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Association of Physical Activity Intensity With Mortality
A National Cohort Study of 403 681 US Adults

Yafeng Wang, MSc; Jing Nie, BSc; Gerson Ferrari, PhD; Juan Pablo Rey-Lopez, PhD; Leandro F. M. Rezende, ScD

IMPORTANCE It is unclear whether, for the same amount of total physical activity, a higher proportion of vigorous physical activity (VPA) to total physical activity is associated with a greater reduction in mortality.

OBJECTIVE To examine the association of the proportion of VPA to total physical activity (defined as moderate to vigorous physical activity [MVPA]) with all-cause mortality, cardiovascular disease mortality, and cancer mortality.

DESIGN, SETTING, AND PARTICIPANTS This cohort study included 403 681 adults from the National Health Interview Survey 1997-2013 who provided data on self-reported physical activity and were linked to the National Death Index records through December 31, 2015. Statistical analysis was performed from May 15, 2018, to August 15, 2020.

EXPOSURES Proportion of VPA to total physical activity among participants performing any MVPA.

MAIN OUTCOMES AND MEASURES All-cause mortality, cardiovascular disease mortality, and cancer mortality. Cox proportional hazards regression models were performed to estimate hazard ratios (HRs) and 95% CIs, adjusted for sociodemographic characteristics, lifestyle risk factors, and total physical activity.

RESULT Among the 403 681 individuals (225 569 women [51.7%]; mean [SD] age, 42.8 [16.3] years) in the study, during a median 10.1 years (interquartile range, 5.4-14.6 years) of follow-up (407.3 million person-years), 36 861 deaths occurred. Mutually adjusted models considering the recommendations of moderate physical activity (MPA; 150-299 vs 0 minutes per week) and VPA (≥75-149 vs 0 minutes per week) showed similar associations for all-cause mortality (MPA: HR, 0.83; 95% CI, 0.80-0.87; and VPA: HR, 0.80; 95% CI, 0.76-0.84) and cardiovascular disease mortality (MPA: HR, 0.75; 95% CI, 0.68-0.83; and VPA: HR, 0.79; 95% CI, 0.70-0.91). For the same contrasts, VPA (HR, 0.89; 95% CI, 0.80-0.99) showed a stronger inverse association with cancer mortality compared with MPA (HR, 0.94; 95% CI, 0.86-1.02). Among participants performing any MVPA, a higher proportion of VPA to total physical activity was associated with lower all-cause mortality but not with cardiovascular disease and cancer mortality. For instance, compared with participants with 0% of VPA (no vigorous activity), participants performing greater than 50% to 75% of VPA to total physical activity had a 17% lower all-cause mortality (hazard ratio, 0.83; 95% CI, 0.78-0.88), independent of total MVPA. The inverse association between proportion of VPA to total physical activity and all-cause mortality was consistent across sociodemographic characteristics, lifestyle risk factors, and chronic conditions at baseline.

CONCLUSIONS AND RELEVANCE This study suggests that, for the same volume of MVPA, a higher proportion of VPA to total physical activity was associated with lower all-cause mortality. Clinicians and public health interventions should recommend 150 minutes or more per week of MVPA but also advise on the potential benefits associated with VPA to maximize population health.

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Supplemental content

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Yafeng Wang, MSc, Department of Epidemiology and Biostatistics, School of Health Sciences, Wuhan University, 185 Donghu Rd, Wuchang District, Wuhan 430071, China (wonyhfon@whu.edu.cn).

Epidemiologic studies provide scientific evidence of the health benefits associated with moderate to vigorous intensity physical activity (MVPA).[1] In several large prospective cohort studies, regular leisure-time physical activity has been associated with a lower risk of noncommunicable diseases and all-cause mortality.[2-5] The 2018 Physical Activity Guidelines for Americans suggest that adults should accumulate at least 150 to 300 minutes per week of moderate intensity physical activity (MPA), 75 to 150 minutes per week of vigorous intensity physical activity (VPA), or an equivalent combination of physical activity of both intensities.[6] The assumption behind the physical activity guidelines is that, at least for some health outcomes, VPA is associated with higher health benefits than MPA.[6,7]

Nevertheless, it remains uncertain whether, for the same amount of total MVPA, VPA may actually offer additional health benefits compared with MPA.[7-10] Some studies have observed that VPA yields larger improvement in functional capacity,[11] cardiorespiratory fitness,[12,13] and certain cardiometabolic risk factors.[14] Higher levels of VPA vs MPA have also been associated with lower all-cause mortality[7,10]; however, these findings were not observed in some studies.[8,9] Accounting for the total amount of MVPA has been argued as an important methodological issue while investigating the role of physical intensity in health outcomes.[7]

In this study, we investigated whether, for the same amount of total physical activity (defined as total MVPA), VPA is associated with greater mortality risk reduction compared with MPA. We examined the association of the proportion of VPA to total MVPA with all-cause mortality, cardiovascular disease (CVD) mortality, and cancer mortality. We hypothesized that, for the same amount of total physical activity, a higher proportion of VPA is associated with lower mortality.

Key Points

Question Is vigorous physical activity associated with additional mortality risk reduction compared with moderate physical activity?

Findings In this cohort study of 403 681 participants, a higher proportion of vigorous physical activity to total moderate to vigorous physical activity was associated with statistically significantly lower all-cause mortality. For the same amount of total moderate to vigorous physical activity, participants with a greater proportion of vigorous physical activity to moderate physical activity had lower all-cause mortality.

