyses of Table 3, the HR remained similar after excluding the first 1 and 2 years of follow-up. With these exclusions, the associations were attenuated by 5% to 8% and CI widened (Table S4).

To better understand the interrelations between light and moderate-to-vigorous PA and total activity volume, we plotted

Table 3. Joint Associations for Quartiles of Accumulated Light and Moderate-to-Vigorous Intensity AC

	Light PA			
	AC ≤61.8	61.8<AC≤80.5	80.5<AC≤98.5	AC >98.5
Moderate-to-Vigorous PA	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
AC ≤50.8	1.00 (REF)	0.69 (0.46, 1.04)	0.64 (0.41, 0.98)	0.59 (0.23, 1.52)
50.8<AC≤110.2	0.40 (0.22, 0.73)	0.43 (0.31, 0.60)	0.40 (0.27, 0.62)	0.42 (0.23, 0.76)
110.2<AC≤187.9	0.48 (0.24, 0.95)	0.17 (0.09, 0.34)	0.24 (0.14, 0.40)	0.15 (0.07, 0.32)
AC >187.9	0.10 (0.02, 0.43)	0.16 (0.06, 0.42)	0.25 (0.13, 0.48)	0.21 (0.09, 0.50)

AC indicates activity counts; CI, confidence interval; HR, hazard ratio; PA, physical activity; REF, referent group.

the 16 hazard ratios in Table 3 by mean TAC and described the proportion of TAC accumulated in each intensity category (Figure). Addition of information about total activity volume demonstrates the strong influence of total activity on mortality risk, and the relative contributions of light and moderate-to-vigorous PA for increasing total activity in these data.

Discussion

In this prospective study conducted in a representative sample of US adults using device-measured PA, we found the volume of both light and moderate-to-vigorous intensity PA to be associated with less mortality after mutual adjustments. However, at similar volumes of PA, moderate-to-vigorous activity was more strongly associated with mortality risk reduction than light-intensity PA (46% versus 31% lower risk). This finding suggests an added benefit of greater-intensity PA (moderate-to-vigorous) over light activity. Our exploration of the joint associations of light- and moderate-to-vigorous activity volume on mortality showed that greater light activity had a stronger influence among those doing the least moderate-to-vigorous intensity activity, but there was only limited evidence of an influence of light activity at greater levels of moderate-to-vigorous intensity activity.

Our findings extend previous accelerometer-based studies of the duration of light and moderate-to-vigorous PA and mortality that may be confounded in part by not considering differences in PA volume associated with intensity. Previous studies examining this question have focused only on the duration of PA (minutes of intensity-specific activity). While the duration of an activity is more easily measured and interpretable, inferences about intensity-specific effects are limited by the lack of control over the total volume of exposure. In these studies, moderate-to-vigorous PA appeared to have substantially greater mortality benefits than did light PA (≈0–30% for light PA and 40–80% for moderate-to-vigorous PA).[7–11] The large difference in risk reduction is consistent with our supplemental analyses (Figure S1). Our study extends previous studies by estimating the volume of intensity-specific PA, using total activity counts—which reflect both the duration and intensity of activity—to estimate PA volume. We found that greater intensity activity appeared to have greater mortality benefits, although the differences we observed (0–24%) were not as large as in previous duration studies, or when compared with our replicated analysis using PA duration (Figure versus Figure S1).

Examination of the relative contributions of light or moderate-to-vigorous PA volume to mortality was challenging. One critical challenge was the limited overlap among the distributions of light and moderate-to-vigorous PA volume. It appears that few individuals accumulate their total PA at relatively similar contributions of light and moderate-to-vigorous PA. For example, the joint quartile 2,2 light:moderate-to-vigorous PA was one of a few that had similar contributions of light and moderate-to-vigorous intensity volume to total (71.9 versus 77.7 AC for a total of 149.6 AC×1000; Table S2). The stratified approach described in Figure provides a good illustration of this issue. The jointly classified categories were associated with wide ranges of TAC; and the upper quartiles of moderate-to-vigorous had much greater total volumes of activity compared with those for light-intensity activity. Thus, while contributing substantially to total activity duration (Figure S1), light-intensity activity was much less of a driver of total activity volume.

