

## Trends in the association between meeting the physical activity guidelines and risk of mortality in US adults

David Martinez-Gomez<sup>a,b,\*</sup>, Fernando Rodriguez-Artalejo<sup>a,b</sup>, Ding Ding<sup>c,d</sup>, Ulf Ekelund<sup>e,f</sup>,  
Veronica Cabanas-Sanchez<sup>a,b</sup>

<sup>a</sup> Department of Preventive Medicine and Public Health, School of Medicine, Universidad Autónoma de Madrid, IdiPaz, and CIBERESP (CIBER of Epidemiology and Public Health), Madrid, Spain

<sup>b</sup> IMDEA-Food Institute, CEI UAM+CSIC, Madrid, Spain

<sup>c</sup> Prevention Research Collaboration, Sydney School of Public Health, The University of Sydney, Sydney, New South Wales, Australia

<sup>d</sup> Charles Perkins Centre, The University of Sydney, Sydney, New South Wales, Australia

<sup>e</sup> Department of Sports Medicine, Norwegian School of Sports Sciences, Oslo, Norway

<sup>f</sup> Department of Chronic Diseases, Norwegian Institute of Public Health, Oslo, Norway

### ARTICLE INFO

#### Keywords:

Physical activity  
Exercise  
Cohort  
Prospective  
Mortality

### ABSTRACT

**Objective:** To examine the trends in the association between meeting the physical activity (PA) guidelines and mortality in adults.

**Methods:** We included seventeen annual representative samples of US adults 1998–2014 ( $n = 482,756$ ) and all-cause and cause-specific mortality ascertained through December 2019. Participants were grouped according to PA Guidelines: 150 or more min/week in aerobic PA and muscle-strengthening activities 2 or more times/week. To provide further context, we also examined the trends in mortality risk associated with other modifiable health factors.

**Results:** Meeting the PA guidelines was associated with lower 5-year mortality risk ( $HR = 0.59$ , 95%CI, 0.55, 0.63) based on the pooled analyses. We consistently observed an inverse association in all years, but there was a nonsignificant trend association ( $P$  for trend = 0.305) between meeting PA guidelines and 5-year mortality across the seventeen annual surveys. Meeting aerobic ( $HR = 0.58$ , 95%CI, 0.56, 0.61) and muscle-strengthening ( $HR = 0.86$ , 95%CI, 0.81, 0.90) guidelines were independently associated with 5-year mortality risk in pooled analyses, without any evidence for trends in the associations. Similar results were found with cause-specific mortality and 10-year mortality risk. In pooled analyses, attaining a high educational level, body mass index  $<30$  kg/m<sup>2</sup>, being noncurrent smoker, nonheavy drinker, and living without history of hypertension and diabetes with 5-year mortality were 0.70 (95%CI, 0.67, 0.73), 1.19 (95%CI, 1.15, 1.23), 0.56 (95%CI, 0.54, 0.59), 0.85 (95%CI, 0.79, 0.92), 0.91 (95%CI, 0.88–0.94) and 0.65 (95%CI, 0.88, 0.94), respectively. Only no history of diabetes showed a significant trend analysis ( $B = 0.77$ , 95%CI, 0.46, 0.91,  $P$  for trend  $<0.001$ ).

**Conclusion:** Meeting PA guidelines lower mortality risk and this association does not seem to have varied over time. Encouraging adults to meet the PA guidelines may provide substantial health benefits, despite social, demographic and lifestyle changes, as well as the advances in medical technology and pharmacological treatments.

### Introduction

Compelling evidence suggests that regular physical activity (PA) prevents premature mortality.<sup>1,2</sup> To obtain this and others health

benefits, the 2018 US PA guidelines<sup>3</sup> suggest that adults do at least 150 min a week of moderate-intensity, 75 min a week of vigorous-intensity, or an equivalent combination of moderate- and vigorous-intensity aerobic PA. Muscle-strengthening activities on 2 or more days a week are

**Abbreviations:** CDC, Centers for Disease Control and Prevention; CI, confidence interval; HR, hazard ratios; ICD, International Classification of Diseases; MET, metabolic equivalent of task; NCHS, National Center for Health Statistics; NHIS, National Health Interview Survey; PA, physical activity; US, United States.

\* Corresponding author at: Department of Preventive Medicine and Public Health, School of Medicine, Universidad Autonoma de Madrid, 28029 Madrid, Spain.

E-mail address: [d.martinez@uam.es](mailto:d.martinez@uam.es) (D. Martinez-Gomez).

<https://doi.org/10.1016/j.pcad.2024.02.011>

Available online 27 February 2024

0033-0620/© 2024 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC license (<http://creativecommons.org/licenses/by-nc/4.0/>).

