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Title: PREPRINT: Associations between aerobic and muscle-strengthening physical activity, sleep duration and risk of all-cause mortality: a prospective cohort study of 278,405 US adults

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Abstract

Objectives: To examine the joint associations between meeting guidelines for physical activity and sleep duration with all-cause mortality risk among adults.

Methods: Adults (n=278,405) aged 18-84 y who participated in the 2004-2014 US National Health Interview Survey. Mortality status was ascertained using the National Death Index to December, 2015. Self-reported physical activity (Active: meeting both aerobic (*AER*) and muscle-strengthening (*MSA*) guidelines, *AER* only (*AER*), *MSA* only (*MSA*), or not meeting either *AER* or *MSA* (*Inactive*)) and sleep duration (*Short*, recommended (*Rec*), or *Long*) were classified according to guidelines, and 12 physical activity-sleep categories were derived. Adjusted hazard ratios (HRs) and 95% CIs for all-cause mortality risk were estimated using Cox proportional hazards regression models.

Results: A total of 278,405 participants (55% female;) were included; 18,696 deaths (6.7%) occurred over an average follow-up of 5.7 y. Relative to the *Active-Rec* group, all other physical activity-sleep groups were associated with increased mortality risk except for the *Active-Short* group (HR [95% CI] = 1.09 [0.93, 1.28]). For a given sleep duration, mortality risk progressively increased among participants classified as *AER*, *MSA*, and *Inactive*. The greatest mortality risks were observed for any activity level in combination with long sleep duration.

Conclusions and Relevance: All-cause mortality risk progressively increased among adults meeting guidelines for either aerobic only, muscle-strengthening only, or neither physical activity guideline, and varied according to sleep duration. These results support interventions targeting both physical activity and sleep duration to reduce mortality risk.

Introduction:

Both physical activity and sleep are important determinants of health and well-being.^{1,2} There are clear dose-response relationships between higher levels of physical activity and reduced risk of all-cause, cardiovascular (CVD), and cancer-related mortality.^{1,3} It is recommended that adults engage in a combination of aerobic activity (AER) and muscle-strengthening activity (MSA) to optimise the health benefits of physical activity.^{4,5} Relative to not meeting guidelines for either AER or MSA activity, meeting either the AER or MSA activity guidelines reduces mortality risk; however, the greatest benefits are achieved by meeting guidelines for both AER and MSA.^{6,7} For sleep duration, it is recommended that adults obtain between 7-9 h of sleep per day depending on their age.^{8,9} Meta-analyses report a U-shaped relationship between sleep duration and mortality risk, with short (i.e., <7 h/day) and long sleep durations (i.e., ≥9 h/day) associated with increased risk.¹⁰⁻¹² Physical activity and sleep duration behaviours cluster together,^{13,14} share a bidirectional relationship,¹⁵⁻¹⁷ and influence common health outcomes through overlapping mechanistic pathways,^{2,18,19} yet few studies have assessed the combined influence of physical activity and sleep duration on mortality.²⁰⁻

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Reported prospective associations between combinations of physical activity and short sleep duration have been inconsistent. One study found that meeting guidelines for aerobic activity offset the risks associated with short sleep duration,²² while other studies have reported that mortality risks remain significantly elevated among adults who are physically active with short sleep.^{23,24} The reported joint association between physical activity and long sleep duration on all-cause mortality risk has also been inconsistent across studies.²²⁻²⁴ Thus, it is unclear how different combinations of physical activity levels with short or long sleep duration influence mortality risk. To our knowledge, no study to date has examined the joint association of physical activity and sleep duration with mortality when assessing engagement in muscle-strengthening activity (MSA). Doing so can help to better understand the health benefits associated with meeting both physical activity and sleep

duration guidelines. Therefore, the aims of the current study were to examine: (1) the joint associations between meeting guidelines for aerobic and muscle-strengthening physical activity, and sleep duration, with all-cause mortality risk among adults; and (2) the multiplicative and additive interaction effects of different combinations of meeting guidelines for physical activity and sleep duration with all-cause mortality risk.

Methods:

Study Population

The study used data from the National Health Interview Survey (NHIS), an ongoing annual nationally representative cross-sectional household survey of civilian non-institutionalised individuals living in the US. NHIS participants are randomly selected using a stratified multistage probability design. Further details on the sampling approach and survey items are available elsewhere.^{27,28} The data are publicly available and data used in the current study were downloaded from the Integrated Public Use Microdata Series (IPUMS) NHIS database from the IPUMS website.²⁹ All participants provided consent to participate in the NHIS. The current study included data obtained from the 2004-2014 surveys, with data linked to the National Death Index through 31 December 2015. This date range was selected because: (1) sleep duration data were not collected prior to 2004; and (2) the surveys conducted after 2014 were omitted to allow at least 12 months of follow-up from survey completion, since mortality data were only available to 31 December 2015. The number of participants in each survey ranged from 21,781 in 2008 to 36,697 in 2014; overall, there were 325,884 participants across the 2004-2014 surveys. Details of the items used to assess exposure measures, potential confounders, and their subsequent classifications are detailed in Supplementary Table 1.

Outcome

Mortality status was assessed using probabilistic record matching methods to link NHIS participants to the National Death Index using the public use-linked mortality file.³⁰⁻³² Eligible NHIS participants from 2004 to 2014 were linked to the National Death Index records until 31 December 2015. Follow-up duration was calculated in whole years from participation in the NHIS to the date of death or 2015 for survivors.

Exposures

Participants self-reported the duration and frequency of light- or moderate- and vigorous-intensity aerobic physical activity performed in leisure time that was at least 10 minutes in duration, and the number of times they performed muscle-strengthening activities. There is no specific information available on the psychometric properties of the physical activity instrument used in NHIS, although it provides comparable estimates of physical activity to other survey instruments that have acceptable validity and reliability.³³ Standard NHIS scoring protocols were used to estimate weekly duration of aerobic physical activity (vigorous-intensity activity weighted by two), and weekly frequency of MSA.³⁴ The US Physical Activity Guidelines recommend engaging in both aerobic activity (≥ 150 minutes of moderate-intensity, ≥ 75 minutes of vigorous-intensity or ≥ 150 minutes of moderate- and vigorous-intensity physical activity per week) and MSA (≥ 2 times per week).⁵ These guidelines were used to classify participants into one of the following four mutually exclusive groups: *Active* (meeting the aerobic guidelines and meeting the muscle-strengthening activity guidelines), *AER* (meeting the aerobic guidelines and not meeting the muscle-strengthening activity guidelines), *MSA* (not meeting the aerobic guidelines and meeting the muscle-strengthening activity guidelines), and *Inactive* (not meeting either the aerobic or muscle-strengthening activity guidelines).

Participants reported their average sleep duration in a 24-hour period using a single item. There are no psychometric data available on this item; however, single-item measures are frequently used to assess sleep duration in cohort studies and demonstrate replicable associations with a range of health outcomes.^{10,11,35} Reported sleep durations were classified into one of three groups based on age-specific guidelines from the National Sleep Foundation:⁸ *Recommended Sleep* (*Rec*: ages 18-64 y: 7-9 hours; ages 65+ y: 7-8 hours), *Short Sleep* (*Short*: ages 18-64 y: ≤ 6 hours; ages 65+ y: ≤ 6 hours), or *Long Sleep* (*Long*: ages 18-64 y: ≥ 10 hours; ages 65+ y: ≥ 9 hours). Using physical activity and sleep duration categories, 12 combined physical activity and sleep duration categories were created: *Active-Rec*, *AER-Rec*, *MSA-Rec*, *Inactive-Rec*, *Active-Short*, *AER-Short*, *MSA-Short*, *Inactive-Short*, *Active-Long*, *AER-Long*, *MSA-Long*, *Inactive-Long*.

