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ORIGINAL RESEARCH

Association of Objective and Self-Reported Sleep Duration With All-Cause and Cardiovascular Disease Mortality: A Community-Based Study

Binbin Zhao, PhD; Yuxuan Meng, PhD; Xiaoying Jin, MD; Wenyu Xi, PhD; Qingyan Ma, PhD; Jian Yang, PhD; Xiancang Ma, PhD; Bin Yan, MD, PhD

BACKGROUND: Previous studies found an association between self-reported sleep duration and mortality. This study aimed to compare the effects of objective and self-reported sleep duration on all-cause and cardiovascular disease (CVD) mortality.

METHODS AND RESULTS: A total of 2341 men and 2686 women (aged 63.9±11.1 years) were selected from the SHHS (Sleep Heart Health Study). Objective sleep duration was acquired using in-home polysomnography records, and self-reported sleep duration on weekdays and weekends was based on a sleep habits questionnaire. The sleep duration was categorized as ≤4 hours, 4 to 5 hours, 5 to 6 hours, 6 to 7 hours, 7 to 8 hours, and >8 hours. Multivariable Cox regression analysis was used to investigate the association of objective and self-reported sleep duration with all-cause and CVD mortality. During a mean follow-up period of 11 years, 1172 (23.3%) participants died, including 359 (7.1%) deaths from CVD. All-cause and CVD mortality rates decreased gradually with increasing objective sleep duration. In multivariable Cox regression analysis, the greatest association for all-cause and CVD mortality was with an objective sleep duration of 5 hours or shorter. In addition, we found a J-shaped association of self-reported sleep duration on both weekdays and weekends with all-cause and CVD mortality. Self-reported short (≤4 hours) and long (>8 hours) sleep duration on weekdays and weekends were associated with an increased risk of all-cause and CVD mortality compared with 7 to 8 hours sleep duration. Furthermore, a weak correlation was observed between objective and self-reported sleep duration.

CONCLUSIONS: This study showed that both objective and self-reported sleep duration were associated with all-cause and CVD mortality, but with different characteristics.

REGISTRATION: URL: https://clinicaltrials.gov/ct2/show/NCT00005275; Unique identifier: NCT00005275.

Key Words: all-cause mortality ■ cardiovascular disease mortality ■ objective sleep duration ■ self-reported sleep duration ■ SHHS

Sleep is a complicated set of brain processes that plays a pivotal role in maintaining mental and physical health.[1] Insufficient sleep can lead to multiple adverse medical consequences, including cardiovascular diseases (CVDs),[2,3] metabolic disorders,[4] psychiatric disorders,[5] and impaired cognition.[6,7] Sleep duration is an important indicator of nighttime sleep, which can be objectively measured using polysomnography and wrist actigraphy or collected from self-reported sleep questionnaires.

Accumulating evidence indicates that sleep duration is strongly associated with mortality; however, most studies have focused on the effects of self-reported sleep duration.[8,9] There is often a discrepancy between self-reported and objective sleep duration assessments caused by sleep misperception.[10] Self-reported

Correspondence to: Bin Yan, MD, PhD, Department of Clinical Research Center, the First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China. Email: yanbin.1987@hotmail.com

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CLINICAL PERSPECTIVE

What Is New?

- Self-reported and objective sleep duration had different effects on the all-cause and cardiovascular disease mortality.
- There is a J-shaped association of self-reported sleep duration on weekdays and weekends with all-cause and cardiovascular disease mortality.
- Objective sleep duration is inversely associated with all-cause and cardiovascular disease mortality.

What Are the Clinical Implications?

- Self-reported sleep duration may not fully reflect people's sleep duration.
- Objective sleep monitoring is necessary and important to identify the real sleep duration and fluctuations.

Nonstandard Abbreviations and Acronyms

ARIC	Atherosclerosis Risk in Communities
CHS	Cardiovascular Health Study
SHHS	Sleep Heart Health Study
SHS	Strong Heart Study
T_{90}	oxygen desaturation <90%

sleep duration generally overestimated objectively measured sleep in previous observational studies.[11,12] A U-shaped or J-shaped association has been observed between self-reported sleep duration and all-cause and CVD mortality.[13,14] Reinhard et al showed that objective sleep duration was inversely correlated with mortality in patients with chronic heart failure.[15]

To our knowledge, there is little evidence comparing the different characteristics of self-reported and objective sleep duration on all-cause and CVD mortality in the general population. The present study was designed to investigate the role of objective and self-reported sleep duration in all-cause and CVD mortality based on a community-based population from the decade-long SHHS (Sleep Heart Health Study).

METHODS

Data Sharing Statement

The data used in this study were obtained from SHHS data sets (https://doi.org/10.25822/ghy8-ks59).