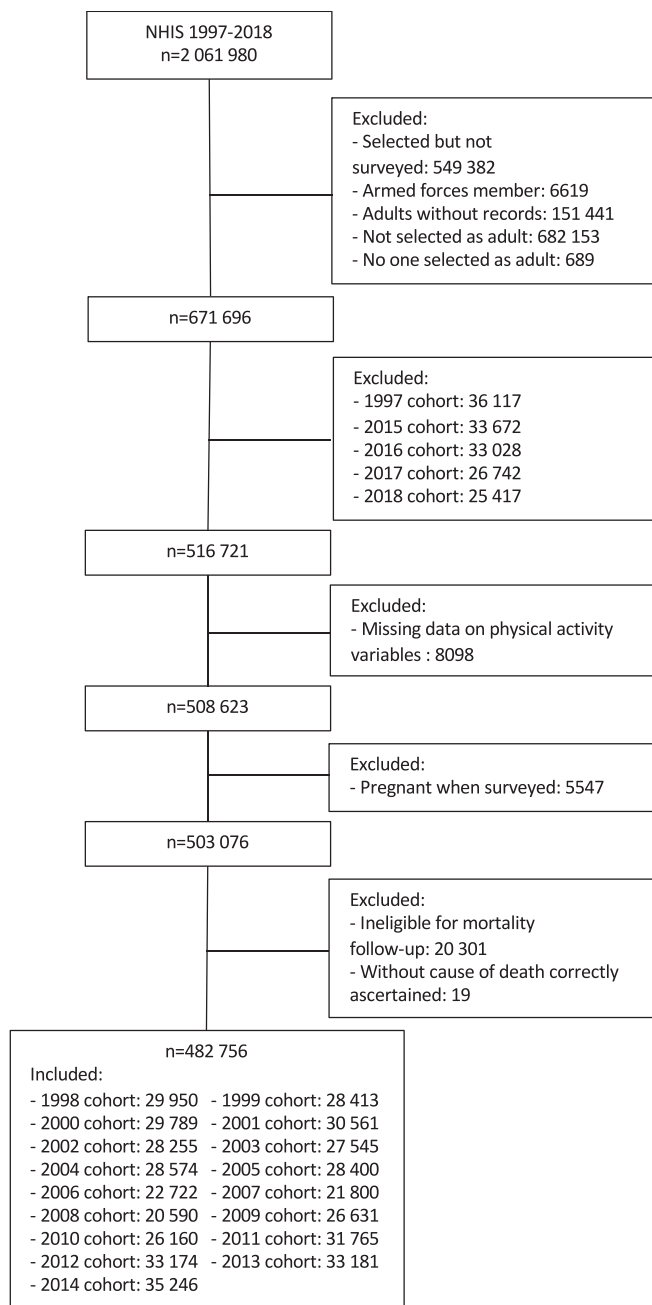


Fig. 1. Participants flow diagram.

also recommended. Recent surveillance data suggest a positive trend in the prevalence of adults meeting the PA guidelines in the US.<sup>4,5</sup> From 1998 to 2018, the prevalence of meeting the aerobic guidelines increased from 40% to 54%,<sup>4</sup> meeting the muscle-strengthening guidelines increased from 18% to 28%,<sup>5</sup> and meeting the combined aerobic and muscle-strengthening guidelines increased from 14% to 24%.<sup>5</sup>

Besides changes in PA patterns, the US population has also undergone other changes in lifestyle risk factors. For example, the prevalence of adult cigarette smoking has steadily declined,<sup>6</sup> whereas alcohol consumption, specially binge drinking behavior, has increased.<sup>7,8</sup> The prevalence of adult obesity has increased<sup>9</sup> simultaneously with an improvement in diet quality.<sup>10</sup> These changes in lifestyle risk factors coincide with demographic changes including increasingly diverse ethnic composition.<sup>11</sup>

While the US population is characterized by rapid aging,<sup>12</sup> mortality rates have declined by 17% and life expectancy increased by two years

from 1998 to 2018<sup>13</sup>; the corresponding decreases in cardiovascular and cancer mortality were 40% and 26%, respectively. This seemingly paradox may partly be explained by major medical advances in the last decades in disease prevention, detection, and treatment of major chronic conditions (e.g., cardiovascular disease and cancer), and the management of modifiable health factors (e.g., quit tobacco, losing weight, high blood sugar and blood pressure control).

It is unclear how the changes of the last decades have influenced the relationship between the recommended PA guidelines for the US population and the risk of mortality. Thus, the aim of this study was to examine the trends (i.e., variations over time) in the association between meeting PA guidelines and mortality in annual nationwide US populations from the last two decades. To provide a context for our findings, we also examined the trends in mortality risk associated with other health factors, such as smoking and obesity in these populations.

## Methods

### Study design and participants

Data for this study are from the US National Health Interview Survey (NHIS). The NHIS is a survey annually conducted by the National Center for Health Statistics (NCHS), which is part of the US Centers for Disease Control and Prevention (CDC). The NHIS uses a multi-stage probability sampling designed to collect nationally representative estimates of the US civilian, noninstitutionalized population, and has monitored the health of the nation since 1957. Data are currently collected through in-person household computer-assisted personal interviewing, with telephone follow-up when the interview cannot be completed in person. Further details on this survey are available on the NHIS website (<https://www.cdc.gov/nchs/nhis/>). All participants provided informed consent before participation, and NHIS procedures were approved by the NCHS Research Ethics Review Board. No additional institutional approval was required to conduct secondary analyses using NHIS public-use data.

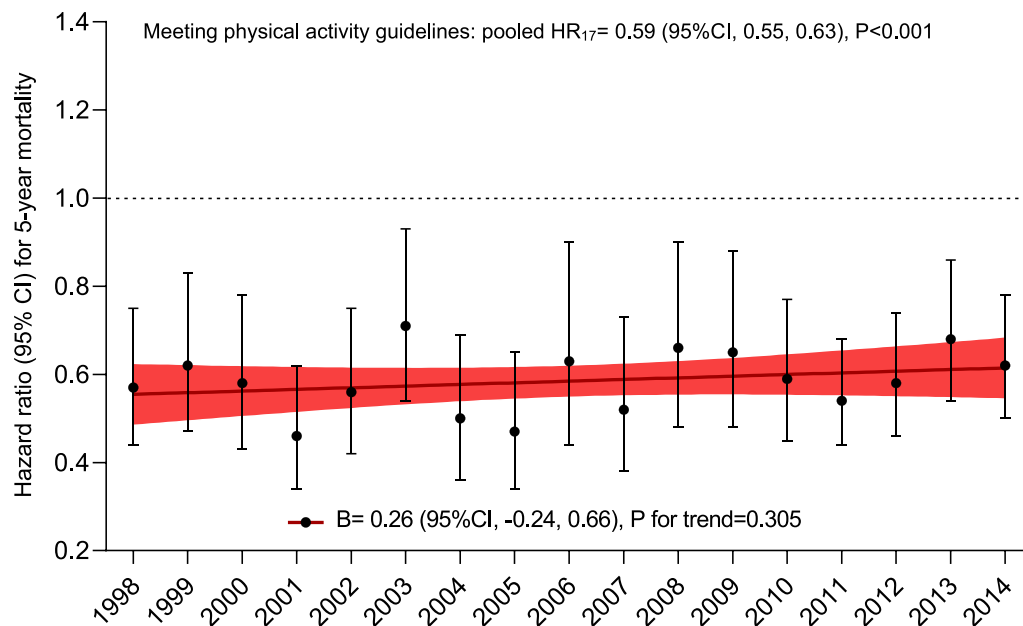
For this work we selected NHIS surveys from 1998 to 2014 (Fig. 1). Since the NHIS protocols underwent major revisions in 1997 and 2019, we did not include surveys from before 1997 or after 2018. The 1997 cohort was excluded because the PA questionnaire was not administered in the same format throughout the year. The cohorts from 2015 to 2018 were also excluded because the last available date ascertained for vital status (December 31, 2019) did not allow a minimum of 5 years follow-up for these participants. In each cohort, we also excluded participants lacking data on PA variables, pregnant women at interview time, and those without information on vital status. Finally, a total of 482,756 participants from 17 annual surveys, aged 18 years or older, met the enrollment criteria and were included in this study.