Meaning Although most of the health benefit associated with meeting recommended weekly physical exercise goals may be achieved through moderate physical activity, the results suggest that an increased proportion of vigorous physical activity is associated with additional health benefits.

Methods

Study Design and Population

The National Health Interview Survey (NHIS), conducted by the Centers for Disease Control and Prevention from the National Center for Health Statistics, is an annual national cross-sectional survey of civilian, noninstitutionalized participants from the US. The survey uses a stratified, multistage sample design to select approximately 35 000 households from randomly selected clusters. A sample of adults (aged ≥18 years) was randomly selected from each household for a detailed interview on health status, health care services, lifestyle risk factors, and other health issues. More details of the NHIS design and methods have been published elsewhere.[15,16]

We used NHIS data from 17 cross-sectional waves conducted from 1997 to 2013, which included physical activity questionnaires and information on covariates. A total of 493 365 participants were linked to the National Death Index records, with follow-up to date of death or December 31, 2015, whichever came first (herein called a nationally representative cohort study). We excluded those with missing data on physical activity (n = 14 994), those with disabilities (needing help for daily life activities) (n = 10 388) or unable to perform moderate or vigorous physical activity (n = 10 725), and those with a diagnosis of heart disease, stroke, or cancer at baseline (n = 53 577). Our final analytic sample included 403 681 participants. The design of the NHIS has been reviewed and approved by the Centers for Disease Control and Prevention Institutional Review Board. This study was based on secondary analyses of publicly available and deidentified NHIS data; therefore, no further institutional review board approval is needed for this study.

Ascertainment of Outcome

Participants were linked to the National Death Index records through December 31, 2015. The causes of death were determined using the *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* codes. Details about linkage of NHIS data with National Death Index records have been published elsewhere.[17] On average, approximately 96% of participants (range, 91%-98% across survey years) were eligible for the mortality follow-up.[17] In this study, we considered the following mortality outcomes: all-cause mortality, CVD mortality (codes I00-I09, I11, I13, I20-I51, and I60-I69), and cancer mortality (codes C00-C97).[18]

Assessment of Physical Activity

Leisure-time physical activity was measured with 2 sets of questions:

1. Frequency of light intensity physical activity or MPA: "How often do you do light or moderate leisure-time physical activities for at least 10 minutes that cause only light sweating or a slight to moderate increase in breathing or heart rate?" Duration: "About how long do you do these light or moderate leisure-time physical activities each time?"[19]
2. Frequency of VPA: "How often do you do vigorous leisure-time physical activities for at least 10 minutes that cause heavy sweating or large increases in breathing or heart rate?" Duration: "About how long do you do these vigorous leisure-time physical activities each time?"[19]

We calculated the total amount of MPA and VPA (in minutes per week) by multiplying frequency and duration. To account for intensity, total physical activity (defined as total

MVPA in minutes per week) was weighted by multiplying VPA by 2: total physical activity = MPA (minutes per week) + [2 × VPA (minutes per week)].[5,7,10] Among participants performing any MVPA, we calculated the proportion of VPA to total physical activity as the following: VPA × 2/MVPA × 100%.[7,10] Our proportion of weighted VPA to total physical activity assumes that, for example, 75 minutes of VPA provides similar benefit associated with reducing mortality risk as 150 minutes of MPA, as recommended in the Physical Activity Guidelines for Americans.[6] For instance, according to our exposure definition, a given participant doing 60 minutes per week of VPA and 30 minutes per week of MPA would be considered physically active in the Physical Activity Guidelines, with 80% of VPA to total physical activity (ie, proportion of VPA = 60 × 2/[30 + (60 × 2)]. Proportion of VPA to total physical activity was categorized as 0% (no vigorous activity), 0% to 25%, greater than 25% to 50%, greater than 50% to 75%, greater than 75% to less than 100%, and 100% (all vigorous activity).

Covariates

Covariates included age, sex (female and male), race/ethnicity (Hispanic, non-Hispanic White, non-Hispanic Black, and other), marital status (married or living with partner; divorced, separated, or widowed; never married; or missing or unknown), educational level (less than high school degree, high school degree, more than high school degree, or missing or unknown), and income (measured as the federal poverty income ratio [PIR]: high income, PIR ≥4; middle income, PIR >1 and <4; income at or below the federal poverty level, PIR ≤1).[20,21] Income reflects the annual family income relative to the federal poverty level (PIR). Lifestyle risk factors included smoking status (never, former, current, or missing or unknown) and alcohol consumption (abstainer, former drinker, current drinker, or missing or unknown).[22] Body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) was calculated using self-reported weight and height (<25, 25.0-29.9, or ≥30).[22] Self-reported medical diagnosis of hypertension and type 1 and 2 diabetes were also obtained at baseline.