Study Population

The SHHS is a community-based multicenter cohort study (participants enrolled between November 1, 1995, and January 31, 1998) with a primary aim of investigating the cardiovascular and other consequences of sleep-disordered breathing (ClinicalTrials.gov Identifier: NCT00005275). A total of 6441 men and women 40 years and older were enrolled from large "parent" cohorts (including the Framingham Offspring Study; the Hagerstown and Minneapolis/St. Paul sites of the ARIC [Atherosclerosis Risk in Communities] study; the Hagerstown, Sacramento, and Pittsburgh sites of the CHS [Cardiovascular Health Study]; the SHS [Strong Heart Study] sites in South Dakota, Oklahoma, and Arizona; and studies of respiratory disease in Tucson and of hypertension in New York). Outcomes data such as all-cause mortality, coronary artery disease and stroke were monitored for more than 10 years (between baseline and 2011). Details of the study design and quality control procedures have been previously reported.[16–18] All of the participants in the SHHS provided written informed consent. The exclusion criteria were as follows: (1) 637 participants from the SHS were excluded because of sovereignty issues (SHS participants are not included in the shared SHHS data); and (2) 777 participants were excluded because of missing follow-up data (the New York University-Cornell site did not have outcome data). Ultimately, 5027 participants were included in the analysis.

Objective and Self-Reported Sleep Duration

All participants in the present study underwent electroencephalography-based overnight unattended polysomnography (P-Series, Compumedics) at their residence. The sleep monitor was set up by trained and certified technicians. Objective sleep duration, acquired from the polysomnography records, was defined as the total sleep time consisting of rapid eye movement sleep and non-REM sleep. If the polysomnography monitoring was inadequate, a repeat monitoring request was initiated (Data S1).

Self-reported sleep duration was obtained from sleep habit questionnaires such as "How many hours of sleep do you usually get at night (or What time do you usually fall asleep and wake up) on weekdays or workdays?" and "How many hours of sleep do you usually get at night (or What time do you usually fall asleep and wake up) on weekends or your nonworkdays?" We also collected the sleep duration from the morning survey based on the question "How long did you sleep last night?" Sleep duration was further categorized as ≤4 hours, 4 to 5 hours, 5 to 6 hours, 6 to 7 hours, 7 to 8 hours, and >8 hours in this study.

Covariates

Baseline characteristics of the study sample, including age, sex, race, body weight, smoking status, alcohol use, medical history, and medication use, were acquired from the SHHS baseline survey and parent study. The apnea-hypopnea index was defined as all episodes of apnea and hypopnea per hour associated with an oxygen desaturation of ≥4%. The percentage of sleep time with oxygen desaturation <90% (T_{90}) was defined as the ratio of time spent with oxygen desaturation <90% of the total sleep time.

Outcomes

Deaths from any cause were assessed in the parent study, which was identified and confirmed by follow-up interviews. When a participant could not be reached for a scheduled follow-up, all known contacts of the participant were called to determine the participant's survival status. All deaths including CVD death were investigated by reviewing local hospital records, including ECGs, heart catheterizations, cardiac surgery, echocardiography, nuclear medicine scans, radiographs, computed tomography and magnetic resonance imaging, cerebral angiograms, lumbar punctures, pathology reports, death certificates, autopsy reports, and laboratory tests. In addition, the participant's physician and the family members or other proxies who were with the participant at the time of death were interviewed to obtain detailed information about the circumstances of their death. Community obituaries were also monitored and linked to the Social Security Administration Death Master File.[19]

Statistical Analysis

Comparisons of baseline characteristics are presented as mean±SD for continuous variables and number (percentages) for categorical variables. Differences in the characteristics were analyzed using chi-square test for categorical variables and independent Student *t* test for continuous variables. Unadjusted Kaplan–Meier plots were used to evaluate the overall survival of different sleep duration categories. Multivariable Cox proportional hazard regression models were used to assess the association between objective and self-reported sleep duration categories and all-cause and CVD mortality. Covariates were selected in our multivariable analysis based on: (1) the variables considered clinically relevant or used in previous study; and (2) the variable was significantly associated with mortality in univariate analysis ($P<0.05$). The model was adjusted for age, sex, race, body mass index, smoking status, alcohol use, diabetes, hypertension, history of major CVD (including myocardial infarction, congestive heart failure, and stroke), history of chronic respiratory disease (including chronic obstructive pulmonary disease and chronic bronchitis), lipid-lowering medication use, benzodiazepine use, apnea-hypopnea index, and T_{90}.