### Exposures

Participants were asked how often and, if applicable, the duration of aerobic activities during leisure-time in i) vigorous (i.e., heavy sweating or large increases in breathing or heart rate) and ii) light-to-moderate (i.e., light sweating or slight to moderate increases in breathing or heart rate) levels.<sup>4,5</sup> The total amount of aerobic PA was calculated by summing the minutes of vigorous-intensity (equivalent to around 6 metabolic equivalents) PA weighted by a factor of 2 and light-to-moderate-intensity PA (equivalent to around 3 metabolic equivalents). Muscle strengthening activity was assessed with the following question<sup>5</sup>: “How often do you do physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?”. The PA guidelines for adults recommend at least 150 min per week in aerobic PA and participating in muscle-strengthening activities 2 or more times per week, and hence, participants were categorized as meeting the PA guidelines if they reported meeting both recommendations.<sup>3</sup>

**Table 1**  
Baseline characteristics of the analytical sample from the National Health Interview Surveys 1998–2014 surveys.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
<i>n</i>	29,950	28,413	29,789	30,561	28,255	27,545	28,574	28,400	22,722	21,800	20,590	26,631	26,160	31,765	33,174	33,181	35,246
<b>Sex, %</b>																	
Female	51.4	51.5	51.5	51.5	51.2	51.4	51.4	51.3	51.3	51.2	51.2	51.2	51.2	51.0	51.3	51.4	51.3
<b>Age, %</b>																	
18–39 years	43.1	42.5	42.1	41.5	40.8	40.5	40.1	39.7	39.3	39.3	39.0	38.6	38.7	38.3	37.9	37.7	37.5
40–59 years	34.9	35.6	36.2	36.9	37.2	37.3	37.2	37.6	38.0	37.1	37.4	37.3	36.5	36.2	36.2	35.9	35.5
60 or more years	22.0	21.9	21.7	21.6	22.0	22.2	22.6	22.7	22.6	23.6	23.5	24.1	24.7	25.4	25.9	26.4	27.0
<b>Race or ethnicity, %</b>																	
Non-Hispanic white	75.5	75.1	74.4	73.9	73.7	72.8	72.7	72.2	70.3	69.7	69.3	69.1	68.7	68.4	67.2	66.8	66.4
Non-Hispanic black	11.0	11.0	11.2	11.2	11.2	11.0	11.1	11.3	11.5	11.6	11.6	11.7	11.8	11.7	11.7	11.8	12.0
Hispanic	9.8	10.1	10.4	10.6	10.8	12.1	12.1	12.2	13.0	13.2	13.5	13.7	14.0	14.1	14.9	15.1	15.3
Other	3.7	3.7	4.0	4.3	4.3	3.9	4.1	4.2	5.1	5.4	5.3	5.2	5.4	5.7	6.0	6.1	6.2
<b>Education, %</b>																	
< High school	48.7	47.9	48.4	46.9	46.4	46.2	45.6	45.8	45.8	44.3	43.0	42.6	41.3	40.9	40.4	39.8	39.2
High school or FED	28.2	28.5	28.2	29.0	28.8	29.2	29.1	28.3	28.7	28.5	29.9	30.4	30.3	31.2	31.1	30.8	30.7
> High school	22.6	22.9	22.9	23.4	24.2	23.9	24.6	25.4	24.7	26.4	26.5	26.6	28.0	27.5	28.2	29.1	29.6
<b>Marital status, %</b>																	
Married or living with a partner	59.8	58.4	58.1	57.9	57.8	57.6	57.2	57.0	56.6	55.8	55.0	54.5	54.2	53.3	53.0	52.8	52.9
Divorced/separated/widowed	18.9	19.4	19.4	19.6	19.2	19.3	19.4	19.5	19.4	19.5	19.7	19.8	19.9	20.3	19.8	20.2	19.9
Never married	21.0	21.9	22.2	22.4	22.8	22.9	22.9	23.3	23.7	24.4	25.1	25.5	25.8	26.3	27.1	26.8	27.0
<b>Chronic conditions, %</b>																	
Heart disease	6.0	5.5	5.8	6.4	6.3	6.1	6.6	6.7	6.5	6.3	6.5	6.6	6.7	6.7	6.6	6.6	6.0
Stroke	2.3	2.2	2.3	2.4	2.4	2.5	2.6	2.5	2.7	2.5	2.9	2.7	2.8	2.7	2.8	2.8	2.7
Cancer	6.3	6.7	6.6	7.0	7.2	6.8	7.2	7.5	7.3	7.5	8.0	8.4	8.5	8.3	8.5	8.6	8.6
Respiratory disease	12.9	12.1	13.1	15.1	14.2	13.1	13.3	14.0	14.4	13.9	15.7	16.3	15.7	15.7	15.4	14.8	15.4
<b>Cardiometaabolic risk factors, %</b>																	
Hypertension	23.3	23.1	23.0	24.1	24.8	25.7	26.0	26.4	27.5	27.8	29.6	29.3	30.5	30.1	30.1	29.9	31.4
Diabetes	5.4	5.5	6.0	6.5	6.8	6.8	7.2	7.7	8.4	8.4	8.8	9.7	9.8	9.6	9.7	10.1	9.9
<b>Body mass index, %</b>																	
<24.9 kg/m <sup>2</sup>	34.4	33.5	33.1	31.7	30.6	30.7	30.8	30.2	29.7	29.0	28.7	27.4	28.2	28.0	27.1	28.2	26.9
25.0–29.9 kg/m <sup>2</sup>	36.1	35.6	35.3	35.6	35.7	35.6	35.2	34.8	33.8	34.3	34.3	34.5	33.9	33.9	34.2	32.9	33.8
≥30.0 kg/m <sup>2</sup>	27.2	28.3	28.7	29.5	30.2	30.5	31.1	32.1	32.9	32.9	34.1	35.2	35.3	35.5	35.6	36.2	36.4
<b>Smoking, %</b>																	
Never	52.2	52.9	53.9	54.4	53.9	55.4	56.7	56.7	57.4	57.8	57.5	57.0	58.7	58.8	59.5	59.8	61.2
Former	23.1	23.1	22.3	22.4	23.0	22.1	21.8	21.8	21.3	21.8	21.6	22.1	21.7	21.9	22.1	22.1	22.0
Current	24.4	23.8	23.5	23.0	22.8	22.2	21.2	21.3	21.0	20.0	20.7	20.8	19.6	19.1	18.2	17.9	16.7
<b>Alcohol consumption, %</b>																	
Abstainer	21.1	21.9	23.5	21.9	21.3	23.8	23.6	23.2	24.4	22.9	20.6	19.4	20.4	19.6	20.6	20.7	20.9
Former drinker	15.8	14.7	14.2	14.7	15.0	14.1	14.3	14.2	14.0	14.7	14.4	14.9	14.3	14.6	14.3	14.0	13.5
Light-moderate drinker	58.4	58.6	57.9	58.2	58.5	57.0	56.6	57.1	55.7	56.4	59.3	60.3	60.4	61.1	60.3	60.1	60.6
Heavy drinker*	3.9	4.1	3.7	4.1	4.2	4.1	3.7	4.0	4.3	4.2	4.6	4.4	4.1	3.9	3.9	4.3	4.2
<b>Meeting physical activity guidelines, %</b>																	
Aerobic guidelines	40.7	41.3	42.5	43.3	43.2	43.9	42.0	41.1	41.2	41.4	43.5	46.7	46.7	48.2	49.5	49.2	49.3
Muscle-strengthening guidelines	18.2	18.4	18.4	20.5	20.7	20.9	19.9	20.3	19.5	19.9	21.9	22.4	23.9	23.9	23.7	23.9	24.2
Both guidelines	14.7	15.2	15.1	16.7	16.8	17.3	16.2	16.5	16.0	16.4	18.1	18.8	20.2	20.4	20.2	20.4	20.9