Statistical Analysis

Statistical analysis was performed from May 15, 2018, to August 15, 2020. Mortality rates per 10 000 person-years were age standardized for age groups of 18 to 44 years, 45 to 64 years, and 65 years or older using direct method and overall NHIS sample (n = 493 365) as the standard population. Survival time was counted from the baseline survey to the date of death or the end of the study period (December 31, 2015), whichever came first. The proportional hazards assumption was not violated as examined by log-log survival plots and Schoenfeld residual plots.[23] Cox proportional hazards regression models were performed to estimate hazard ratios (HRs) and 95% CIs for the association of proportion of VPA to total physical activity (reference category, 0% of VPA) with all-cause mortality, CVD mortality, and cancer mortality. Models were adjusted for the major potential confounders, including age at baseline (as a continuous variable), sex, race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and other), educational level (less than high school degree, high school degree, more than high school degree, or missing or unknown), income (low, PIR ≤1; middle, PIR >1 and <4; high, PIR ≥4), marital status (married or living with partner; divorced, separated, or widowed; never married; or missing or unknown), BMI (<25, 25.0-29.9, ≥30, or missing or unknown), smoking status (never, former, current, or missing or unknown), alcohol consumption (lifetime abstainer, former drinker, current drinker, or missing or unknown), and total amount of physical activity (0, 1-149, 150-299, and ≥300 minutes per week).[7-10] Given the small amount of missing data (≤5% for each covariate), we used the missing data indicator.[24] Covariates were selected for multivariable models based on known or suspected confounders for the association between physical activity and mortality.[7] Subgroup analyses were performed by age at baseline, sex, BMI, smoking, alcohol consumption, total physical activity, and chronic conditions (hypertension and diabetes) at baseline. Interactions were formally tested using the adjusted Wald test.

We performed sensitivity analyses by excluding those who died in the first 2 years of follow-up to investigate the potential role of reverse causation in our main findings. Moreover, missing values for covariates were also imputed for the main analysis, using 5 imputations without accounting for the complex design. We compared results from our analytic sample with a complete case sample to further assess the influence of missing data on our main results. We also examined the association between associations of proportion of VPA to total physical activity with all-cause mortality, CVD mortality, and cancer mortality when volume of VPA was not weighted (ie, multiplied by 2 to account for intensity).

Finally, we examined the association of MPA (0, 1-149, 150-299, and ≥300 minutes per week) and VPA (0, 1-74, 75-149, and ≥150 minutes per week) with mortality by creating mutually adjusted Cox proportional hazards regression models. We further examined the joint association between MPA (0, 1-149, 150-299, and ≥300 minutes per week) and VPA (0, 1-74, 75-149, and ≥150 minutes per week) by deriving a combined variable with 4 × 4 groups, where the combined lowest MPA (0 minutes per week) and VPA (0 minutes per week) served as the reference group. Multiple comparisons may have increased the potential for type I error; therefore, findings for the joint analyses should be interpreted carefully (as exploratory analysis).

All analyses accounted for sample weights provided on the 2015 linked mortality data to prevent biased mortality estimates. Adjusted weights, strata, and clusters were used to account for complex multistage sampling design during the analysis.[17] We performed sensitivity analysis by considering competing risks (but not accounting for complex multistage sampling design) for CVD mortality and cancer mortality. For statistically significant results in our main analysis, we used the E-value to estimate the strength of the associations, on the risk ratio scale, of an unmeasured confounder with both exposure and outcome needed to explain away the observed associations.[25] All data management and analyses were con-

ducted using Stata, version 13.0 software (StataCorp LLC). A 2-sided $P < .05$ was considered statistically significant.

Results

Among the 403 681 individuals (225 569 women [51.7%]; mean [SD] age, 42.8 [16.3] years) in the study, during a median 10.1 years (interquartile range, 5.4-14.6 years) of follow-up (407.3 million person-years), 36 861 deaths occurred, including 7634 from CVD and 8902 from cancer. Baseline characteristics of the 403 681 participants by proportion of VPA to total physical activity are displayed in the **Table 1**. Overall, participants were more likely to be women, younger than 45 years, current alcohol drinkers, and never smokers. Less than half (45.0%) of the participants met the physical activity guidelines and 34.3% had no MVPA. Among those who reported any MVPA (65.7%), the proportions of VPA to total physical activity were distributed as follows: 32.5% had 0% of VPA (no vigorous activity), 5.1% had 25% or more of VPA, 10.0% had more than 25% to 50% of VPA, 21.3% had more than 50% to 75% of VPA, 15.8% had more than 75% to less than 100% of VPA, and 15.2% had 100% of VPA (all vigorous activity). Participants who were younger, men, non-Hispanic White, with a higher educational level, with a normal BMI (<25), with a high income level, and with no smoking history were more likely to report 25% or more of VPA to total physical activity (Table 1).

Association of Proportion of VPA to Total Physical Activity With All-Cause Mortality, CVD Mortality, and Cancer Mortality

For the same amount of total physical activity, a greater proportion of VPA to MPA was associated with lower all-cause mortality (**Table 2**).[25] For instance, the age-standardized all-cause mortality rate (per 10 000 participants) for participants with 0% of VPA was 96.0, for those with more than 50% to 75% of VPA was 64.7, and for those with more than 75% to 99% of VPA was 64.1. Compared with participants with 0% of VPA, participants with more than 50% to 75% of VPA to total physical activity had a 17% lower all-cause mortality (HR, 0.83; 95% CI, 0.78-0.88), independent of total MVPA. The HR for participants with more than 75% to 99% of VPA was 0.85 (95% CI, 0.79-0.91) compared with 0% VPA. The magnitude of unmeasured confounding, on the risk ratio scale, needed to explain away these associations were 1.70 for more than 50% to 75% of VPA and 1.63 for more than 75% to 99% of VPA (Table 2).[25]

The inverse association between proportion of VPA to total physical activity and all-cause mortality was consistent across sociodemographic characteristics, lifestyle risk factors, and chronic conditions at baseline. However, associations were attenuated among smokers (**Table 3**).