Strengths of this study include evaluation of a nationally representative cohort of US adults with device-measured PA. We examined the associations between PA and mortality while adjusting for various confounders, including age, comorbidities, and mobility limitations. Information on these confounders is not always readily available for consideration in etiologic studies examining the benefits of PA; however, despite these adjustments, we cannot rule out possible larger effects among older individuals at higher risk for mobility complications. Our method to estimate intensity-specific activity volume is also novel and a strength of this study. The application of device-based measures of PA is evolving[17]; our estimates of light and moderate-to-vigorous intensity activity duration have been evaluated and found to be reasonably accurate in comparison to a range of criterion

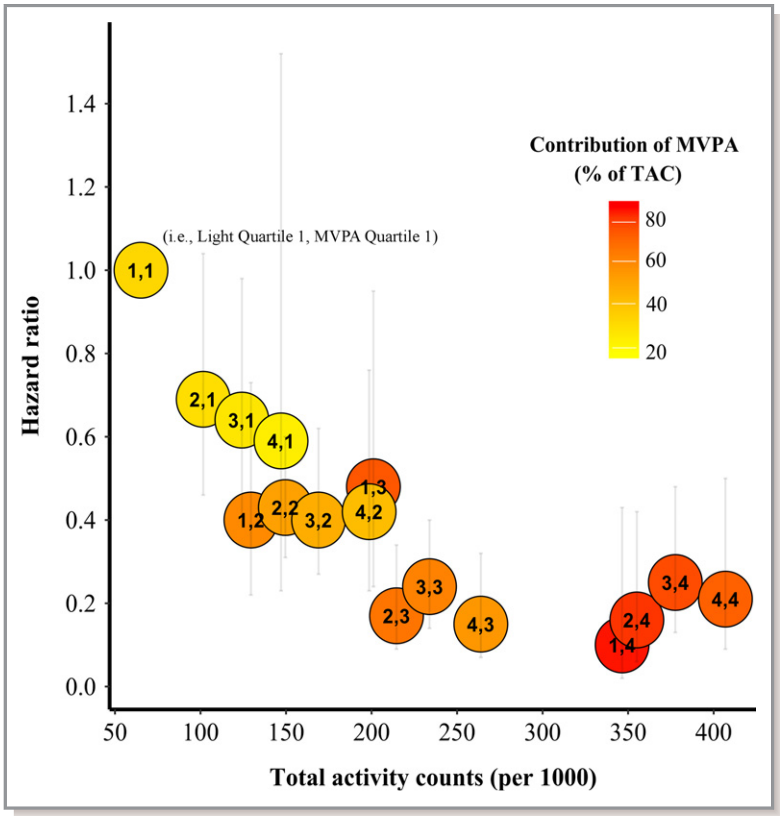


Figure. Hazard ratios* for jointly classified quartiles of light, moderate-to-vigorous physical activity (PA) from Table 3 for each category: by total activity counts (TAC, per 1000). *HR 1,1 is for quartile 1 for both types of activity, while HR 4,1 is for quartile 4 of light PA and quartile 1 of moderate-to-vigorous PA, etc. The amount of moderate-to-vigorous PA (MVPA) as a proportion of total activity counts (TAC) is reflected by color (least MVPA bright yellow, most MVPA dark red). For example, quartiles 2,2 accumulated on average 150 counts (per 1000) in total activity and ≈50% of the TAC was accumulated in moderate-to-vigorous PA intensity. The remaining 50% were accumulated in light PA intensity. Joint quartiles filled with orange indicate joint distributions with relatively similar contributions of moderate-to-vigorous and light PA to total physical activity.