**Fig. 2.** Associations between meeting physical activity guidelines and 5-year mortality in the National Health Interview Surveys 1998–2014. Pooled analysis included 17 annual surveys (1998–2014) as a unique cohort. Trend analysis was summarized with linear regression estimates (standardized B) that used the hazard ratio and survey year as dependent and independent variables, respectively. Meeting physical activity guidelines include both recommended aerobic and muscle strengthening activities. The color line indicates linear regression and its 95%CI. Hazard ratios were adjusted for sex, age, race, education, marital status, chronic conditions, cardiometabolic risk factors, body mass index, smoking, and alcohol consumption.

#### Mortality outcomes

Leading underlying cause of death was determined by NCHS based on probabilistic matches of survey participants' NHIS records to National Death Index and classified using the 10th revision of the International Statistical Classification of Diseases, Injuries, and Causes of Death (ICD-10).<sup>14</sup> The accuracy of information on cause of death mortality in the National Death Index records has been validated in previous works.<sup>15,16</sup> In the present study and to minimize bias owing to different follow-up durations, we calculated 5-year all-cause mortality for all participants. Deaths due to cardiovascular (I00-I09, I11, I13, I20-I51, I60-I69) and cancer (C00-C97) diseases, the leading causes of death in US, were also included as secondary study outcomes.

#### Other study variables

Additional study variables were also reported during the interview. Sociodemographic factors included sex (male, female), age (years), race and ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, other), marital status (married or living with a partner, divorced, separated, or widowed, never married), and educational attainment (less than high school, high school grade or equivalent, and more than high school). Self-reported medical diagnoses of chronic and cardiometabolic conditions such as heart disease (yes, no), stroke (yes, no), respiratory disease (yes, no) including chronic bronchitis, asthma, or emphysema, hypertension (yes, no), and diabetes (yes, no) were also obtained in the survey. People taking blood pressure-lowering or anti-diabetic medications, including insulin, were also included as having hypertension or diabetes, respectively. Never, former, and current smokers were identified, and alcohol consumers were classified as never, former, light-moderate, and heavy if they drank  $\geq 14$  drinks/week for men and  $\geq 10$  drinks/week for women during the past year. Self-reported weight and height was used to calculate the body mass index ( $\text{kg}/\text{m}^2$ ). Since self-reported body mass index values are subject to measurement error (e.g., tendency to over-report height and under-report weight), we initially adjusted these values with the Stommel & Schoenborn's equation<sup>17,18</sup> derived from measured and self-reported

weight and height data taken from the National Health and Nutrition Examination Survey 2001–2006, and after this adjustment, participants were classified as non-overweight/obesity ( $<25.0 \text{ kg}/\text{m}^2$ ), overweight ( $25.0\text{--}29.9 \text{ kg}/\text{m}^2$ ), and obesity ( $\geq 30.0 \text{ kg}/\text{m}^2$ ). Missing data in each of these variables (due to participants not being sure, not knowing the answer, or refusing to respond), always lower than 5%, were handled using a missing indicator approach.

#### Statistical analysis

Baseline characteristics of the study sample by NHIS cohort are presented as frequency (%). Cox regression was used to estimate hazard ratios (HR) and 95% confidence interval (CI) for the pooled association (i.e., all cohorts as a unique cohort) between meeting PA guidelines (no vs. yes) and 5-year mortality across the seventeen cohorts from 1998 to 2014. To examine the trends in the associations, we initially calculated the HR and 95%CI for the association between meeting the PA guidelines and 5-year mortality separately for each cohort and thereafter summarized the time trend analysis with standardized B and P for trend values obtained from linear regressions, that used the HR and survey year as dependent and independent variables, respectively. All Cox regression models were adjusted for sex, age, ethnicity and race, educational attainment, marital status, smoking, alcohol consumption, body mass index, heart disease, stroke, cancer, respiratory disease, hypertension, and diabetes. These main analyses were also stratified by nonmodifiable characteristics that have changed in the US society, including sex, age, ethnicity and race, and chronic conditions (healthy people without chronic conditions and people with one or more chronic conditions; cardiovascular disease, cancer, and respiratory disease were also specifically considered for stratification).

Additional analyses examined i) the dose-response association between four combined categories of meeting PA guidelines (i.e., insufficient aerobic and muscle strengthening activities, insufficient aerobic activity and recommended muscle strengthening activity, recommended aerobic activity and insufficient muscle strengthening activity, recommended both aerobic and muscle strengthening activities) and 5-year mortality, ii) the mutually adjusted associations of meeting the

**Table 2**

Associations between meeting physical activity guidelines and 5-year mortality stratified by non-modifiable characteristics.