Confounders

Potential confounders were selected *a priori* based on evidence for association with the exposures and the outcome.^{36,37} Selected confounding variables comprised age (years), sex (female, male), height and weight (i.e., to calculate body mass index [BMI]; kg/m²), race and ethnicity, education, employment classification, smoking status, alcohol consumption, self-rated health, and prior diagnosis of chronic diseases.

Statistical Analysis

All analyses were conducted using Stata MP 17.0 using a two-tailed significance level of 0.05. Unweighted descriptive statistics summarising participants' sociodemographic, behavioural, and health characteristics stratified by sleep duration are presented. Comparison of the sociodemographic, behavioural, and health characteristics of the included and excluded participants are presented using unweighted descriptive statistics.

Analyses examining the association of physical activity and sleep duration with risk of mortality accounted for the weighted and clustered sampling design of NHIS using the Stata svy prefix suite of commands. A series of Cox proportional hazard models was used to examine the association between physical activity and sleep duration with all-cause mortality, with time to death or final follow-up (31 December 2015). The proportional hazards assumption was assessed using log-log plots,³⁸ with no noticeable violations detected for any variable included in any of the models. To limit the potential influence of reverse causality, only participants with at least one year of follow-up were included in the analyses. All participants alive at final follow-up (31 December 2015) were treated as right-censored and the Breslow method was used to handle ties.

The associations of joint categories of physical activity and sleep duration with mortality (Aim 1) were examined using a single exposure variable with 12 levels as described previously. The multiplicative (e.g., physical activity $\times$ sleep duration) and additive interactions between physical activity and sleep duration were estimated (Aim 2) as recommended.^{39,40} The additive interactions were expressed as the Relative Excess Risk due to the Interaction (RERI), the Attributable Portion due to the interaction (AP), and the Synergy Index (SI) with their 95% confidence intervals estimated using the delta method.^{39,40} To aid in the interpretation of any interaction effects, the association of physical activity with mortality within strata of sleep duration (reference category: *Active*) and sleep duration with mortality within strata of physical activity (reference category: *Rec.* sleep duration) were examined.³⁹ In each series of analyses, three models were conducted: first, an unadjusted model (Model 1); second, a minimally adjusted model adjusted for age and sex (Model 2); and third, a model adjusted for age, sex, education, ethnicity, work status, BMI, alcohol consumption, smoking status, and self-rated health (Model 3). Sensitivity analyses were conducted to examine potential bias due to pre-existing chronic conditions, replicating the above analyses and omitting those participants who reported the presence of coronary heart disease, stroke, or cancer.⁴¹

Results

In the current study, participants were excluded if they died within one year of baseline ($n = 2,372$) or had missing or unusable data for physical activity ($n = 12,515$), sleep duration ($n = 7,067$), or any of the potentially confounding variables ($n = 25,525$; Figure 1). For each of the exposure variables and confounders, the percentage of missing data was less than 5% of the overall sample. Since missing data rates were low, missing data were handled by listwise deletion (complete case analyses) assuming data were missing completely at random (MCAR), and imputation was not performed. Characteristics of included and excluded participants are reported in Table S2. A higher proportion of included participants were aged 18-39 years, male, employed, classified as light-moderate drinkers, and were classified as *Active*, compared to excluded participants.

A total of 278,405 participants (55% female; 42% aged 40-64 years; 61% non-Hispanic white ethnicity) were included in the current study. More than one-half of participants were *Inactive* (51%), 18% were *Active*, and 65% met the recommended sleep duration guidelines (Table 1). A total of 18,696 deaths (6.7%) occurred, and the average follow-up time was 5.7 years. The number of deaths by joint categories of physical activity and sleep duration are presented in Table S3.

The general pattern of associations between combinations of physical activity and sleep duration guidelines with mortality risk were similar between the unadjusted and minimally adjusted (Models 1-2; Table S4-S5) and adjusted models so only the adjusted model results are presented in text (Table 2, Figure 2). Relative to the *Active-Rec* group, all other combinations of physical activity and sleep duration were associated with increased mortality risk except for the *Active-Short* group (HR = 1.09; 95% CI 0.93, 1.28). Relative to the *Active-Rec* group, for a given sleep duration the mortality risks progressively increased among participants classified as either *AER*, *MSA*, or *Inactive* (Table 2, Figure 2). For instance, relative to the *Active-Rec* group, the *AER-Rec* (HR=1.26;

1.14, 1.39), *MSA-Rec* (HR=1.75; 1.52, 2.02) and *Inactive-Rec* (HR=1.91; 1.74, 2.10) groups were associated with increased mortality risk (Table 2). Furthermore, the greatest magnitude of mortality risk was found for any level of activity in combination with long sleep duration. Within each stratum of sleep duration, relative to *Active*, the *AER*, *MSA* and *Inactive* groups were associated with increased risk of mortality in a dose-response manner (Table 2). Within each stratum of physical activity, relative to *Rec. sleep*, *Short* sleep was not associated with mortality risk, although *Long* sleep was associated with increased risk of mortality (Table 2).

The negative multiplicative and negative additive interactions for both *MSA-Short* and *Inactive-Short* suggested that the combined effect of these exposures on mortality risk was less than the product and the sum of the separate exposures (Table 2). Positive multiplicative and positive additive interactions were present for *MSA-Long*, suggesting that their combined effects on mortality were synergistic. Negative multiplicative and positive additive interactions were present for *Inactive-Long*, suggesting that the combined effects of these exposures were inconsistent when examined on multiplicative and additive scales (Table 3). Sensitivity analyses omitting participants with selected pre-existing chronic conditions revealed a similar pattern of association to the primary analyses (Table S6-S9).

Discussion

This study examined the prospective associations of joint categories of physical activity and sleep duration with all-cause mortality in a large representative cohort of adults living in the US. For a given sleep duration, the risk of mortality progressively increased among adults meeting guidelines for either aerobic activity only, muscle-strengthening activity only or not meeting either physical activity guideline. The elevated mortality risks associated with short sleep duration appeared to be attenuated by meeting both physical activity guidelines. The greatest mortality risks were observed

adults who reported long sleep duration, and the effects of long sleep, in combination with either meeting muscle-strengthening activity only or neither physical activity guideline, was additive. To our knowledge, this is the first study to examine the joint association of physical activity and sleep duration with mortality when considering muscle-strengthening activity as a distinct form of activity and not simply considering aerobic-based activity.