measures.[15,16,18] To determine the volume of PA, we estimated intensity-specific activity counts—a metric demonstrated to be a good proxy for total volume of PA.[13] We also chose a widely accepted threshold to distinguish sedentary behavior from PA (100 AC)[19] and a light/moderate-to-vigorous threshold designed to capture a broader range of lifestyle and ambulatory activities in adults (760 AC).[14] There are a variety of published cut points,[18] and NHANES studies have commonly used 2020 counts/min, which is based on ambulatory calibrations, to define moderate-to-vigorous PA. The choice of a cut point calibrated to capture a broader range of moderate-to-vigorous activity or one calibrated to capture only walking and running to distinguish light from moderate-to-vigorous PA has important implications when classifying activity. Although we recognize there may be a wide range of opinions about the best method, we believe potential misclassification with our approach will provide a more conservative estimate of the association between mortality for each PA intensity. Thus, if the 760 count/min threshold overestimates moderate PA, light-intensity activity would be classified as moderate activity, potentially diluting the strength of the observed moderate-intensity associations. In contrast, if ambulatory cut points underestimate moderate PA, moderate-intensity activity would be classified as light activity, potentially overestimating the strength of the light-intensity associations. A potential limitation of our approach is that the accuracy of our estimates of light and moderate-to-vigorous PA volume has not been fully explored; it may be that measurement error is greater for our estimates of light intensity.[20] This limitation also relates to a general limitation of device-based monitors that are not able to capture nonambulatory activities (eg, bicycling or activities while standing). There were also a relatively small number of deaths. This limited our ability to match activity volumes by intensity and to create finer gradations of volumes to study combined-intensity effects. Furthermore, although we controlled for many relevant confounding factors and several chronic conditions, and our sensitivity analysis did not reveal consistent evidence of reverse causality, we cannot completely rule out the influence of reverse-causality bias.

To our knowledge, this is the first study to explore the differences in volume accumulated through light and moderate-to-vigorous PA and their associations with all-cause mortality. We found moderate-to-vigorous PA to provide greater benefits than light PA; however, the difference in benefits because of intensity was less than that associated with PA duration (Figure versus Figure S1). Future studies should explore these associations using data from other cohorts, with longer follow-up periods, and more sophisticated methods of activity intensity classification. A better understanding of the interplay between light PA and moderate-to-vigorous PA for mortality risk reduction is critical and can have important implications for clinical practice and public health recommendations. The current US PA guidelines reinforce the importance of volume by allowing for various combinations of moderate and vigorous intensity activities to achieve the recommended amounts of PA per week. The examination of the relative contribution of light PA to total PA volume can clarify whether lower-intensity activities can be factored into these recommendations. As demonstrated in our study, the benefit ratio between light and moderate is hard to disentangle. While our findings suggest that light PA has benefits, participation in moderate-to-vigorous PA is needed to obtain maximal health benefits. The consideration of light-intensity activities to achieve benefits for health is particularly important among inactive individuals, who are at higher risk for comorbidities and are less likely to engage in physically active behaviors.

Disclosures

None.