		Pooled analysis*		Trend analysis**	
	n/deaths	Hazard ratio (95%CI)	P	B (95% CI)	P for trend
Sex					
Men	214,526/ 13,122	0.61 (0.56, 0.67)	<0.001	0.30 (−0.20, 0.68)	0.227
Women	254,193/ 14,037	0.54 (0.49, 0.60)	<0.001	0.02 (−0.45, 0.50)	0.910
Age					
18–59 years	351,166/ 5506	0.67 (0.59, 0.76)	<0.001	0.12 (−0.37, 0.57)	0.625
≥ 60 years	131,590/ 21653	0.55 (0.51, 0.60)	<0.001	0.36 (−0.14, 0.71)	0.151
Race or ethnicity					
Non-Hispanic white	305,201/ 19,886	0.57 (0.53, 0.62)	<0.001	0.22 (−0.28, 0.63)	0.222
Non-Hispanic black	69,981/ 4178	0.58 (0.48, 0.71)	<0.001	−0.39 (−0.73, 0.10)	0.118
Hispanic	82,308/ 2298	0.74 (0.57, 0.97)	0.030	−0.26 (−0.66, 0.24)	0.306
Chronic conditions					
0 chronic conditions	355,104/ 11,284	0.70 (0.63, 0.77)	<0.001	0.04 (−0.44, 0.51)	0.853
≥1 chronic conditions	127,536/ 15,862	0.50 (0.45, 0.55)	<0.001	0.25 (−0.26, 0.65)	0.332
Cardiovascular disease	42,523/ 9134	0.54 (0.47, 0.62)	<0.001	0.22 (−0.28, 0.63)	0.380
Cancer	38,556/ 6694	0.44 (0.39, 0.50)	<0.001	0.02 (−0.46, 0.50)	0.917
Respiratory disease	70,911/ 5943	0.55 (0.47, 0.65)	<0.001	0.16 (−0.34, 0.59)	0.527

Meeting physical activity guidelines include recommended both aerobic physical activity and muscle-strengthening activities. \* Pooled analysis with 17 annual surveys (1998–2014) as a unique cohort. \*\* Linear regression estimates (standardized B) that used the hazard ratio and survey year as dependent and independent variables, respectively. Hazard ratios were adjusted for sex, age, race, education, marital status, chronic conditions, cardiometabolic risk factors, body mass index, smoking, and alcohol consumption.

aerobic PA and muscle-strengthening recommendations with 5-year mortality, and iii) the dose-response associations of amounts of aerobic PA (i.e., 0 min/week, 1.0–149.9 min/week, 150–300 min/week, and > 300 min/week) and muscle-strengthening activity (0 times/week, 0.1–1.9 times/week, 2.0–3.9 times/week, and ≥ 4 times/week) with 5-year mortality.

To place our trend analysis in context, we conducted a further analysis to investigate the association of modifiable health factors with 5-year mortality in pooled and time trend analysis. Among the health factors we selected: i) attain a high educational level (more than high school), ii) manage weight (body mass index <30 kg/m<sup>2</sup>), iii) noncurrent smoker, iv) nonheavy drinker, v) manage blood pressure (never diagnosed with hypertension neither taking related medication), and vi) manage blood sugar (never diagnosed with diabetes neither taking related medication).

We performed the following sensitivity analyses. First, we examined if the main results varied with cause-specific mortality due to

cardiovascular and cancer diseases. For this cause-specific mortality analysis, we also excluded participants with prevalent cardiovascular disease for the cardiovascular mortality analysis and with prevalent cancer for the cancer mortality analysis. Second, to account with a larger follow-up and consequently a greater number of deaths in each cohort year, we performed main analyses using 10-year mortality restricted to NHIS cohorts from 1998 to 2009.

All analyses accounted for the complex survey design of NHIS by considering sample weights, and primary sampling units and stratum for variance estimation. All analyses were conducted using STATA version 14.2 (Stata Corp, College Station, TX, USA), with level of significance set at two-sided  $p < 0.05$ .

## Results

Baseline characteristics of the analytical sample included in this study are presented by survey year in Table 1. Overall, population in recent surveys are older, with a greater number of Hispanic people, more educated, never been married, never smokers, and with a higher prevalence of cancer, respiratory diseases, hypertension, and obesity. Adults in recent surveys seem to be more physically active since a greater percentage of people meet the PA guidelines for adults.

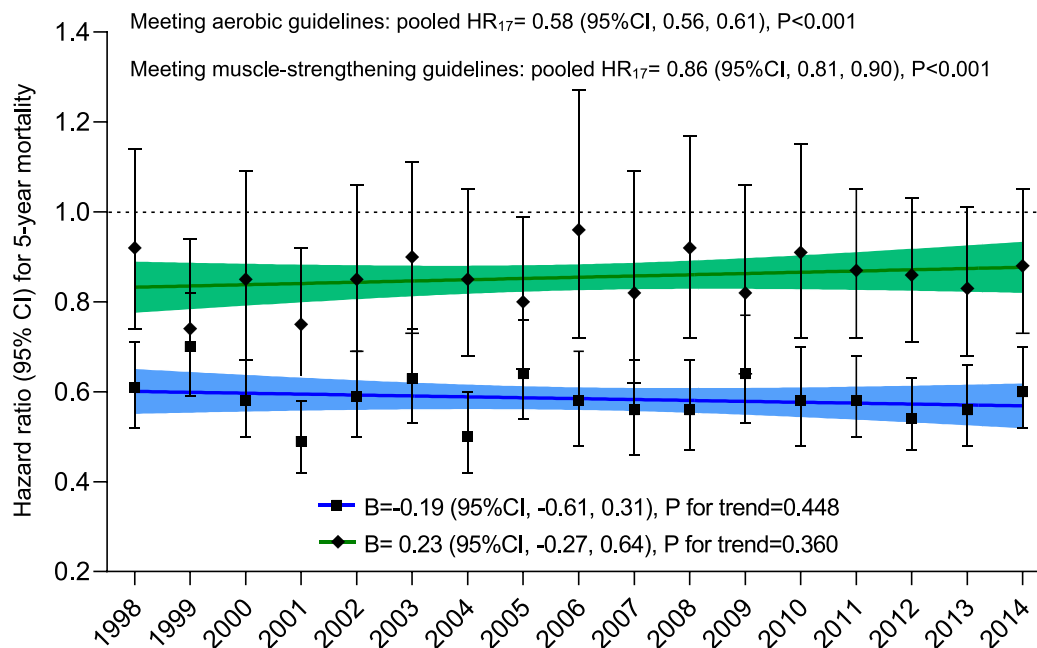
During the 5 years follow-up, a total of 27,159 participants died, ranging from 1766 deaths in 1998 (5.9%) to 2213 in 2014 (6.3%). Meeting the PA guidelines was associated with lower 5-year mortality risk (HR = 0.59, 95%CI, 0.55, 0.63) based on the pooled analyses (Fig. 2). We consistently observed an inverse association in all years, but there was a nonsignificant trend association (B = 0.26, 95%CI, −0.24, 0.66, P for trend = 0.305) between meeting PA guidelines and 5-year mortality across the seventeen annual surveys. Dose-response associations between the four combined groups of PA guidelines and 5-year mortality found similar results in pooled and trends analyses (Fig. S1). Without exceptions, the pooled association between meeting PA guidelines with 5-year mortality were consistent when stratified by sex, age, ethnicity and race, and chronic conditions, without any trend associations (all P for trend >0.1) (Table 2).