A higher proportion of VPA to total physical activity was also associated with lower CVD mortality and cancer mortality (Table 2).[25] However, statistically significant associations were found only for more than 50% to 75% of VPA and more than 75% to 99% of VPA to total physical activity. These findings were consistent across different subgroups of participants (eTable 2 in the Supplement).

Sensitivity Analysis

Excluding deaths during the first 2 years of follow-up showed results consistent with our main findings (eTable 3 in the Supplement). The association of proportion of VPA to MVPA with all-cause mortality was similar in results from the analytic sample, complete case, and multiple imputation analysis (ie, HRs were within 0.02 of previous estimates; eTable 3 in the Supplement). Our sensitivity analysis accounting for competing risks (but not considering the complex survey design) suggested that the HR for CVD mortality and cancer mortality may be overestimated in our main results (eTable 4 in the Supplement). The results displayed in eTable 5 in the Supplement showed that associations of the proportion of unweighted VPA to total physical activity (ie, VPA was not multiplied by 2 to account for intensity) with all-cause mortality, CVD mortality, and cancer mortality were similar to our main analysis.

Association of Amount of MPA and VPA With All-Cause Mortality, CVD Mortality, and Cancer Mortality

We found that MVPA was associated with lower all-cause mortality, CVD mortality, and cancer mortality. Mutually adjusted models considering the recommendations of MPA (150-299 vs 0 minutes per week) and VPA (≥75-149 vs 0 minutes per week) showed similar associations for all-cause mortality (MPA: HR, 0.83; 95% CI, 0.80-0.87; and VPA: HR, 0.80; 95% CI, 0.76-0.84) and CVD mortality (MPA: HR, 0.75; 95% CI, 0.68-0.83; and VPA: HR, 0.79; 95% CI, 0.70-0.91). For the same contrasts, VPA (HR, 0.89; 95% CI, 0.80-0.99) showed a stronger inverse association with cancer mortality compared with MPA (HR, 0.94; 95% CI, 0.86-1.02) (eTable 1 in the Supplement).

Exploratory joint associations of MPA and VPA (reference: no MVPA) suggested the lowest all-cause mortality risk among participants performing 150 to 299 minutes per week of MPA and 150 minutes per week or more of VPA (HR, 0.64; 95% CI, 0.58-0.71) (**Table 4**). For CVD mortality, the optimum MPA and VPA combination was 1 to 149 minutes per week of MPA and 150 minutes per week or more of VPA (HR, 0.56; 95% CI, 0.45-0.69). For cancer mortality, 300 minutes per week or more of MPA and 1 to 74 minutes per week of VPA showed the strongest inverse association (HR, 0.67; CI, 0.52-0.86).

Discussion

Findings from this nationally representative cohort of US adults support the hypothesis that VPA is associated with greater mortality risk reduction compared with MPA. We found that, for the same amount of total physical activity, participants with a greater proportion of VPA to MPA had a lower all-cause mortality. For instance, among participants doing any MVPA, more than 50% to 75% of VPA to total physical activity was associated with 17% lower all-cause mortality, even after adjusting for the total amount of MVPA. On the other hand, we did not find a consistent inverse association of proportion of VPA with CVD and cancer mortality. Participants performing 150 to 299 minutes per week of MPA and 150 minutes per week or more of VPA had the lowest all-cause mortality risk.

Table 1. Baseline Characteristics of Participants by the Proportion of VPA to Total Physical Activity, NHIS 1997-2013[a]