References

1. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT; Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012;380:219–229.
2. Hoyert DL, Xu J. Deaths: preliminary data for 2011. *Natl Vital Stat Rep*. 2012;61:1–51.
3. Tremblay MS, Warburton DE, Janssen I, Paterson DH, Latimer AE, Rhodes RE, Kho ME, Hicks A, Leblanc AG, Zehr L, Murumets K, Duggan M. New Canadian physical activity guidelines. *Appl Physiol Nutr Metab*. 2011;36:36–46, 47–58.
4. Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Report, 2008*. Washington, DC: U.S. Department of Health and Human Services; 2008.
5. World Health Organization. *Global Recommendations on Physical Activity for Health*. Lausanne, Switzerland: World Health Organization; 2010.
6. Schmid D, Ricci C, Leitzmann MF. Associations of objectively assessed physical activity and sedentary time with all-cause mortality in US adults: the NHANES study. *PLoS One*. 2015;10:e0119591.
7. Loprinzi PD. Light-intensity physical activity and all-cause mortality. *Am J Health Promot*. 2017;31:340–342.
8. Borgundvaag E, Janssen I. Objectively measured physical activity and mortality risk among American adults. *Am J Prev Med*. 2017;52:e25–e31.
9. Matthews CE, Keadle SK, Troiano RP, Kahle L, Koster A, Brychta R, Van Domelen D, Caserotti P, Chen KY, Harris TB, Berrigan D. Accelerometer-measured dose-response for physical activity, sedentary time, and mortality in US adults. *Am J Clin Nutr*. 2016;104:1424–1432.
10. Evenson KR, Wen F, Herring AH. Associations of accelerometry-assessed and self-reported physical activity and sedentary behavior with all-cause and cardiovascular mortality among US adults. *Am J Epidemiol*. 2016;184:621–632.
11. Fishman EI, Steeves JA, Zipunnikov V, Koster A, Berrigan D, Harris TA, Murphy R. Association between objectively measured physical activity and mortality in NHANES. *Med Sci Sports Exerc*. 2016;48:1303–1311.
12. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40:181–188.
13. Chomistek AK, Yuan C, Matthews CE, Troiano RP, Bowles HR, Rood J, Barnett JB, Willet WC, Rimm EB, Bassett DR. Physical activity assessment with the ActiGraph GT3X and doubly labeled water. *Med Sci Sports Exerc*. 2017;49:1935–1944.
14. Matthew CE. Calibration of accelerometer output for adults. *Med Sci Sports Exerc*. 2005;37(11 suppl):S512–S522.
15. Crouter SE, DellaValle DM, Haas JD, Frongillo EA, Bassett DR. Validity of ActiGraph 2-regression model, Matthews cut-points, and NHANES cut-points for assessing free-living physical activity. *J Phys Act Health*. 2013;10:504–514.
16. Welk GJ, McClain JJ, Eisenmann JC, Wickel EE. Field validation of the MTI Actigraph and BodyMedia armband monitor using the IDEEA monitor. *Obesity (Silver Spring)*. 2007;15:918–928.
17. Troiano RP, McClain JJ, Brychta RJ, Chen KY. Evolution of accelerometer methods for physical activity research. *Br J Sports Med*. 2014;48:1019–1023.
18. Matthews CE, Keadle SK, Sampson J, Lyden K, Bowles HR, Moore SC, Libertine A, Freedson PS, Fowke JH. Validation of a previous-day recall measure of active and sedentary behaviors. *Med Sci Sports Exerc*. 2013;45:1629–1638.
19. Migueles JH, Cadenas-Sanchez C, Ekelund U, Delisle Nystrom C, Mora-Gonzalez J, Lof M, Ruiz JR, Ortega FB. Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Med*. 2017;47:1821–1845.
20. Calabro MA, Lee JM, Saint-Maurice PF, Yoo H, Welk GJ. Validity of physical activity monitors for assessing lower intensity activity in adults. *Int J Behav Nutr Phys Act*. 2014;11:119.

SUPPLEMENTAL MATERIAL

Table S1. Weighted means (Standard Error) for physical activity variables by quartiles of light and moderate-to-vigorous physical activity.

	Light PA				Moderate-to-Vigorous PA			
	Q1 (n = 1159)	Q2 (n = 1215)	Q3 (n = 1236)	Q4 (n = 1230)	Q1 (n = 1174)	Q2 (n = 1217)	Q3 (n = 1229)	Q4 (n = 1220)
	% (SE)	**% (SE)**	**% (SE)**	**% (SE)**	**% (SE)**	**% (SE)**	**% (SE)**	**% (SE)**
Physical Activity (counts)								
Sedentary (AC<100)	7.7 (0.1)	8.3 (0.1)	8.7 (0.1)	8.6 (0.1)	8.3 (0.1)	8.6 (0.1)	8.5 (0.1)	8.0 (0.1)
Light (100≥AC<760)	47.7 (0.4)	71.6 (0.2)	89.1 (0.2)	115.1 (0.6)	58.5 (0.80	80.5 (0.7)	89.4 (0.7)	93.4 (0.6)
Moderate-to-vigorous (AC≥760)	85.2 (4.4)	141.8 (4.8)	167.8 (4.3)	198.3 (0.6)	27.1 (0.5)	80.2 (0.7)	145.5 (0.8)	288.5 (3.0)
Total (AC≥100)	133.0 (4.6)	213.4 (4.8)	256.9 (4.3)	313.5 (4.8)	85.6 (1.2)	160.7 (0.9)	234.9 (0.8)	381.6 (2.9)
Physical Activity (minutes)								
Sedentary (AC<100)	582.0 (4.3)	519.2 (3.9)	474.2 (4.3)	417.7 (3.3)	572.9 (4.4)	520.6 (2.9)	484.0 (4.2)	432.8 (3.8)
Light (100≥AC<760)	163.4 (1.2)	224.2 (0.9)	270.5 (0.7)	336.5 (1.6)	202.6 (2.6)	251.7 (1.9)	268.9 (2.0)	272.2 (1.5)
Moderate-to-vigorous (AC≥760)	49.6 (2.1)	86.9 (2.1)	110.2 (2.1)	137.1 (2.4)	22.7 (0.4)	62.0 (0.5)	101.7 (0.7)	169.9 (1.5)
Total (AC≥100)	352.9 (2.3)	212.9 (2.6)	380.7 (2.3)	473.6 (2.7)	225.4 (2.9)	313.7 (2.1)	370.6 (2.3)	442.1 (2.1)
Wear Time (minutes)	794.9 (4.2)	830.3 (4.8)	854.9 (4.4)	891.3 (4.8)	798.3 (4.9)	834.3 (3.1)	854.5 (3.2)	874.9 (4.6)
Number of Valid Days	5.1 (0.1)	5.7 (0.1)	5.8 (0.1)	5.9 (0.1)	5.3 (0.1)	5.6 (0.1)	5.8 (0.1)	5.8 (0.1)