Meeting aerobic PA (HR = 0.58, 95%CI, 0.56, 0.61) and muscle-strengthening (HR = 0.86, 95%CI, 0.81, 0.90) guidelines were independently associated with 5-year mortality risk in pooled analyses, without any evidence for trends in the associations (P for trend = 0.448 and 0.360, respectively) (Fig. 3). In mutually adjusted analyses (Fig. S2), compared with the referent (i.e., no aerobic PA), risk reductions were 31%, 44% and 50% for 5-year mortality by increasing amounts of aerobic PA; the corresponding risk reductions for increasing categories of muscle-strengthening activities were 17%, 17% and 3%, independently of aerobic PA. The dose-response associations of amounts of aerobic and muscle-strengthening activities and mortality risk were stable during the study time (all P for trend >0.1).

In pooled analyses, attaining a high educational level, body mass index <30 kg/m<sup>2</sup>, being noncurrent smoker, nonheavy drinker, and living without history of hypertension and diabetes with 5-year mortality were 0.70 (95%CI, 0.67, 0.73), 1.19 (95%CI, 1.15, 1.23), 0.56 (95%CI, 0.54, 0.59), 0.85 (0.79, 0.92), 0.91 (0.88–0.94) and 0.65 (0.88, 0.94), respectively (Fig. 4). Trend analyses of these health factors showed nonsignificant associations (all P for trend >0.4), with the exception of living without diabetes that showed a tendency (P for trend <0.001) that the association between living without diabetes and mortality were attenuated over the study time (B = 0.77, 95%CI, 0.46, 0.91).

We rerun the main analyses with the secondary study outcomes of 5-year cardiovascular mortality (8805 cases) and cancer mortality (6742 cases) (Fig. S3). Meeting the recommended PA guidelines was associated with 5-year cardiovascular (HR = 0.59, 95%CI, 0.50, 0.69) and cancer mortality (pooled HR = 0.76, 95%CI, 0.64, 0.90). There was no indication of trend in the associations for these cause-specific mortality analyses (P for trend = 0.975 and 0.366, respectively).





**Fig. 3.** Associations between meeting aerobic (blue) or muscle-strengthening guidelines (green) and 5-year mortality in the National Health Interview Surveys 1998–2014. Pooled analysis included 17 annual surveys (1998–2014) as a unique cohort. Trend analysis was summarized with linear regression estimates (standardized B) that used the hazard ratio and cohort year as dependent and independent variables, respectively. The color lines indicate linear regressions and its 95%CI. Hazard ratios were adjusted for sex, age, race, education, marital status, chronic conditions, cardiometabolic risk factors, body mass index, smoking, alcohol consumption, and meeting the other guideline. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Restricting our main results to cohorts with at least 10 years of follow-up (surveys from 1998 to 2009,  $n = 323,230$ ), and including a total of 38,816 deaths, did not materially change the results ( $HR = 0.68$ , 95%CI, 0.65, 0.72 for the pooled analysis, and  $B = -0.11$ , 95%CI, -0.64, 0.48,  $P$  for trend = 0.711, for the trend analysis) (Fig. S4).

## Discussion

In the present study, we found that meeting the PA guidelines was associated with lower mortality risk in each of the seventeen annual nationwide cohorts of US adults from 1998 to 2014. The magnitude of the association remained stable over the study time, suggesting that the role of PA has always been important and remains important. These findings imply that all Americans should be physically active despite social, demographic and lifestyle changes in the US society in the last decades, as well as the advances in medical technology and pharmacological treatments.