Relative to the *Active-Rec* group, the mortality risks associated with short sleep duration were reduced among participants who met both the aerobic and muscle-strengthening guidelines; however, mortality risk remained elevated among participants in all other activity groups (Table 2). Meeting both physical activity guidelines also appeared to partially reduce the mortality risk of long sleep, although it remained associated with increased mortality risk (HR = 1.52) relative to recommended sleep duration. This extends knowledge from meta-analyses that examined sleep duration only, without considering how sleep duration and physical activity may jointly effect mortality.^{10,11} The potential protective effect of being physically active in combination with short sleep is broadly consistent with the results of Wennman and colleagues,²² and contrasts those of other studies which still observed increased mortality risk among the most active participants with short sleep.^{23,24} The existing literature observes inconsistent associations between physical activity and long sleep duration with mortality in terms of the statistical significance and direction of associations across studies.^{22,24} In the current study, the mortality risk of long sleep remained elevated (HR = 1.52-2.76) irrespective of activity level; however, mortality risks were the lowest among those classified as *Active* or *AER* (HR = 1.52-1.78). These observations suggest the mortality risk of short and long sleep may be offset, either fully or partially, by being physically active at a level that meets current guidelines for aerobic activity only, or guidelines for both aerobic activity and muscle-strengthening activity. If replicated in other studies, these findings can assist to inform preventative health campaigns that explicitly target improvement in both physical activity and sleep duration, although relatively few interventions are available.^{42,43}

Long sleep was associated with the greatest mortality risk for a given activity level in the current study, which is consistent with existing meta-analytic evidence examining sleep duration.^{10,44,45} There is some speculation that the greater health risk posed by long sleep is due to underlying medical conditions;^{46,47} the sensitivity analyses omitting participants with chronic conditions are broadly consistent with the main analyses in the current study, suggesting that confounding due to chronic disease is not a significant issue (Table S9). The established U-shaped relationship between sleep duration and all-cause mortality risk was observed only among participants classified as *Active* or *AER* and not those classified as *MSA* and *Inactive*.^{10,44,45} Previous studies examining the joint association between physical activity and sleep duration with mortality have not consistently observed this U-shaped relationship either;^{22,24} however, these studies only assessed aerobic activity whereas the current study also examined muscle-strengthening activity. It is noteworthy that for a given sleep duration, relative to participants classified as *Active*, mortality risks increased by ~25% among participants classified as *AER*, and by ~45-95% among those classified as *MSA*. These results suggest aerobic-based activity may offer a greater reduction in mortality risk than muscle-strengthening activity. This observation is consistent with other studies, including an analysis of the NHIS cohort, that compared aerobic only, muscle-strengthening activity only, and their combination on mortality risk.^{6,7} The underlying mechanisms responsible for these differences are unclear, although there is some evidence that aerobic activity has a greater impact on body composition, resting heart rate and blood pressure, and cardio-metabolic factors than muscle-strengthening activity.⁴⁸

The additive interactions for the *MSA-Short* and *MSA-Long*, *Inactive-Short* and *Inactive-Long* groups were not consistent in direction, suggesting less than additive effects for these groups in combination with short sleep duration, and more than additive or synergistic effects in combination

with long sleep duration (Table 2). The less than additive effects for activity in combination with short sleep are due to the greater mortality risk observed in the recommended sleep duration group in comparison to the short sleep group. This was unexpected and the reasons for this are not clear and warrant further examination.

Limitations

Strengths of this study include the use of a large representative population sample and examining the joint associations of physical activity and sleep duration when considering the unique contributions of engaging in muscle-strengthening activity as well as aerobic activity, and investigating both short and long sleep duration. Some joint physical activity and sleep groups had relatively small sample sizes and number of events corresponding to wide confidence intervals for some estimates which; limited the ability to examine sleep duration in more detail (e.g., <5 h, 5-7 h). Both exposures were assessed using self-report which has inherent limitation. Due to available data, only sleep duration was examined rather than other important dimensions of healthy sleep such as sleep quality, timing, or daytime dysfunction which may provide greater insight on how physical activity and sleep jointly influence mortality ⁴⁹. The current US guidelines (along with Australia and the World Health Organisation) omit the minimum 10-minute bout requirement for physical activity. Therefore, the physical activity classifications used in the current study do not strictly align with these; however, the bout requirement is a feature of many self-report physical activity measures and is an inherent limitation of using self-reported physical activity.

In summary, we observed that all-cause mortality risk progressively increased among adults meeting guidelines for either aerobic activity only, muscle-strengthening activity only, or neither physical activity guideline. The increased mortality risk varied according to sleep duration, with the greatest risk observed among those participants with long sleep.

Author Contributions: MJD conceived the study, drafted analysis plan and conducted statistical analyses. EGH reviewed the analysis plan and helped to draft the manuscript. SO assisted with data cleaning and preparation and helped to draft the manuscript. RP helped to draft the manuscript. CEK helped to draft the manuscript and provided input on the analysis plan.

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Table 1 - Unweighted frequency (%) of participant characteristics by sleep duration category among (n=278,405) adults in NHIS survey (2004-2014)

	Sleep Duration Category			
	Rec.	Short	Long	Total
	N=180,084	N=82,940	N=15,381	N=278,405
Age Group				
18-39	71,009 (39.4%)	30,475 (36.7%)	3,466 (22.5%)	104,950 (37.7%)
40-64	75,485 (41.9%)	38,678 (46.6%)	3,458 (22.5%)	117,621 (42.2%)
65-85	33,590 (18.7%)	13,787 (16.6%)	8,457 (55.0%)	55,834 (20.1%)
Sex				
Male	81,241 (45.1%)	36,948 (44.5%)	6,384 (41.5%)	124,573 (44.7%)
Female	98,843 (54.9%)	45,992 (55.5%)	8,997 (58.5%)	153,832 (55.3%)
Ethnicity				
Hispanic	33,238 (18.5%)	13,535 (16.3%)	2,171 (14.1%)	48,944 (17.6%)
Non-hispanic white	112,130 (62.3%)	48,615 (58.6%)	9,758 (63.4%)	170,503 (61.2%)
Non-hispanic black	23,265 (12.9%)	15,356 (18.5%)	2,816 (18.3%)	41,437 (14.9%)
Other race	11,451 (6.4%)	5,434 (6.6%)	636 (4.1%)	17,521 (6.3%)
Marital status				
Married	85,851 (47.7%)	34,866 (42.0%)	5,806 (37.7%)	126,523 (45.4%)
Widowed/divorced/separated	44,932 (25.0%)	26,343 (31.8%)	6,247 (40.6%)	77,522 (27.8%)
Never married/unknown	49,301 (27.4%)	21,731 (26.2%)	3,328 (21.6%)	74,360 (26.7%)
Education				
Did not complete high school	28,821 (16.0%)	13,725 (16.5%)	4,420 (28.7%)	46,966 (16.9%)
High school/GED	46,785 (26.0%)	22,808 (27.5%)	5,021 (32.6%)	74,614 (26.8%)
Some College/No degree	52,172 (29.0%)	27,029 (32.6%)	3,807 (24.8%)	83,008 (29.8%)
Bachelor's degree or higher	52,306 (29.0%)	19,378 (23.4%)	2,133 (13.9%)	73,817 (26.5%)
Smoking Status				
Current smoker	31,348 (17.4%)	20,013 (24.1%)	3,060 (19.9%)	54,421 (19.5%)