Variable	Participants, No. (%) (N = 403 681)						
		Proportion of VPA to total MVPA[b]					
	No MVPA	0%	>0% to ≤25%	>25% to ≤50%	>50% to ≤75%	>75% to <100%	100%
Total	147 675 (34.3)	87 222 (32.5)	12 414 (5.1)	24 548 (10.0)	53 089 (21.3)	39 182 (15.8)	39 551 (15.2)
Age, y							
<45	72 692 (51.6)	38 928 (46.6)	7622 (62.2)	15 826 (65.1)	34 701 (65.7)	26 615 (68.5)	26 142 (67.4)
45-65	47 414 (33.1)	30 840 (36.9)	3842 (31.5)	7106 (29.5)	15 019 (29)	10 318 (26.8)	10 536 (26.6)
>65	27 569 (15.3)	17 454 (16.5)	950 (6.3)	1616 (5.4)	3369 (5.3)	2249 (4.7)	2873 (5.9)
Sex							
Male, %	59 881 (45.3)	30 631 (38.5)	6028 (51.9)	11 921 (51.9)	26 741 (53.5)	21 147 (57.3)	21 763 (58.9)
Race/ethnicity							
Hispanic	36 447 (18.5)	14 103 (11.9)	1314 (7.8)	2761 (8.3)	7045 (9.8)	5536 (10.7)	8176 (15.9)
Non-Hispanic White	77 134 (61.2)	56 221 (71.9)	9129 (79.6)	18 102 (79.4)	36 779 (75.7)	26 235 (73.2)	22 859 (65.2)
Non-Hispanic Black	26 984 (15.1)	11 789 (10.4)	1360 (8.3)	2487 (7.8)	6479 (9.7)	5267 (11.1)	6041 (13.1)
Non-Hispanic other	7110 (5.2)	5109 (5.8)	611 (4.3)	1198 (4.6)	2786 (4.8)	2144 (5.0)	2475 (5.9)
Educational level							
<High school degree	41 979 (24.8)	14 027 (13.8)	1092 (8.3)	1811 (6.8)	4282 (7.4)	3036 (7.7)	5325 (12.2)
High school degree	48 884 (34.8)	25 609 (30)	2893 (23.3)	5219 (21.9)	10 775 (20.8)	7711 (20.2)	9634 (25.2)
>High school degree	55 519 (39.5)	47 253 (55.7)	8404 (68.3)	17 470 (71.1)	37 904 (71.5)	28 350 (71.9)	24 464 (62.3)
Marital status							
Married or living with partner	75 548 (61.8)	47 562 (65.9)	7231 (68.0)	13 729 (65.3)	28 367 (63.3)	19 824 (59.6)	20 067 (59.3)
Widowed, divorced, or separated	40 860 (18.6)	22 909 (17.1)	2136 (10.7)	4189 (10.8)	9237 (10.9)	6573 (10.4)	7159 (11.3)
Never married	30 811 (19.4)	16 562 (16.9)	3029 (21.2)	6593 (23.9)	15 389 (25.7)	12 716 (29.8)	12 246 (29.3)
Income							
Low	32 628 (17.2)	12 839 (10.9)	1399 (8.5)	2639 (8.1)	5951 (8.4)	4415 (8.6)	5343 (10.7)
Middle	82 537 (56.1)	45 139 (50.1)	5636 (43.7)	10 846 (42.5)	23 279 (41.8)	16 801 (40.9)	18 805 (45.5)
High	32 510 (26.7)	29 244 (38.9)	5379 (47.8)	11 063 (49.4)	23 859 (49.8)	17 966 (50.5)	15 403 (43.8)
BMI							
<25	53 375 (36.2)	33 288 (38.1)	4794 (38.9)	10 335 (41.5)	22 911 (43.0)	17 260 (44.0)	16 615 (42.1)
25-30	48 383 (32.7)	28 996 (33.3)	4306 (35.1)	8429 (34.8)	18 707 (35.4)	14 030 (35.7)	14 128 (35.7)
>30	39 489 (26.7)	22 343 (25.6)	3083 (24.2)	5301 (21.8)	10 449 (19.8)	7251 (18.7)	7883 (19.9)
Lifestyle factors							
Current cigarette smoker	37 020 (25.7)	17 805 (20.5)	2853 (22.2)	5130 (20.2)	9854 (17.9)	6971 (17.4)	7962 (19.5)
Current alcohol drinker	73 052 (51.4)	54 130 (63.8)	9582 (78.1)	19 031 (77.2)	40 429 (76.2)	30 400 (77.7)	27 728 (70.4)
Chronic conditions							
Hypertension	40 153 (25.5)	24 959 (27.0)	2463 (19.3)	4421 (17.4)	8831 (16.1)	6251 (15.3)	6860 (16.4)
Type 1 and 2 diabetes	11 509 (7.2)	6442 (6.9)	561 (4.3)	918 (3.6)	1860 (3.4)	1297 (3.1)	1441 (3.4)
Total physical activity, min/wk							
0	147 675 (100)	0	0	0	0	0	0
1-149	0	54 265 (63.0)	2657 (22.1)	5351 (22.5)	6123 (11.8)	2975 (7.7)	10 232 (25.6)
150-299	0	18 769 (21.1)	2751 (21.9)	5789 (23.7)	13 107 (24.8)	6316 (16.4)	10 168 (25.8)
≥300	0	14 188 (15.8)	7006 (56.0)	13 408 (53.9)	33 859 (63.4)	29 891 (75.9)	19 151 (48.6)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); MVPA, moderate to vigorous intensity physical activity; NHIS, National Health Interview Survey; VPA, vigorous intensity physical activity.

[a] The NHIS used a multistage area probability sampling design. Analyses of percentage values presented in this table were conducted using the final weights, which represent a product of weights for corresponding units computed in each of the sampling stages. See the statistical analysis section of the Methods for details.

[b] We multiplied VPA (minutes per week) by 2 to calculate total MVPA, and proportion of VPA to total physical activity (defined as total MVPA) in terms of its intensity and potential health benefits.

These findings are in line with those of recent studies showing that, for the same amount of total physical activity, VPA is associated with lower all-cause mortality compared with MPA.[7,10] To our knowledge, only 4 epidemiologic studies have investigated the association between proportion of VPA to total physical activity and mortality.[7-10] Two studies showed that a

Table 2. Associations of the Proportion of VPA to Total Physical Activity With All-Cause Mortality, CVD Mortality, and Cancer Mortality Among Participants Who Had Any MVPA