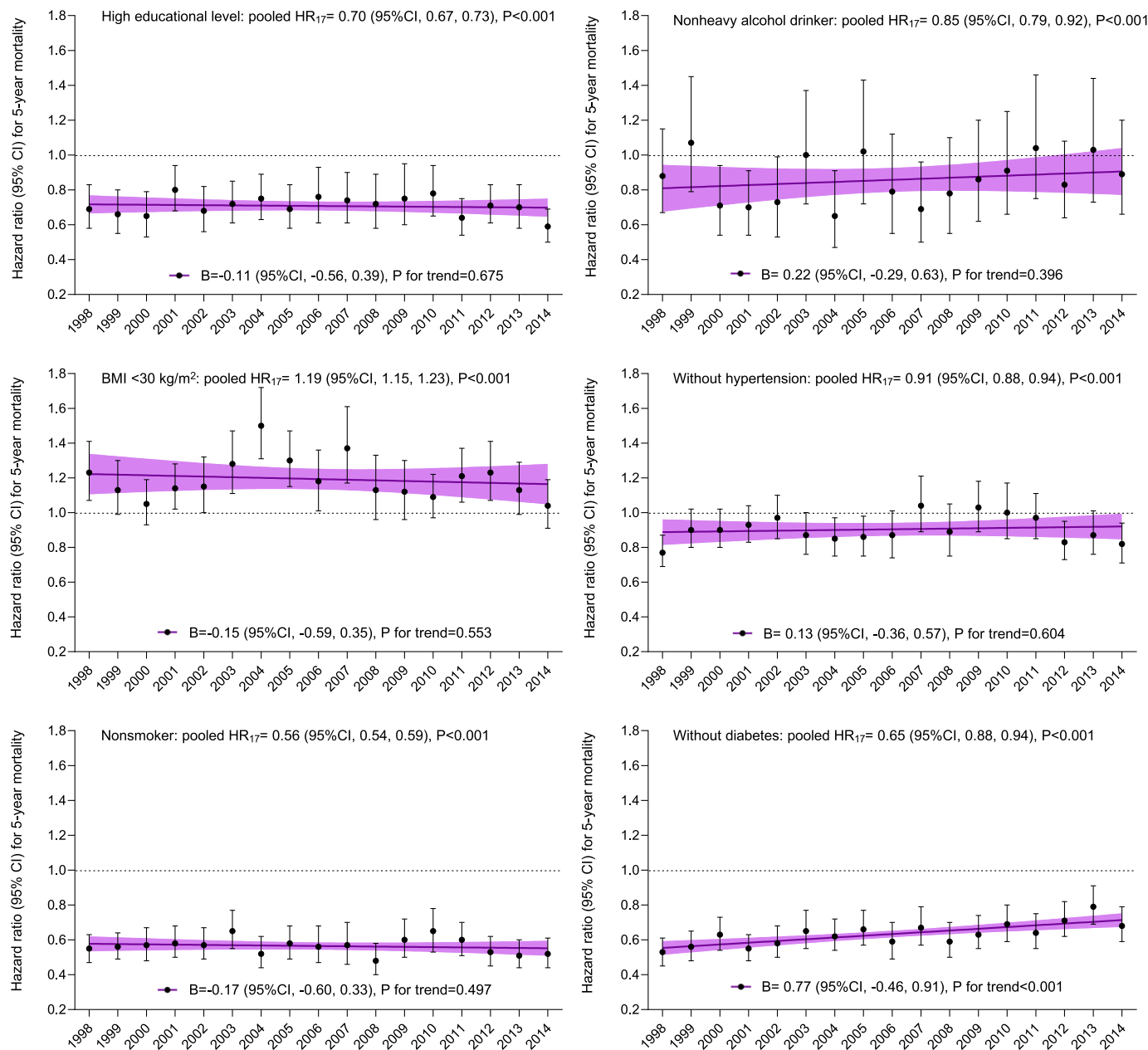
A previous study by O'Donovan et al.,<sup>19</sup> with a different aim that the one examined in the present study, showed the associations between meeting aerobic PA guidelines and all-cause mortality, stratified by survey and survey year as additional analyses. That study included eleven population-based British cohorts, eight from the Health Survey for England (1994, 1997, 1998, 1999, 2003, 2004, 2006, 2008) and three from the Scottish Health Survey (1995, 1998, 2003), including a total of 63,591 participants, aged 40 years or older. In agreement with the present study, in all cohorts, meeting aerobic PA guidelines lower all-cause mortality. Although interesting and allowing us to provide certain data to compare our results, these results from the O'Donovan and colleagues' work must be interpreted with caution because i) only age- and sex-adjusted HRs were included and hence, secular changes in sociodemographic, lifestyle, and health conditions in the British population could be not taken into account since only age- and sex-adjusted estimated were presented, ii) each cohort had different follow-up durations (mean = 8.8, SD = 4.4 years), which hamper direct comparisons across cohorts, and iii) PA data required certain harmonization due to slight differences by survey and changes over survey years.

Farrell et al.<sup>20</sup> examined whether the association between cardiorespiratory fitness, whose primary driver is PA levels, and mortality in an early cohort of men (1971 to 1991,  $n = 24,475$ ) persisted when evaluated in a more contemporary cohort of men (1992 to 2013,  $n = 23,387$ ) with identical follow-up periods. They found a significant inverse trend ( $P < 0.001$ ) between fitness levels and all-cause mortality in both cohorts (per 1-MET increment,  $HR = 0.86$ , 95%CI, 0.82, 0.90 in cohort 1 and  $HR = 0.87$ , 95%CI, 0.83, 0.91 in cohort 2). This study demonstrated that fitness also remains strongly associated with mortality in the current era of enhanced medical care.

In our study, mortality benefits of meeting PA guidelines were stable when main analyses were stratified by sex, but also by age, and race and ethnicity; two sociodemographic conditions that have changed over time in the US nation. Also, we hypothesized that among people with chronic conditions who require medical care,<sup>21</sup> the beneficial effect on survival associated with PA will decrease over time because of improvements in health care and disease management which prolong life; however, we observed stability in all these associations.

As expected, meeting the aerobic PA guidelines reduced the mortality at greater extent than meeting muscle-strengthening activity guidelines, but both types of PA showed analogous benefits over time. The mortality risk reductions of different amounts of aerobic and muscle-strengthening PA were also stable over time; when we could think that lower amounts of PA would lose benefits due to medical advances and higher amounts would be needed to maintain them. Finally, to put our results in context, we examined the trends in the associations of other health metrics with mortality risk, including six modifiable health factors. This further analysis also found stability in the mortality benefits associated to healthier factors over time, with the exception of living with diabetes, that showed an attenuation in the association ( $P$  for trend  $< 0.001$ ). Mortality benefits of living without diabetes as compared to people with diabetes among US people seem to be reducing every year. Improvements in early detection and development and accessibility to new medications could be playing an important role in this result that, albeit positive, warrants further research.

The strengths of the present study include the use of large, annual,



**Fig. 4.** Associations between health factors and health behaviors and 5-year mortality in the National Health Interview Surveys 1998–2014. Pooled analysis included 17 annual surveys (1998–2014) as a unique cohort. Trend analysis was summarized with linear regression estimates (standardized B) that used the hazard ratio and cohort year as dependent and independent variables, respectively. High educational level: more than high school. Heavy drinker:  $\geq 14$  drinks/week for men and  $\geq 10$  drinks/week for women during the past year. The color line indicates lineal regression and its 95%CI. Hazard ratios were adjusted for sex, age, race, marital status, chronic conditions, meeting physical activity guidelines, and the other health factors.

and nationally representative cohorts of the US population. In addition, and importantly, all study variables were measured with the same methods across the surveys. However, some study limitations should be considered. First, information on PA was self-reported and, hence, prone to information bias from recall and social desirability (e.g., tendency to overreporting). To reduce these limitations, more objective methods to assess PA (e.g., accelerometers) may be considered in future studies. Second, we only had a single PA assessment at baseline; repeated measures of the exposure variable, at least, could have minimized measurement error and within-individual variability during the follow-up.<sup>22</sup> These potential reporting and measurement biases would likely have led to an underestimation of the observed effect sizes of PA on

mortality in our work.<sup>22</sup> Third, although the analyses were adjusted for sociodemographic, lifestyle, and health-related conditions, residual confounding is still likely due to unmeasured (e.g., diet and subclinical diseases) and poorly measure confounders (e.g., self-reported weight and height, and alcohol). Fifth, this was an observational study, which limits causal inference. Finally, the other health factors analyzed in our study were also based on self-report. Thus, there may also be prone to the form of biases as PA data. Further research should consider including more accurate measurements (e.g., clinical blood pressure monitoring, fasting glucose or glycosylated hemoglobin in blood samples, measures of body weight with a balance and stature with a stadiometer, accelerometers) and repeated measures for these health factors to confirm our

results.