AC – Activity counts
PA – Physical activity
Light PA Quartiles: Q1- 1st Quartile (AC ≤61.8); Q2 – 2nd Quartile (61.8< AC ≤80.5); Q3 – 3rd Quartile (80.5< AC ≤ 98.5); Q4 – 4th Quartile (AC > 98.5)
Moderate-to-Vigorous PA Quartiles: Q1- 1st Quartile (AC ≤13.7); Q2 – 2nd Quartile (13.7< AC ≤49.1); Q3 – 3rd Quartile (49.1< AC ≤ 113.6); Q4 – 4th Quartile (AC > 113.6)
Weighted mean (Standard Error) age for quartiles 1 through 4 of Light PA were 62.5 (0.6), 57.1 (0.4), 55.3 (0.6), and 53.6 (0.2) yrs, respectively;
Weighted mean (Standard Error) age for quartiles 1 through 4 of Moderate-to-Vigorous PA were 69.9 (0.6), 58.0 (0.5), 54.2 (0.4), and 50.6 (0.4) yrs, respectively.

Table S2. U.S. population weighted means (Standard Error) for physical activity counts and minutes across joint classifications of light and moderate-to-vigorous physical activity quartiles.

	Light PA							
Moderate-to-vigorous PA	AC ≤61.8		61.8< AC ≤80.5		80.5< AC ≤98.5		AC >98.5	
Physical activity (counts)	N	Mean (SE)	N	Mean (SE)	N	Mean (SE)	N	Mean (SE)
Sedentary (<100)								
AC ≤50.8	717	7.8 (0.1)	288	8.4 (0.2)	115	9.2 (0.3)	54	10.2 (0.5)
50.8< AC ≤110.2	228	7.4 (0.1)	375	8.4 (0.1)	371	9.2 (0.2)	243	9.2 (0.1)
110.2< AC ≤187.9	122	7.7 (0.3)	302	8.4 (0.2)	387	8.7 (0.1)	418	8.7 (0.1)
AC >187.9	92	7.4 (0.2)	250	7.9 (0.1)	363	8.1 (0.1)	515	8.1 (0.1)
Light PA (100≥AC<760)								
AC ≤50.8	717	43.0 (0.6)	288	69.7 (0.5)	115	88.1 (0.6)	54	108.4 (1.6)
50.8< AC ≤110.2	228	51.6 (0.7)	375	71.9 (0.4)	371	88.2 (0.4)	243	113.0 (1.1)
110.2< AC ≤187.9	122	53.0 (0.8)	302	72.3 (0.4)	387	89.3 (0.3)	418	115.6 (1.1)
AC >187.9	92	54.0 (0.6)	250	71.9 (0.4)	363	89.9 (0.3)	515	116.1 (0.7)
Moderate-vigorous PA (AC≥760)								
AC ≤50.8	717	22.2 (0.6)	288	31.9 (0.7)	115	36.1 (1.0)	54	38.7 (1.4)
50.8< AC ≤110.2	228	77.9 (1.3)	375	77.7 (1.0)	371	80.9 (1.0)	243	85.7 (1.5)
110.2< AC ≤187.9	122	148.1 (2.1)	302	142.3 (1.4)	387	144.3 (1.4)	418	148.3 (1.6)
AC >187.9	92	292.5 (12.3)	250	283.1 (6.7)	363	287.7 (5.6)	515	290.8 (5.9)
Total (AC≥100)								
AC ≤50.8	717	65.2 (1.0)	288	101.6 (0.9)	115	124.2 (1.2)	54	147.1 (2.4)
50.8< AC ≤110.2	228	129.5 (1.7)	375	149.6 (1.1)	371	169.0 (1.1)	243	198.6 (1.4)
110.2< AC ≤187.9	122	201.1 (2.2)	302	214.6 (1.3)	387	233.9 (1.7)	418	263.9 (2.0)
AC >187.9	92	346.5 (12.0)	250	355.1 (6.8)	363	377.6 (5.6)	515	406.9 (6.0)
Physical activity (minutes)								