Former smoker	38,238 (21.2%)	17,563 (21.2%)	4,730 (30.8%)	60,531 (21.7%)
Never smoker	110,498 (61.4%)	45,364 (54.7%)	7,591 (49.4%)	163,453 (58.7%)
BMI Classification				
BMI <18.5 kg/m2	3,092 (1.7%)	1,311 (1.6%)	452 (2.9%)	4,855 (1.7%)
BMI 18.5-24.9 kg/m2	67,566 (37.5%)	26,239 (31.6%)	5,315 (34.6%)	99,120 (35.6%)
BMI 25-29.9 kg/m2	63,769 (35.4%)	28,408 (34.3%)	4,984 (32.4%)	97,161 (34.9%)
BMI>30 kg/m2	45,657 (25.4%)	26,982 (32.5%)	4,630 (30.1%)	77,269 (27.8%)
Employment Classification				
Employed	112,364 (62.4%)	52,484 (63.3%)	3,290 (21.4%)	168,138 (60.4%)
Not employed	67,720 (37.6%)	30,456 (36.7%)	12,091 (78.6%)	110,267 (39.6%)
Chronic Disease				
No chronic disease	105,509 (58.6%)	42,331 (51.0%)	5,133 (33.4%)	152,973 (54.9%)
Has chronic disease	74,575 (41.4%)	40,609 (49.0%)	10,248 (66.6%)	125,432 (45.1%)
Alcohol Consumption				
Never Drinker	41,412 (23.0%)	16,493 (19.9%)	4,416 (28.7%)	62,321 (22.4%)
Former Drinker	24,921 (13.8%)	13,731 (16.6%)	3,970 (25.8%)	42,622 (15.3%)
Light-to-moderate drinker	104,579 (58.1%)	48,232 (58.2%)	6,173 (40.1%)	158,984 (57.1%)
Heavy Drinker	9,172 (5.1%)	4,484 (5.4%)	822 (5.3%)	14,478 (5.2%)
Physical Activity Category				
Active	35,223 (19.6%)	14,801 (17.8%)	1,274 (8.3%)	51,298 (18.4%)
AER	49,078 (27.3%)	21,200 (25.6%)	2,997 (19.5%)	73,275 (26.3%)
MSA	6,433 (3.6%)	3,101 (3.7%)	651 (4.2%)	10,185 (3.7%)
Inactive	89,350 (49.6%)	43,838 (52.9%)	10,459 (68.0%)	143,647 (51.6%)

Notes. Sleep Duration classified according to National Sleep Foundation age specific guidelines for adults. Recommended Sleep (Rec: age 18-64 y: 7-9 hours; age 65+: 7-8 hours), Short Sleep (Short: age 18-64 y: ≤6 hours; age 65+: ≤6 hours), or Long Sleep (Long: age 18-64 y: ≥10 hours; age 65+: ≥9 hours). Physical Activity classified according to 2018 US Physical Activity Guidelines. Active (meeting the aerobic guidelines and meeting the muscle-strengthening activity guidelines), AER (meeting the aerobic guidelines and not meeting the muscle-strengthening activity guidelines), MSA (not meeting the aerobic guidelines and meeting the muscle-

strengthening activity guidelines), and Inactive (not meeting either the aerobic or muscle-strengthening activity guidelines).

Table 2 - Adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=278,405) in NHIS survey (2004-2014).

	Sleep Duration Categories									HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long		
	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]
Physical Activity‡															
Active	1.00			1.09	[0.93,	1.28]	1.52	[1.20,	1.92]	1.02	[0.87,	1.20]	1.57	[1.23,	1.99]
AER	1.26	[1.14,	1.39]	1.36	[1.21,	1.53]	1.78	[1.55,	2.05]	1.07	[0.97,	1.18]	1.45	[1.28,	1.65]
MSA	1.75	[1.52,	2.02]	1.57	[1.27,	1.93]	2.76	[2.21,	3.46]	0.90	[0.72,	1.13]	1.59	[1.27,	1.99]
Inactive	1.91	[1.74,	2.10]	1.77	[1.59,	1.96]	2.76	[2.49,	3.06]	0.93	[0.88,	0.98]	1.42	[1.35,	1.51]
HR for Physical Activity within Sleep Duration strata†															
AER	1.24	[1.12,	1.37]	1.25	[1.06,	1.46]	1.25	[0.96,	1.64]						
MSA	1.71	[1.49,	1.98]	1.44	[1.15,	1.81]	1.94	[1.43,	2.62]						
Inactive	1.86	[1.69,	2.05]	1.62	[1.39,	1.88]	2.00	[1.57,	2.54]						
Additive Interactions RERI [95%CI]															
AER				0.01	[-0.20,	0.22]	0.01	[-0.43,	0.45]						
MSA				-0.27	[-0.67,	0.13]	0.50	[-0.19,	1.18]						
Inactive				-0.23	[-0.44,	-0.03]	0.33	[-0.04,	0.71]						

Notes. Model 3 adjusted for Model 2 confounders and also education, ethnicity, work status, BMI category, alcohol consumption, smoking status, self-rated health and chronic disease presence (Asthma, Stroke, Diabetes, Coronary Heart Disease, Heart Attack, Hypertension, Cancer, Emphysema). † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 0.99 [95%CI 0.82, 1.19], $p = 0.939$. Multiplicative interactions for MSA & Short are: 0.82 [95%CI 0.63, 1.08], $p = 0.162$. Multiplicative interactions for Inactive & Short are: 0.85 [95%CI 0.72, 1.00], $p = 0.056$. Multiplicative interactions for AER & Long are: 0.94 [95%CI 0.70, 1.25], $p = 0.648$. Multiplicative interactions for MSA & Long are: 1.04 [95%CI 0.75, 1.45], $p = 0.814$. Multiplicative interactions for Inactive & Long are: 0.95 [95%CI 0.74, 1.22], $p = 0.694$.

Additive interactions for AER & Short are: AP [95%CI]: 0.01 [95%CI -0.15, 0.16]; SI [95%CI]: 1.04 [95%CI 0.41, 1.67]. Additive interactions for MSA & Short are: AP: -0.17 [-0.45, 0.11]; SI: 0.68 [0.27, 1.09]. Additive interactions for Inactive & Short are: AP: -0.13 [-0.24, -0.02]; SI: 0.77 [95%CI 0.62, 0.92]. Additive interactions for AER & Long are: AP: 0.01 [-0.24, 0.25]; SI: 1.01 [0.44, 1.59]. Additive interactions for MSA & Long are: AP: 0.18 [-0.04, 0.40]; SI: 1.39 [0.76, 2.02]. Additive interactions for Inactive & Long are: AP: 0.12 [-0.01, 0.26]; SI: 1.23 [0.91, 1.56].

Figure 1 - Sample selection NHIS 2004-2014 (unweighted sample sizes)

Figure 2. Adjusted associations of physical activity classification and sleep duration with all-cause mortality risk among adults (n=278,405) in NHIS surveys (2004-2014).

Note: Estimates based on Model 3. Adjusted for sex, age, education, ethnicity, work status, BMI category

Table S1. Study variables

Table S2 - Unweighted frequency (%) of participant characteristics among those included and excluded from analysis in NHIS survey (2004-2014)

Table S3. Number of events by physical activity and sleep duration category among (n=278,405) adults in NHIS survey (2004-2014)

Table S4- Unadjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=278,405) in NHIS survey (2004-2014).

Table S5- Minimally adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=278,405) in NHIS survey (2004-2014).

Table S6. Number of events by physical activity and sleep duration category among (n=239,862) adults in NHIS survey (2004-2014) sensitivity analysis.