Proportion of VPA to MVPA[a]	No. of participants	No. of deaths	No. of person-years	ASMR per 10 000	Multivariable-adjusted HR (95% CI)[b,c]	*P* value	E-value[d]
All-cause mortality							
0	87 222	9241	856 871	96.0	1 [Reference]	NA	NA
≥0.25	12 414	632	128 101	71.9	0.89 (0.81-0.98)	.02	1.50
>0.25 to 0.5	24 548	1071	251 297	68.6	0.90 (0.83-0.98)	.01	1.46
>0.5 to 0.75	53 089	2100	525 805	64.7	0.83 (0.78-0.88)	<.001	1.70
>0.75 to <1	39 182	1413	384 194	64.1	0.85 (0.79-0.91)	<.001	1.63
1	39 551	2148	416 281	77.9	0.90 (0.85-0.96)	<.001	1.46
CVD mortality							
0	87 222	1919	856 871	19.1	1 [Reference]	NA	NA
≥0.25	12 414	116	128 101	15.4	1.03 (0.83-1.27)	.82	NA
>0.25-0.5	24 548	190	251 297	12.1	1.02 (0.85-1.22)	.87	NA
>0.5 to 0.75	53 089	346	525 805	11.4	0.83 (0.71-0.96)	.01	1.70
>0.75 to <1	39 182	220	384 194	9.9	0.83 (0.70-0.99)	.04	1.70
1	39 551	414	416 281	16.8	1.01 (0.89-1.13)	.93	NA
Cancer mortality							
0	87 222	2338	856 871	24.7	1 [Reference]	NA	NA
≥0.25	12 414	183	128 101	20.2	0.88 (0.73-1.06)	.17	NA
>0.25 to 0.5	24 548	329	251 297	20.9	0.98 (0.85-1.12)	.76	NA
>0.5 to 0.75	53 089	577	525 805	18.5	0.80 (0.72-0.90)	<.001	1.81
>0.75 to <1	39 182	428	384 194	20.7	0.89 (0.77-1.02)	.10	NA
1	39 551	591	416 281	21.5	0.93 (0.83-1.04)	.19	NA

Abbreviations: ASMR, age-standardized mortality rate (per 10 000 participants); CVD, cardiovascular disease; HR, hazard ratio; MVPA, moderate to vigorous intensity physical activity; NA, not available; VPA, vigorous intensity physical activity.

[a] We multiplied VPA (minutes per week) by 2 to calculate total MVPA, and proportion of VPA to total physical activity (defined as total MVPA) in terms of its intensity and potential health benefits.

[b] Adjusted for age, sex, race/ethnicity, educational level, income, marital status, body mass index, smoking status, alcohol consumption, and MVPA.

[c] *P* value for trend including proportion of VPA to total MVPA as continuous variable into the model: all-cause mortality, *P* < .001; CVD mortality, *P* = .17; and cancer mortality, *P* = .03.

[d] The E-value is the minimum strength of association, on the risk ratio scale, that an unmeasured confounder would need to have with both the treatment and outcome, conditional on the measured covariates, to explain away a treatment-outcome association.[25]

higher proportion of VPA to total physical activity was associated with lower all-cause mortality,[7,10] but 1 study did not find such additional benefits associated with VPA vs MPA.[9] The main reason might be that, in the latter study, the MVPA reference group was defined as less than 450 metabolic equivalent minutes per week (<150 minutes per week of MPA), which could have diluted the association between proportion of VPA and mortality. Another study found that proportion of VPA was associated with all-cause mortality in men but not in women.[8] In our study, the benefit associated with low proportion of VPA (1%-50%) was larger in men, but the sex difference disappeared in the higher proportion of VPA (>50%). The null associations between proportion of VPA to total physical activity and CVD mortality and cancer mortality raise doubts about the assumption that VPA may yield larger health benefits compared with MPA.[8,10] Nonetheless, we observed that participants performing more than 50% to 75% of VPA to MVPA had a lower risk of CVD mortality and cancer mortality, even after excluding participants who died during the first 2 years of follow-up (eTable 3 in the Supplement). A potential explanation for the additional health benefits associated with doing some VPA might be owing to greater improvement in peak oxygen consumption, cardiac stroke volume, blood pressure, body composition, and lipid profiles.[12,14,26-28]

Strengths and Limitations

This study has several strengths. Compared with previous epidemiologic studies on physical activity intensity and mortality, our study included a large, representative sample of US adults. Moreover, our main analysis including a reference group of healthy participants doing any MPA (but no VPA), as well as our sensitivity analyses excluding deaths within the first 2 years of follow-up, might have mitigated issues owing to undetected, occult diseases at baseline. Nonetheless, we cannot totally rule out the possibility of reverse causality.

Our study has several limitations. First, residual confounding (eg, dietary factors) cannot be excluded, although we adjusted for several potential confounders at baseline. Second, information on the physical activity was self-reported at a single point in time, which might be susceptible to measurement error.[19,29] Changes in MVPA over time were not accounted for in the analyses, which might have underestimated the magnitude of the associations (regression dilution bias). Third, data collected in the NHIS were not adequately detailed about sit-

Table 3. Subgroup Analyses for the Associations of Proportion of VPA to Total Physical Activity With All-Cause Mortality Among Participants Who Had Any MVPA[a,b]