Sedentary (<100)								
AC ≤50.8	717	604.6 (6.1)	288	542.2 (7.3)	115	519.1 (14.0)	54	492.9 (18.5)
50.8< AC ≤110.2	228	571.9 (4.8)	375	537.7 (5.3)	371	511.2 (6.3)	243	453.3 (8.7)
110.2< AC ≤187.9	122	565.8 (10.6)	302	519.0 (6.8)	387	481.3 (6.1)	418	430.9 (5.4)
AC >187.9	92	525.3 (11.9)	250	484.1 (7.1)	363	428.4 (5.6)	515	388.5 (5.3)
Light (100≥AC<760)								
AC ≤50.8	717	158.2 (1.8)	288	233.3 (1.8)	115	289.9 (2.9)	54	349.6 (6.0)
50.8< AC ≤110.2	228	168.0 (2.3)	375	226.1 (1.4)	371	275.8 (1.7)	243	343.8 (2.9)
110.2< AC ≤187.9	122	167.8 (2.9)	302	223.4 (1.4)	387	268.9 (1.3)	418	339.5 (3.0)
AC >187.9	92	171.0 (2.0)	250	217.1 (1.7)	363	263.7 (1.1)	515	330.4 (1.7)
Moderate-vigorous (AC≥760)								
AC ≤50.8	717	17.8 (0.5)	288	27.3 (0.6)	115	31.7 (0.9)	54	35.0 (1.2)
50.8< AC ≤110.2	228	54.2 (1.2)	375	59.3 (0.6)	371	64.6 (0.8)	243	70.4 (1.1)
110.2< AC ≤187.9	122	87.3 (1.9)	302	94.7 (1.0)	387	102.2 (1.3)	418	111.7 (1.0)
AC >187.9	92	130.5 (7.8)	250	147.6 (2.8)	363	171.1 (2.6)	515	189.3 (3.3)
Total (AC≥100)								
AC ≤50.8	717	176.0 (2.1)	288	260.6 (1.8)	115	321.6 (2.7)	54	384.6 (6.1)
50.8< AC ≤110.2	228	222.1 (2.8)	375	285.4 (1.7)	371	340.3 (1.6)	243	414.6 (2.8)
110.2< AC ≤187.9	122	255.1 (3.6)	302	318.1 (1.7)	387	371.1 (1.5)	418	451.3 (3.1)
AC >187.9	92	301.5 (7.9)	250	364.7 (3.0)	363	434.9 (2.8)	515	519.7 (3.3)

AC – Activity counts

PA – Physical activity

Table S3. Number of deaths occurrences across joint classifications of light and moderate-to-vigorous physical activity quartiles.