Table S7 - Sensitivity analyses unadjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

Table S8- Sensitivity analyses minimally adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

Table S9 - Sensitivity analyses adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

Table S1. Study variables

Measure	Type	Description
Total aerobic physical activity	Self-report	<p>Participants can report frequency as: never/ per day/ per week/ per month/ per year/ unable to do this activity and it is recoded into 'per week' values.</p> <p>Participants can report duration as: hours or minutes and it is recoded into minutes.</p> <ul style="list-style-type: none"> - 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? - For those who do vigorous activity: About how long do you do these vigorous leisure-time physical activities each time? - 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? - For those who do light/moderate activity: About how long do you do these vigorous leisure-time physical activities each time? <p>Vigorous min/week= frequency/week*min/week Light/moderate min/week= frequency/week*min/week Total physical activity min/week= light/moderate min/week + (2* vigorous min/week)</p>
Meeting aerobic physical activity recommendation	Calculated	<ul style="list-style-type: none"> - Meeting aerobic physical activity guidelines: ≥ 150 min total physical activity per week (i.e., 150 min light/moderate physical activity or 75 min vigorous physical activity, or any equivalent combination). - Not meeting aerobic physical activity recommendations: < 150 min/ total physical activity per week.
Muscle-strengthening activity sessions/week	Self-report	<p>Participants can report frequency as: never/ per day/ per week/ per month/ per year/ unable to do this activity and it is recoded into 'per week' values.</p> <ul style="list-style-type: none"> - How often do you do LEISURE-TIME physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics?
Meeting muscle-strengthening recommendation	Calculated	<ul style="list-style-type: none"> - Meeting muscle-strengthening activity recommendation: ≥ 2 sessions/week - Not meeting muscle-strengthening activity recommendation: < 2 sessions/week
Meeting physical activity recommendations	Calculated	<ul style="list-style-type: none"> - Inactive: Reporting < 150 minutes of moderate intensity, < 75 minutes of vigorous intensity or < 150 minutes of moderate and vigorous intensity physical activity per week, and reporting muscle strengthening activity < 2 times per week, - Aerobic Activity Only (AER): Reporting ≥ 150 minutes of moderate intensity, ≥ 75 minutes of vigorous intensity or ≥ 150 minutes of moderate and vigorous intensity physical

activity per week, and reporting muscle strengthening activity <2 times per week,

- Muscle Strengthening Activity Only (MSA): Reporting <150 minutes of moderate intensity, <75 minutes of vigorous intensity or <150 minutes of moderate and vigorous intensity physical activity per week, and reporting muscle strengthening activity ≥ 2 times per week,
- Active: Reporting ≥ 150 minutes of moderate intensity, ≥ 75 minutes of vigorous intensity or ≥ 150 minutes of moderate and vigorous intensity physical activity per week, and reporting muscle strengthening activity ≥ 2 times per week.

Sleep duration	Self-report	Typical number of hours of sleep per 24 hours
Meeting sleep duration recommendations	Calculated	<ul style="list-style-type: none"> - Short sleep (18y+: ≤ 6 hours) - Recommended sleep (age 18-64y: 7-9 hours; age 65+: 7-8 hours) - Long sleep (age 18-64y: ≥ 10 hours; age 65+y: ≥ 9 hours)
Activity-Sleep Group	Calculated	<ol style="list-style-type: none"> 1. Active & Recommended Sleep (Active & Rec.) 2. AER & Recommended Sleep (AER & Rec.) 3. MSA & Recommended Sleep (MSA & Rec.) 4. Inactive (Inactive & Rec.) 5. Active & Shorter Sleep (Active & Short) 6. AER & Shorter Sleep (AER & Short) 7. MSA & Shorter Sleep (MSA & Short) 8. Inactive & Shorter Sleep (Inactive & Short) 9. Active & Longer Sleep (Active & Long.) 10. AER & Longer Sleep (AER & Long) 11. MSA & Longer Sleep (MSA & Long) 12. Inactive & Longer Sleep (Inactive & Long).
Age	Self-report	Years 18-39 years 40-64 years 65-85 years
Sex	Self-report	Male/ female
Ethnicity	Self-report	Hispanic Non-Hispanic white Non-Hispanic black Other ethnicity/race (incl. mixed)
Marital status	Self-report	Married Widowed, divorced, or separated Never married
Highest completed level of education	Self-report	Did not complete high school High school or graduate equivalency degree (GED) Some college with no degree Bachelor's degree or higher'
Employment status	Self-report	Employed Unemployed Retired Not in workforce (home maker, student, due to health reasons/ disability)

Height	Self-report	Feet & inches converted to meters
Body weight	Self-report	Pounds converted to kilos
Body mass index	Calculated	BMI= body weight (kg)/height (m) ² <18.5 kg/m ² 18.5-24.9 kg/m ² 25.0-29.9 kg/m ² ≥30.0 kg/m ²
Smoking history	Self-report	Never smoker Former smoker Current smoker (≥1 cigarettes/day)
Alcohol consumption	Self-report	Never Drinker Former Drinker Light-to-moderate drinker (males: 0-14 drinks/week, females: 0-7 drinks/week) Heavy drinker' (males: >14 drinks/week, females: >7 drinks/week)
Chronic disease diagnosis	Self-report	Yes/No Yes if reporting ever receiving a diagnosis of asthma, stroke, diabetes, coronary heart disease, heart attack or myocardial infarction, hypertension, cancer, or emphysema from a doctor
Self-reported health	Self-report	Excellent-to-very-good (excellent or very good) Good (good) Fair-to-poor (fair or poor)

Table S2 - Unweighted frequency (%) of participant characteristics among those included and excluded from analysis in NHIS survey (2004-2014)

	Included/Omitted Classification		
	Excluded N=47,479	Included N=278,405	Total N=325,884
Age Group			
18-39	15,478 (32.6%)	104,950 (37.7%)	120,428 (37.0%)
40-64	20,461 (43.1%)	117,621 (42.2%)	138,082 (42.4%)
65-85	11,540 (24.3%)	55,834 (20.1%)	67,374 (20.7%)
Sex			
Male	19,865 (41.8%)	124,573 (44.7%)	144,438 (44.3%)
Female	27,614 (58.2%)	153,832 (55.3%)	181,446 (55.7%)
Ethnicity			
Hispanic	8,282 (17.4%)	48,944 (17.6%)	57,226 (17.6%)
Non-hispanic white	28,236 (59.5%)	170,503 (61.2%)	198,739 (61.0%)
Non-hispanic black	7,760 (16.3%)	41,437 (14.9%)	49,197 (15.1%)
Other race	3,201 (6.7%)	17,521 (6.3%)	20,722 (6.4%)
Marital status			
Married	20,194 (42.5%)	126,523 (45.4%)	146,717 (45.0%)
Widowed/divorced/separated	14,331 (30.2%)	77,522 (27.8%)	91,853 (28.2%)
Never married/unknown	12,954 (27.3%)	74,360 (26.7%)	87,314 (26.8%)
Education			
Did not complete high school	8,669 (19.2%)	46,966 (16.9%)	55,635 (17.2%)
High school/GED	12,706 (28.2%)	74,614 (26.8%)	87,320 (27.0%)
Some College/No degree	12,723 (28.2%)	83,008 (29.8%)	95,731 (29.6%)
Bachelor's degree or higher	10,998 (24.4%)	73,817 (26.5%)	84,815 (26.2%)
Smoking Status			
Current smoker	8,221 (18.3%)	54,421 (19.5%)	62,642 (19.4%)
Former smoker	9,767 (21.8%)	60,531 (21.7%)	70,298 (21.7%)
Never smoker	26,875 (59.9%)	163,453 (58.7%)	190,328 (58.9%)
BMI Classification			
BMI <18.5 kg/m2	732 (2.1%)	4,855 (1.7%)	5,587 (1.8%)
BMI 18.5-24.9 kg/m2	12,551 (36.5%)	99,120 (35.6%)	111,671 (35.7%)
BMI 25-29.9 kg/m2	11,796 (34.3%)	97,161 (34.9%)	108,957 (34.8%)
BMI>30 kg/m2	9,328 (27.1%)	77,269 (27.8%)	86,597 (27.7%)
Employment Classification			
Employed	25,602 (55.1%)	168,138 (60.4%)	193,740 (59.6%)
Not employed	20,867 (44.9%)	110,267 (39.6%)	131,134 (40.4%)
Chronic Disease			
No chronic disease	23,277 (56.0%)	152,973 (54.9%)	176,250 (55.1%)
Has chronic disease	18,275 (44.0%)	125,432 (45.1%)	143,707 (44.9%)
Alcohol Consumption			
Never Drinker	11,223 (28.5%)	62,321 (22.4%)	73,544 (23.1%)
Former Drinker	6,870 (17.5%)	42,622 (15.3%)	49,492 (15.6%)
Light-to-moderate drinker	19,617 (49.9%)	158,984 (57.1%)	178,601 (56.2%)
Heavy Drinker	1,631 (4.1%)	14,478 (5.2%)	16,109 (5.1%)
Physical Activity Category			
Active	4,293 (12.3%)	51,298 (18.4%)	55,591 (17.7%)
AER	7,359 (21.0%)	73,275 (26.3%)	80,634 (25.7%)
MSA	1,113 (3.2%)	10,185 (3.7%)	11,298 (3.6%)