Variable	Partici-pants, No.	Proportion of VPA to MVPA, hazard ratio (95% CI)						*P* value for inter-action
		0% (n = 85 806)	≤25% (n = 12 122)	>25% to 50% (n = 23 921)	>50% to 75% (n = 51 646)	>75% to <100% (n = 38 264)	100% (n = 38 248)	
All-cause mortality								
Age, y								
<45	149 834	1 [Reference]	0.98 (0.80-1.20)	0.87 (0.74-1.01)	0.78 (0.69-0.89)	0.74 (0.64-0.86)	0.83 (0.73-0.94)	.52
45-65	77 661	1 [Reference]	0.68 (0.58-0.81)	0.81 (0.70-0.93)	0.70 (0.63-0.79)	0.75 (0.66-0.86)	0.80 (0.72-0.88)	
>65	28 511	1 [Reference]	0.84 (0.72-0.98)	0.78 (0.69-0.87)	0.77 (0.70-0.84)	0.74 (0.67-0.83)	0.82 (0.75-0.90)	
Sex								
Male	118 231	1 [Reference]	0.86 (0.76-0.97)	0.89 (0.81-0.99)	0.83 (0.76-0.90)	0.84 (0.77-0.92)	0.90 (0.84-0.97)	.55
Female	137 775	1 [Reference]	0.94 (0.81-1.09)	0.92 (0.81-1.03)	0.81 (0.74-0.90)	0.83 (0.74-0.94)	0.89 (0.82-0.96)	
BMI								
<25	105 203	1 [Reference]	0.82 (0.70-0.98)	0.93 (0.82-1.05)	0.81 (0.74-0.89)	0.82 (0.74-0.92)	0.90 (0.82-0.99)	.20
25-30	88 596	1 [Reference]	0.87 (0.75-1.02)	0.86 (0.76-0.97)	0.83 (0.75-0.92)	0.85 (0.75-0.96)	0.88 (0.80-0.98)	
>30	56 310	1 [Reference]	1.01 (0.85-1.21)	0.93 (0.79-1.10)	0.81 (0.71-0.93)	0.85 (0.72-1.00)	0.94 (0.83-1.06)	
Smoking status								
Never cigarette	152 338	1 [Reference]	0.92 (0.79-1.07)	0.85 (0.76-0.96)	0.80 (0.72-0.88)	0.81 (0.73-0.91)	0.88 (0.81-0.96)	.03
Former cigarette	52 749	1 [Reference]	0.85 (0.72-1.01)	0.85 (0.73-0.98)	0.90 (0.81-1.00)	0.87 (0.77-0.99)	0.88 (0.79-0.98)	
Current cigarette	50 575	1 [Reference]	0.91 (0.76-1.10)	1.05 (0.91-1.21)	0.80 (0.71-0.91)	0.89 (0.77-1.02)	0.97 (0.87-1.07)	
Alcohol intake								
Lifetime abstainer	43 146	1 [Reference]	0.97 (0.74-1.26)	1.05 (0.85-1.30)	0.93 (0.80-1.07)	0.92 (0.76-1.11)	0.94 (0.83-1.07)	.87
Former drinker	29 864	1 [Reference]	0.84 (0.67-1.05)	0.86 (0.72-1.03)	0.80 (0.70-0.92)	0.82 (0.69-0.97)	0.92 (0.81-1.04)	
Current drinker	181 300	1 [Reference]	0.90 (0.80-1.01)	0.89 (0.80-0.98)	0.82 (0.75-0.89)	0.84 (0.77-0.92)	0.89 (0.83-0.96)	
Total physical activity, min/wk								
1-149	81 603	1 [Reference]	1.04 (0.86-1.27)	0.77 (0.63-0.94)	0.79 (0.68-0.92)	0.86 (0.69-1.07)	0.97 (0.88-1.06)	.18
150-299	56 900	1 [Reference]	0.82 (0.66-1.01)	0.85 (0.72-1.01)	0.86 (0.76-0.97)	0.83 (0.71-0.98)	0.89 (0.81-0.99)	
≥300	117 503	1 [Reference]	0.86 (0.75-0.97)	0.96 (0.86-1.06)	0.81 (0.74-0.88)	0.83 (0.76-0.92)	0.86 (0.78-0.94)	
Chronic conditions[c]								
Yes	58 801	1 [Reference]	0.94 (0.82-1.09)	0.90 (0.79-1.02)	0.86 (0.79-0.95)	0.90 (0.80-1.02)	0.91 (0.83-0.99)	.33
No	197 205	1 [Reference]	0.87 (0.76-0.99)	0.91 (0.82-1.01)	0.81 (0.75-0.88)	0.81 (0.74-0.89)	0.90 (0.84-0.97)	

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); MVPA, moderate to vigorous intensity physical activity; VPA, vigorous intensity physical activity.

[a] Adjusted for age, sex, race/ethnicity, education level, income, marital status, BMI, smoking status, alcohol consumption, and MVPA.

[b] We multiplied VPA (minutes per week) by 2 to calculate total MVPA, and proportion of VPA to total physical activity (defined as MVPA) in terms of its intensity and potential health benefits.

[c] Reporting chronic conditions (diabetes or hypertension) at baseline.

ting time, physical activity at different domains, and sleep time, so we were not able to account for the compositional nature of the data.[30-32] Fourth, it is well established that the competing risk model is recommended to be used for cause-specific mortality. However, the procedure based on Fine-Gray proportional subhazards model in Stata or R does not allow weighting for complex survey designs. Our sensitivity analysis accounting for competing risks (but not considering the complex survey design) suggested that the HR for CVD mortality and cancer mortality may be overestimated in our main analysis.