In conclusion, the association between meeting PA guidelines and mortality risk has not changed in the US adult population over time. Encouraging adults to meet the PA guidelines may provide substantial health benefits for the US population. The findings can be used to reinforce the public health message of the 2018 and future US PA guidelines.

### Funding

DMG is supported by a ‘Ramon y Cajal’ contract (RYC-2016-20546). DD is supported by a National Health and Medical Research Council Investigator Grant (# 2009254).

### CRediT authorship contribution statement

**David Martinez-Gomez:** Supervision. **Fernando Rodriguez-Artalejo:** Supervision. **Ding Ding:** Supervision. **Ulf Ekelund:** Supervision. **Veronica Cabanas-Sanchez:** Supervision.

### Declaration of competing interest

The authors declare that they have no competing interests.

### Data availability

NHIS public use data are available for researchers in the US CDC/NCHS website: <https://www.cdc.gov/nchs/nhis/index.htm>

### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pcad.2024.02.011>.

### References

1. 2018 Physical Activity Guidelines Advisory Committee. *2018 Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, DC: U.S. Department of Health and Human Services; 2018.
2. WHO Guidelines on Physical Activity and Sedentary Behaviour. Geneva: World Health Organization; 2020.
3. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans*. 2nd ed. Washington, DC: U.S. Department of Health and Human Services; 2018.
4. Whitfield GP, Hyde ET, Carlson SA. Participation in leisure-time aerobic physical activity among adults, National Health Interview Survey, 1998–2018. *J Phys Act Health*. 2021 Aug 1;18(S1):S25–S36.
5. Hyde ET, Whitfield GP, Omura JD, Fulton JE, Carlson SA. Trends in meeting the physical activity guidelines: muscle-strengthening alone and combined with aerobic activity, United States, 1998–2018. *J Phys Act Health*. 2021 Aug 1;18(S1):S37–S44.
6. Yang Q, Cogswell ME, Flanders WD, et al. Trends in cardiovascular health metrics and associations with all-cause and CVD mortality among US adults. *JAMA*. 2012 Mar 28;307(12):1273–1283.
7. Dawson DA, Goldstein RB, Saha TD, Grant BF. Changes in alcohol consumption: United States, 2001–2002 to 2012–2013. *Drug Alcohol Depend*. 2015 Mar;1(148):56–61.
8. Breslow RA, Castle IP, Chen CM, Graubard BI. Trends in alcohol consumption among older Americans: National Health Interview Surveys, 1997 to 2014. *Alcohol Clin Exp Res*. 2017 May;41(5):976–986.
9. Sun JY, Huang WJ, Hua Y, et al. Trends in general and abdominal obesity in US adults: evidence from the National Health and nutrition examination survey (2001–2018). *Front Public Health*. 2022 Oct;6(10), 925293.
10. Shan Z, Rehm CD, Rogers G, et al. Trends in dietary carbohydrate, protein, and fat intake and diet quality among US adults, 1999–2016. *JAMA*. 2019 Sep 24;322(12):1178–1187.
11. Yang Q, Cogswell ME, Flanders WD, et al. Trends in cardiovascular health metrics and associations with all-cause and CVD mortality among US adults. *JAMA*. 2012 Mar 28;307(12):1273–1283.
12. United States Census Bureau. Current Population Survey. <https://www.census.gov/programs-surveys/cps/data.html>; 2024.
13. National Center for Health Statistics. Mortality Trends in the United States, 1900–2018. <https://www.cdc.gov/nchs/data-visualization/mortality-trends/index.htm>; 2024.
14. National Center for Health Statistics, Centers for Disease Control and Prevention. The Linkage of National Center for Health Statistics Survey Data to the National Death Index. Linked Mortality File (LMF): Linkage Methodology and Analytic Considerations <https://www.cdc.gov/nchs/data/datalinkage/2019NDI-Linkage-Methods-and-Analytic-Considerations-508.pdf>; 2019.
15. Mirel LB, El Bural Félix S, Zhang C, Golden C, Cox CS. Comparative analysis of the National Health Interview Survey Public-use and restricted-use linked mortality files. *Natl Health Stat Rep*. 2020 Jun;143:1–32.
16. Lochner K, Hummer RA, Bartee S, Wheatcroft G, Cox C. The public-use National Health Interview Survey linked mortality files: methods of reidentification risk avoidance and comparative analysis. *Am J Epidemiol*. 2008 Aug 1;168(3):336–344.
17. Stommel M, Schoenborn CA. Accuracy and usefulness of BMI measures based on self-reported weight and height: findings from the NHANES & NHIS 2001–2006. *BMC Public Health*. 2009 Nov;19(9):421.
18. Keith SW, Stommel M, Allison DB, Schoenborn CA. Self-report corrections for BMI: Comment on Keith et al. *Int J Obes (Lond)*. 2012 Dec;36(12):1591.
19. O'Donovan G, Lee IM, Hamer M, Stamatakis E. Association of “weekend warrior” and other leisure time physical activity patterns with risks for all-cause, cardiovascular disease, and Cancer mortality. *JAMA Intern Med*. 2017 Mar 1;177(3):335–342.
20. Farrell SW, DeFina LF, Radford NB, et al. Relevance of fitness to mortality risk in men receiving contemporary medical care. *J Am Coll Cardiol*. 2020 Apr 7;75(13):1538–1547.
21. Dieleman JL, Cao J, Chapin A, et al. US health care spending by payer and health condition, 1996–2016. *JAMA*. 2020 Mar 3;323(9):863–884.
22. Martinez-Gomez D, Cabanas-Sanchez V, Yu T, et al. Long-term leisure-time physical activity and risk of all-cause and cardiovascular mortality: dose-response associations in a prospective cohort study of 210 327 Taiwanese adults. *Br J Sports Med*. 2022 Aug;56(16):919–926.