Inactive	22,199 (63.5%)	143,647 (51.6%)	165,846 (52.9%)
Sleep Duration Category			
Rec.	25,707 (63.6%)	180,084 (64.7%)	205,791 (64.5%)
Short	11,966 (29.6%)	82,940 (29.8%)	94,906 (29.8%)
Long	2,739 (6.8%)	15,381 (5.5%)	18,120 (5.7%)

Notes. Sleep Duration classified according to National Sleep Foundation age specific guidelines for adults. Recommended Sleep (Rec: age 18-64 y: 7-9 hours; age 65+: 7-8 hours), Short Sleep (Short: age 18-64 y: ≤ 6 hours; age 65+: ≤ 6 hours), or Long Sleep (Long: age 18-64 y: ≥ 10 hours; age 65+: ≥ 9 hours). Physical Activity classified according to 2018 US Physical Activity Guidelines. Active (meeting the aerobic guidelines and meeting the muscle-strengthening activity guidelines), AER (meeting the aerobic guidelines and not meeting the muscle-strengthening activity guidelines), MSA (not meeting the aerobic guidelines and meeting the muscle-strengthening activity guidelines), and Inactive (not meeting either the aerobic or muscle-strengthening activity guidelines).

Table S3. Number of events by physical activity and sleep duration category among (n=278,405) adults in NHIS survey (2004-2014)

	% Events	No. Events	Total
Total	(6.7%)	18,696 /	278,405
Activity & Sleep Duration Category			
Active & Rec.	(2.1%)	724 /	35,223
AER & Rec.	(3.9%)	1,938 /	49,078
MSA & Rec.	(7.0%)	450 /	6,433
Inactive & Rec.	(8.3%)	7,428 /	89,350
Active & Short	(2.0%)	301 /	14,801
AER & Short	(3.8%)	815 /	21,200
MSA & Short	(6.4%)	198 /	3,101
Inactive & Short	(8.3%)	3,631 /	43,838
Active & Long	(8.5%)	108 /	1,274
AER & Long	(12.6%)	379 /	2,997
MSA & Long	(23.0%)	150 /	651
Inactive & Long	(24.6%)	2,574 /	10,459
Physical Activity Category			
Active	(2.2%)	1,133 /	51,298
AER	(4.3%)	3,132 /	73,275
MSA	(7.8%)	798 /	10,185
Inactive	(9.5%)	13,633 /	143,647
Sleep Duration Category			
Rec.	(5.9%)	10,540 /	180,084
Short	(6.0%)	4,945 /	82,940
Long	(20.9%)	3,211 /	15,381

Table S4- Unadjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=278,405) in NHIS survey (2004-2014).

	Sleep Duration Categories									HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long		
	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]
Physical Activity‡															
Active	1.00			1.00	[0.83,	1.22]	3.44	[2.55,	4.64]	1.00	[0.83,	1.21]	3.43	[2.54,	4.63]
AER	1.75	[1.55,	1.97]	1.82	[1.57,	2.10]	5.49	[4.51,	6.68]	1.04	[0.92,	1.18]	3.16	[2.64,	3.79]
MSA	2.59	[2.15,	3.13]	2.89	[2.22,	3.75]	9.24	[6.70,	12.74]	1.11	[0.83,	1.48]	3.54	[2.54,	4.94]
Inactive	3.26	[2.91,	3.64]	3.35	[2.96,	3.79]	11.51	[10.14,	13.06]	1.03	[0.96,	1.10]	3.52	[3.26,	3.81]
HR for Physical Activity within Sleep Duration strata†															
AER	1.75	[1.55,	1.97]	1.81	[1.49,	2.20]	1.59	[1.13,	2.24]						
MSA	2.59	[2.14,	3.13]	2.87	[2.16,	3.83]	2.66	[1.74,	4.05]						
Inactive	3.25	[2.91,	3.63]	3.34	[2.80,	3.98]	3.34	[2.50,	4.48]						
Additive Interactions RERI [95%CI]															
AER				0.06	[-0.23,	0.36]	1.30	[-0.12,	2.72]						
MSA				0.29	[-0.53,	1.11]	4.21	[1.15,	7.26]						
Inactive				0.09	[-0.19,	0.37]	5.81	[4.42,	7.19]						

Notes. Estimates based on Model 1. † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 1.04 [95%CI 0.82, 1.30], p = 0.766. Multiplicative interactions for MSA & Short are: 1.11 [95%CI 0.79, 1.56], p = 0.550. Multiplicative interactions for Inactive & Short are: 1.03 [95%CI 0.84, 1.25], p = 0.803. Multiplicative interactions for AER & Long are: 0.91 [95%CI 0.63, 1.31], p = 0.621. Multiplicative interactions for MSA & Long are: 1.04 [95%CI 0.65, 1.66], p = 0.885. Multiplicative interactions for Inactive & Long are: 1.03 [95%CI 0.75, 1.40], p = 0.867.

Additive interactions for AER & Short are: AP [95%CI]: 0.04 [95%CI -0.12, 0.19]; SI [95%CI]: 1.09 [95%CI 0.67, 1.50]. Additive interactions for MSA & Short are: AP: 0.10 [-0.16, 0.36]; SI: 1.18 [0.64, 1.73]. Additive interactions for Inactive & Short are: AP: 0.03 [-0.06, 0.11]; SI: 1.04 [95%CI 0.91, 1.17]. Additive interactions for AER & Long are: AP: 0.24 [0.01, 0.47]; SI: 1.41 [0.86, 1.95]. Additive interactions for MSA & Long are: AP: 0.46 [0.25, 0.66]; SI: 2.04 [1.14, 2.94]. Additive interactions for Inactive & Long are: AP: 0.50 [0.41, 0.60]; SI: 2.24 [1.73, 2.74].

Table S5- Minimally adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=278,405) in NHIS survey (2004-2014).