Public Health Implications

The overall findings of this study based on 3 mortality outcomes (all-cause mortality, CVD mortality, and cancer mor-

Table 4. Adjusted Hazard Ratios for Joint Associations of MPA and VPA With All-Cause Mortality, CVD Mortality, and Cancer Mortality[a,b]

Mortality	MPA, hazard ratio (95% CI)			
	0 min/wk	1-149 min/wk	150-299 min/wk	≥300 min/wk
All-cause mortality (36 861 deaths)				
VPA, min/wk				
0	1.00 [Reference]	0.86 (0.83-0.89)	0.80 (0.76-0.84)	0.78 (0.73-0.82)
1-74	0.84 (0.77-0.92)	0.71 (0.66-0.76)	0.74 (0.64-0.86)	0.66 (0.58-0.76)
75-149	0.73 (0.67-0.81)	0.66 (0.61-0.72)	0.74 (0.65-0.85)	0.74 (0.64-0.85)
≥150	0.69 (0.64-0.75)	0.64 (0.59-0.69)	0.64 (0.58-0.71)	0.68 (0.62-0.74)
CVD mortality (7634 deaths)				
VPA, min/wk				
0	1.00 [Reference]	0.85 (0.79-0.92)	0.73 (0.64-0.82)	0.71 (0.62-0.81)
1-74	0.78 (0.63-0.97)	0.80 (0.69-0.94)	0.78 (0.56-1.09)	0.70 (0.51-0.97)
75-149	0.85 (0.67-1.07)	0.61 (0.50-0.76)	0.60 (0.41-0.89)	0.64 (0.45-0.91)
≥150	0.71 (0.60-0.84)	0.56 (0.45-0.69)	0.56 (0.45-0.72)	0.55 (0.44-0.68)
Cancer mortality (8902 deaths)				
VPA, min/wk				
0	1.00 [Reference]	0.93 (0.86-1.00)	0.93 (0.84-1.03)	0.88 (0.78-0.98)
1-74	0.83 (0.69-1.00)	0.76 (0.66-0.86)	0.72 (0.55-0.94)	0.67 (0.52-0.86)
75-149	0.83 (0.69-1.00)	0.75 (0.64-0.87)	1.06 (0.83-1.36)	0.93 (0.74-1.16)
≥150	0.83 (0.73-0.96)	0.73 (0.62-0.85)	0.71 (0.58-0.87)	0.82 (0.70-0.97)

Abbreviations: CVD, cardiovascular disease; HR, hazard ratio; MPA, moderate intensity physical activity; VPA, vigorous intensity physical activity.

[a] Adjusted for age, sex, race/ethnicity, educational level, income, body mass index, smoking, and alcohol intake.

[b] Moderate intensity physical activity, VPA, and the interaction term were simultaneously included in a multivariable model including age, sex, race/ethnicity, educational level, income, body mass index, smoking, and alcohol intake. Adjusted Wald test was used to formally test interaction. *P* values for interaction: all-cause mortality, $P < .001$; CVD mortality, $P = .93$; and cancer mortality, $P = .04$.

tality) show the importance of accumulating a minimal amount of 150 minutes per week or more of MVPA. Our study also supported the hypothesis that VPA may be associated with greater health benefits compared with MPA. From a public health perspective, the main message should be about reaching the minimal amount of 150 minutes per week of MVPA, as most of the benefits could be obtained at MPA. Although MPA may be more palatable and applied to most of the population, clinicians and public health interventions may advise that increasing the relative proportion of VPA to total physical activity may be associated with additional health benefits. For instance, our study suggested that participants performing more than 50% to 75% of VPA to MVPA had a 17% lower all-cause mortality compared with those performing only MPA, independent of the total physical activity. Approximately 150 to 299 minutes per week of MPA and 150 or more minutes per week of VPA was found to be the threshold for lowest all-cause mortality. These findings could be useful for clinical or individual counseling. Overall, our findings could be summarized in a clear clinical and public health message: Although most of the health benefit associated with meeting recommended weekly physical activity goals could be achieved through moderate activity, our results suggest that increased proportion of vigorous activity is associated with additional health benefits.

Conclusions

This study suggests that a higher proportion of VPA to total physical activity was associated with lower all-cause mortality. Clinicians and public health interventions should encourage achieving the physical activity guidelines to reduce mortality but also advise on the potential benefits associated with VPA to maximize population health.

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Author Affiliations: Department of Epidemiology and Biostatistics, School of Health Sciences, Wuhan University, Wuhan, China (Wang); Department of Sociology and Institute for Empirical Social Science Research, School of Humanities and Social Sciences, Xi'an Jiaotong University, Xi'an, China (Nie); Laboratorio de Ciencias de la Actividad Física, el Deporte y la Salud, Facultad de Ciencias Médicas, Universidad de Santiago de Chile CH, Santiago, Chile (Ferrari); i+HEALTH Research Group, Department of Health Sciences, Universidad Europea Miguel de Cervantes, Valladolid, Spain (Rey-Lopez); Departamento de Medicina Preventiva, Universidade Federal de São Paulo, Escola Paulista de Medicina, São Paulo, Brazil (Rezende).

Author Contributions: Mr Wang had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Wang, Ferrari, Rey-Lopez, Rezende.
Acquisition, analysis, or interpretation of data: Wang, Nie, Rezende.
Drafting of the manuscript: Wang, Ferrari, Rezende.
Critical revision of the manuscript for important intellectual content: Wang, Nie, Rey-Lopez, Rezende.
Statistical analysis: Wang, Nie.
Administrative, technical, or material support: Wang, Ferrari.
Supervision: Wang, Rey-Lopez, Rezende.

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