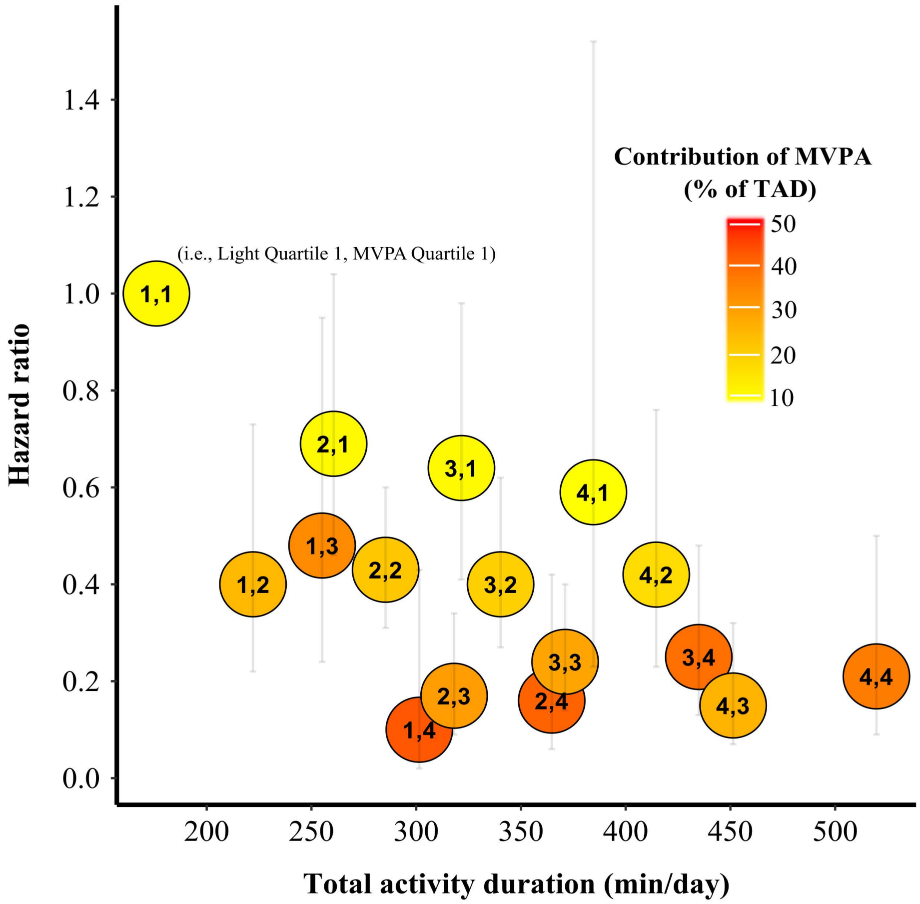
	Light PA							
Moderate-to-vigorous PA	AC ≤61.8		61.8< AC ≤80.5		80.5< AC ≤98.5		AC >98.5	
Mortality Records (n)	N	Deaths	N	Deaths	N	Deaths	N	Deaths
AC ≤50.8	717	309	288	84	115	27	54	9
50.8< AC ≤110.2	228	30	375	44	371	54	243	25
110.2< AC ≤187.9	122	13	302	18	387	18	418	19
AC >187.9	92	3	250	8	363	19	515	20

Table S4. Joint associations for quartiles of accumulated light and moderate-to-vigorous intensity activity counts after excluding first 2 years of follow-up.

	Light PA			
Moderate-to-vigorous PA	AC ≤61.8	61.8< AC ≤80.5	80.5< AC ≤98.5	AC >98.5
	HR (95% CI)	HR (95% CI)	HR (95% CI)	HR (95% CI)
AC ≤50.8	1.00 (REF)	0.73 (0.45, 1.17)	0.72 (0.42, 1.26)	0.61 (0.21, 1.75)
50.8< AC ≤110.2	0.52 (0.28, 0.97)	0.50 (0.33, 0.77)	0.48 (0.31, 0.74)	0.42 (0.23, 0.80)
110.2< AC ≤187.9	0.45 (0.22, 0.94)	0.15 (0.07, 0.31)	0.29 (0.17, 0.48)	0.18 (0.08, 0.39)
AC >187.9	0.06 (0.01, 0.45)	0.17 (0.06, 0.47)	0.26 (0.12, 0.58)	0.28 (0.11, 0.72)

AC – Activity counts
PA – Physical activity
HR – Hazard ratio
95% CI – 95% Confidence interval

Figure S1. Hazard ratios* for jointly classified quartiles of light, moderate-to-vigorous physical activity from Table 3 for each category: by Total activity duration (TAD).



*HR 1,1 is for quartile 1 for both type of activity, while HR 4,1 is for quartile 4 of light PA and quartile 1 of moderate-to-vigorous PA, etc.

The amount of moderate-to-vigorous PA (MVPA) as a proportion of total activity counts (TAC) is reflected by color (least MVPA bright yellow, most MVPA dark red). For example, quartiles 4,1 spent on average 400 minutes in total activity and approximately 10% of the total activity duration was spent on moderate-to-vigorous PA intensity. The remaining 90% were spent in light PA intensity. Joint quartiles filled with orange indicate joint distributions with relatively similar contributions of moderate-to-vigorous and light PA to total physical activity.