	Sleep Duration Categories									HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long		
	HR	[95% CI]		HR	[95% CI]		HR	[95% CI]		HR	[95% CI]		HR	[95% CI]	
Physical Activity‡															
Active	1.00			1.12	[0.95, 1.31]		1.88	[1.49, 2.37]		1.12	[0.95, 1.31]		1.86	[1.46, 2.37]	
AER	1.43	[1.30, 1.58]		1.61	[1.44, 1.81]		2.53	[2.20, 2.90]		1.13	[1.02, 1.25]		1.79	[1.58, 2.04]	
MSA	2.12	[1.84, 2.45]		2.13	[1.74, 2.62]		4.40	[3.49, 5.56]		1.00	[0.80, 1.25]		2.11	[1.65, 2.69]	
Inactive	2.56	[2.34, 2.80]		2.72	[2.47, 3.00]		4.80	[4.34, 5.30]		1.06	[1.01, 1.12]		1.86	[1.76, 1.97]	
HR for Physical Activity within Sleep Duration strata†															
AER	1.42	[1.28, 1.57]		1.46	[1.24, 1.70]		1.35	[1.05, 1.75]							
MSA	2.10	[1.82, 2.43]		1.93	[1.54, 2.43]		2.31	[1.71, 3.13]							
Inactive	2.53	[2.31, 2.77]		2.47	[2.14, 2.85]		2.51	[2.01, 3.13]							
Additive Interactions RERI [95%CI]															
AER				0.07	[-0.16, 0.29]		0.22	[-0.32, 0.76]							
MSA				-0.11	[-0.62, 0.40]		1.40	[0.36, 2.44]							
Inactive				0.05	[-0.17, 0.27]		1.36	[0.88, 1.84]							

Notes. Model 2 adjusted for age and sex. † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 1.01 [95%CI 0.84, 1.22], p = 0.919. Multiplicative interactions for MSA & Short are: 0.90 [95%CI 0.68, 1.18], p = 0.446. Multiplicative interactions for Inactive & Short are: 0.95 [95%CI 0.81, 1.13], p = 0.581. Multiplicative interactions for AER & Long are: 0.94 [95%CI 0.71, 1.24], p = 0.657. Multiplicative interactions for MSA & Long are: 1.10 [95%CI 0.79, 1.54], p = 0.564. Multiplicative interactions for Inactive & Long are: 1.00 [95%CI 0.79, 1.26], p = 0.990.

Additive interactions for AER & Short are: AP [95%CI]: 0.04 [95%CI -0.10, 0.18]; SI [95%CI]: 1.12 [95%CI 0.66, 1.58]. Additive interactions for MSA & Short are: AP: -0.05 [-0.30, 0.19]; SI: 0.91 [0.52, 1.31]. Additive interactions for Inactive & Short are: AP: 0.02 [-0.06, 0.10]; SI: 1.03 [95%CI 0.90, 1.17]. Additive interactions for AER & Long are: AP: 0.09 [-0.12, 0.29]; SI: 1.16 [0.70, 1.63]. Additive interactions for MSA & Long are: AP: 0.32 [0.14, 0.50]; SI: 1.70 [1.08, 2.32]. Additive interactions for Inactive & Long are: AP: 0.28 [0.19, 0.38]; SI: 1.56 [1.27, 1.85].

Table S6. Number of events by physical activity and sleep duration category among (n=239,862) adults in NHIS survey (2004-2014) sensitivity analysis.

	% Events	No. Events	Total
Total	(4.6%)	11,118 /	239,862
Activity & Sleep Duration Category			
Active & Rec.	(1.6%)	498 /	32,110
AER & Rec.	(2.9%)	1,280 /	43,737
MSA & Rec.	(5.0%)	270 /	5,447
Inactive & Rec.	(5.9%)	4,514 /	76,630
Active & Short	(1.5%)	208 /	13,579
AER & Short	(2.9%)	545 /	18,676
MSA & Short	(5.0%)	129 /	2,595
Inactive & Short	(5.8%)	2,093 /	36,321
Active & Long	(5.8%)	60 /	1,040
AER & Long	(8.4%)	190 /	2,255
MSA & Long	(16.3%)	68 /	416
Inactive & Long	(17.9%)	1,263 /	7,056
Physical Activity Category			
Active	(1.6%)	766 /	46,729
AER	(3.1%)	2,015 /	64,668
MSA	(5.5%)	467 /	8,458
Inactive	(6.6%)	7,870 /	120,007
Sleep Duration Category			
Rec.	(4.2%)	6,562 /	157,924
Short	(4.2%)	2,975 /	71,171
Long	(14.7%)	1,581 /	10,767

Table S7 - Sensitivity analyses unadjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

	Sleep Duration Categories									HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long		
	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]
Physical Activity‡															
Active	1.00			1.00	[0.83,	1.22]	3.44	[2.55,	4.64]	1.00	[0.83,	1.21]	3.43	[2.54,	4.63]
AER	1.75	[1.55,	1.97]	1.82	[1.57,	2.10]	5.49	[4.51,	6.68]	1.04	[0.92,	1.18]	3.16	[2.64,	3.79]
MSA	2.59	[2.15,	3.13]	2.89	[2.22,	3.75]	9.24	[6.70,	12.74]	1.11	[0.83,	1.48]	3.54	[2.54,	4.94]
Inactive	3.26	[2.91,	3.64]	3.35	[2.96,	3.79]	11.51	[10.14,	13.06]	1.03	[0.96,	1.10]	3.52	[3.26,	3.81]
HR for Physical Activity within Sleep Duration strata†															
AER	1.75	[1.55,	1.97]	1.81	[1.49,	2.20]	1.59	[1.13,	2.24]						
MSA	2.59	[2.14,	3.13]	2.87	[2.16,	3.83]	2.66	[1.74,	4.05]						
Inactive	3.25	[2.91,	3.63]	3.34	[2.80,	3.98]	3.34	[2.50,	4.48]						
Additive Interactions RERI [95%CI]															
AER				0.06	[-0.23,	0.36]	1.30	[-0.12,	2.72]						
MSA				0.29	[-0.53,	1.11]	4.21	[1.15,	7.26]						
Inactive				0.09	[-0.19,	0.37]	5.81	[4.42,	7.19]						

Notes. Sensitivity analyses omit participants with pre-existing conditions of coronary heart disease, stroke or cancer. † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 1.04 [95%CI 0.82, 1.30], p = 0.766. Multiplicative interactions for MSA & Short are: 1.11 [95%CI 0.79, 1.56], p = 0.550. Multiplicative interactions for Inactive & Short are: 1.03 [95%CI 0.84, 1.25], p = 0.803. Multiplicative interactions for AER & Long are: 0.91 [95%CI 0.63, 1.31], p = 0.621. Multiplicative interactions for MSA & Long are: 1.04 [95%CI 0.65, 1.66], p = 0.885. Multiplicative interactions for Inactive & Long are: 1.03 [95%CI 0.75, 1.40], p = 0.867.

Additive interactions for AER & Short are: AP [95%CI]: 0.04 [95%CI -0.12, 0.19]; SI [95%CI]: 1.09 [95%CI 0.67, 1.50]. Additive interactions for MSA & Short are: AP: 0.10 [-0.16, 0.36]; SI: 1.18 [0.64, 1.73]. Additive interactions for Inactive & Short are: AP: 0.03 [-0.06, 0.11]; SI: 1.04 [95%CI 0.91, 1.17]. Additive interactions for AER & Long are: AP: 0.24 [0.01, 0.47]; SI: 1.41 [0.86, 1.95]. Additive interactions for MSA & Long are: AP: 0.46 [0.25, 0.66]; SI: 2.04 [1.14, 2.94]. Additive interactions for Meets & Long are: AP: 0.50 [0.41, 0.60]; SI: 2.24 [1.73, 2.74].

Table S8- Sensitivity analyses minimally adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

Sleep Duration Categories															HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long							
	HR	[95% CI]		HR	[95% CI]		HR	[95% CI]		HR	[95% CI]		HR	[95% CI]						
Physical Activity‡																				
Active	1.00			1.09	[0.90, 1.32]		1.66	[1.24, 2.22]		1.08	[0.89, 1.31]		1.64	[1.21, 2.22]						
AER	1.37	[1.22, 1.55]		1.56	[1.35, 1.80]		2.27	[1.86, 2.76]		1.13	[1.00, 1.28]		1.71	[1.42, 2.05]						
MSA	1.85	[1.54, 2.23]		2.23	[1.72, 2.89]		3.85	[2.84, 5.21]		1.20	[0.90, 1.58]		2.09	[1.49, 2.93]						
Inactive	2.34	[2.10, 2.62]		2.46	[2.18, 2.78]		4.33	[3.82, 4.91]		1.05	[0.98, 1.12]		1.83	[1.69, 1.98]						
HR for Physical Activity within Sleep Duration strata†																				
AER	1.36	[1.21, 1.54]		1.44	[1.18, 1.76]		1.36	[0.97, 1.91]												
MSA	1.84	[1.53, 2.22]		2.06	[1.54, 2.75]		2.21	[1.47, 3.34]												
Inactive	2.32	[2.08, 2.59]		2.29	[1.92, 2.73]		2.55	[1.91, 3.40]												
Additive Interactions RERI [95%CI]																				
AER				0.10	[-0.18, 0.37]		0.24	[-0.40, 0.88]												
MSA				0.28	[-0.35, 0.91]		1.33	[0.05, 2.61]												
Inactive				0.03	[-0.22, 0.28]		1.33	[0.77, 1.89]												

Notes. Sensitivity analyses omit participants with pre-existing conditions of coronary heart disease, stroke or cancer. Model 2 adjusted for age and sex. † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 1.04 [95%CI 0.83, 1.31], p = 0.719. Multiplicative interactions for MSA & Short are: 1.10 [95%CI 0.78, 1.55], p = 0.577. Multiplicative interactions for Inactive & Short are: 0.96 [95%CI 0.79, 1.18], p = 0.726. Multiplicative interactions for AER & Long are: 1.00 [95%CI 0.70, 1.42], p = 0.983. Multiplicative interactions for MSA & Long are: 1.25 [95%CI 0.78, 1.99], p = 0.346. Multiplicative interactions for Inactive & Long are: 1.11 [95%CI 0.82, 1.51], p = 0.481.

Additive interactions for AER & Short are: AP [95%CI]: 0.06 [95%CI -0.11, 0.24]; SI [95%CI]: 1.21 [95%CI 0.50, 1.92]. Additive interactions for MSA & Short are: AP: 0.13 [-0.13, 0.39]; SI: 1.30 [0.56, 2.04]. Additive interactions for Inactive & Short are: AP: 0.01 [-0.09, 0.12]; SI: 1.02 [95%CI 0.84, 1.20]. Additive interactions for AER & Long are: AP: 0.10 [-0.17, 0.38]; SI: 1.23 [0.52, 1.94]. Additive interactions for MSA & Long are: AP: 0.35 [0.10, 0.60]; SI: 1.88 [0.81, 2.95]. Additive interactions for Inactive & Long are: AP: 0.31 [0.19, 0.43]; SI: 1.66 [1.24, 2.09].

Table S9 - Sensitivity analyses adjusted joint and stratified associations between physical activity and sleep duration with mortality among adults (n=239,862) in NHIS survey (2004-2014).

	Sleep Duration Categories									HR for Sleep Duration within Physical Activity strata #					
	Rec.			Short			Long			Short			Long		
	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]	HR	[95%	CI]
Physical Activity‡															
Active	1.00			1.06	[0.87,	1.28]	1.34	[1.00,	1.78]	0.99	[0.82,	1.20]	1.35	[1.00,	1.83]
AER	1.20	[1.06,	1.36]	1.32	[1.14,	1.53]	1.59	[1.30,	1.93]	1.08	[0.96,	1.23]	1.35	[1.13,	1.62]
MSA	1.54	[1.28,	1.86]	1.67	[1.29,	2.17]	2.49	[1.85,	3.36]	1.12	[0.85,	1.47]	1.60	[1.15,	2.23]
Inactive	1.77	[1.58,	1.99]	1.64	[1.44,	1.86]	2.58	[2.27,	2.94]	0.93	[0.87,	0.99]	1.44	[1.33,	1.55]
HR for Physical Activity within Sleep Duration strata†															
AER	1.18	[1.05,	1.34]	1.25	[1.03,	1.53]	1.29	[0.92,	1.80]						
MSA	1.52	[1.26,	1.83]	1.59	[1.19,	2.11]	1.95	[1.31,	2.90]						
Inactive	1.73	[1.53,	1.94]	1.56	[1.30,	1.87]	2.12	[1.59,	2.83]						
Additive Interactions RERI [95%CI]															
AER				0.06	[-0.19,	0.32]	0.05	[-0.43,	0.53]						
MSA				0.07	[-0.43,	0.57]	0.61	[-0.25,	1.47]						
Inactive				-0.19	[-0.43,	0.04]	0.47	[0.05,	0.89]						

Notes. Sensitivity analyses omit participants with pre-existing conditions of coronary heart disease, stroke or cancer. Model 3 adjusted for Model 2 confounders and also education, ethnicity, work status, BMI category, alcohol consumption, smoking status, self-rated health and chronic disease presence (Asthma, Diabetes, Heart Attack, Hypertension, Emphysema). † - Reference category for Physical Activity within Sleep Categories strata is Active. ‡ - Reference category for joint categories of physical activity and sleep is Active & Rec.. # - Reference category for Sleep Duration Categories within Physical Activity Categories strata is Rec..

Multiplicative interactions for AER & Short are: HR [95%CI], p-value: 1.04 [95%CI 0.83, 1.31], p = 0.741. Multiplicative interactions for MSA & Short are: 1.02 [95%CI 0.73, 1.43], p = 0.894. Multiplicative interactions for Inactive & Short are: 0.87 [95%CI 0.71, 1.07], p = 0.185. Multiplicative interactions for AER & Long are: 0.99 [95%CI 0.70, 1.40], p = 0.945. Multiplicative interactions for MSA & Long are: 1.21 [95%CI 0.77, 1.90], p = 0.416. Multiplicative interactions for Inactive & Long are: 1.09 [95%CI 0.81, 1.47], p = 0.574.

Additive interactions for AER & Short are: AP [95%CI]: 0.05 [95%CI -0.14, 0.24]; SI [95%CI]: 1.24. Additive interactions for MSA & Short are: AP: 0.04 [-0.25, 0.33]; SI: 1.12 [0.25, 1.98]. Additive interactions for Inactive & Short are: AP: -0.12 [-0.26, 0.02]; SI: 0.77 [95%CI 0.56, 0.98]. Additive interactions for AER & Long are: AP: 0.03 [-0.27, 0.33]; SI: 1.09 [0.13, 2.05]. Additive interactions for MSA & Long are: AP: 0.24 [-0.05, 0.53]; SI: 1.69 [0.45, 2.93]. Additive interactions for Inactive & Long are: AP: 0.18 [0.02, 0.34]; SI: 1.43 [0.90, 1.95].