Restricted cubic spline Cox regression was applied to assess the dose–response association of objective and self-reported sleep duration with all-cause and CVD mortality (5 knots at the 5.0th, 27.5th, 50.0th, 72.5th, and 95.0th percentiles). Pearson correlation was used to determine the correlation between objective and self-reported sleep duration. All statistical analyses were performed using SPSS statistics software (version 24.0, IBM) and R software version 3.6.3 (R Core Team). All statistical significance was 2-sided, and a *P* value <0.05 was considered statistically significant.

RESULTS

Baseline Characteristics of Participants

A total of 5027 participants (2341 men and 2686 women [mean age, 63.9±11.1 years]) were enrolled in the present study. Compared with people alive, individuals with all-cause death had shorter objective sleep duration (5.7±1.1 hours versus 6.1±1.0 hours, $P<0.001$) and longer self-reported sleep duration on weekdays (7.6±1.4 hours versus 7.3±1.1 hours, $P<0.001$) (Table 1). No significant difference was observed between the number of people alive and all-cause deaths in self-reported sleep duration on weekends. Additionally, objective sleep duration weakly correlated with self-reported sleep duration (Figure S1).

Association of Objective Sleep Duration With All-Cause and CVD Mortality

During an average of 10.7±3.0 years of follow-up, 1172 (23.3%) all-cause deaths were identified, including 359 (7.1%) CVD deaths. Individuals with objective sleep duration of ≤4 hours (45.9%), 4 to 5 hours (31.3%), 5 to 6 hours (25.0%), and 6 to 7 hours (21.9%) had a higher all-cause mortality than those with a sleep duration of 7 to 8 hours (13.5%). All-cause mortality was similar for the objective sleep duration at 7 to 8 hours and >8 hours. Unadjusted Kaplan–Meier analysis showed lower overall survival among participants with a shorter objective sleep duration (Figure 1).

After adjusting for age, sex, race, body mass index, smoking status, alcohol use, diabetes, hypertension, history of major CVD, history of chronic respiratory disease, lipid-lowering medication use, benzodiazepine use, apnea-hypopnea index, and T_{90}, multivariable Cox regression analysis found that objective sleep duration ≤4 hours (hazard ratio [HR], 2.43 [95% CI, 1.83–3.22], $P<0.001$), 4 to 5 hours (HR, 1.66 [95% CI, 1.30–2.12],

Table 1. Baseline Characteristics of the Study Sample According to Alive and All-Cause Death

Characteristics	Total (N=5027)	All-cause death (n=1172)	Alive (n=3855)	*P* value
Age, y	63.9±11.1	73.5±8.9	61.0±10.1	<0.001
Sex, n (%)				<0.001
Men	2341 (46.6)	622 (35.1)	1719 (44.6)	—
Women	2686 (53.4)	550 (46.9)	2136 (55.4)	—
Race and ethnicity, n (%)*				0.320
White	4375 (87.0)	1030 (87.9)	3345 (86.8)	—
Other	652 (13.0)	142 (12.1)	510 (13.2)	—
Body weight, n (%)				<0.001
Obesity	1540 (30.9)	315 (27.2)	1225 (32.0)	—
Overweight	2121 (42.6)	488 (42.2)	1633 (42.7)	—
Normal	1320 (26.5)	353 (30.6)	967 (25.3)	—
Smoking status, n (%)				<0.001
Current	487 (9.7)	114 (9.7)	373 (9.7)	—
Former	2210 (44.1)	576 (49.3)	1634 (42.5)	—
Never	2316 (46.2)	479 (41.0)	1837 (47.8)	—
Alcohol use, n (%)				<0.001
At least 1 drink per day	2014 (42.8)	404 (35.5)	1610 (45.1)	—
None	2691 (57.2)	733 (64.5)	1958 (54.9)	—
Medical history, n (%)				
MI	341 (6.8)	177 (15.1)	164 (4.3)	<0.001
CHF	140 (2.8)	101 (8.6)	39 (1.0)	<0.001
Stroke	153 (3.0)	70 (6.0)	83 (2.2)	<0.001
COPD	59 (1.2)	27 (2.3)	32 (0.8)	<0.001
Chronic bronchitis	75 (1.5)	92 (7.8)	7 (0.2)	<0.001
Diabetes	367 (7.3)	179 (15.3)	188 (4.9)	<0.001
Hypertension	2031 (40.4)	713 (60.8)	1318 (34.2)	<0.001
Lipid-lowering medication use, n (%)	634 (12.6)	165 (14.1)	469 (12.2)	0.084
Benzodiazepine use, n (%)	284 (5.6)	94 (8.0)	190 (4.9)	<0.001
Sleep duration, h				
Objective	6.0±1.1	5.7±1.1	6.1±1.0	<0.001
Self-reported weekday	7.4±1.2	7.6±1.4	7.3±1.1	<0.001
Self-reported weekend	7.7±1.3	7.7±1.5	7.7±1.2	0.871
AHI, events/h	10.1±13.4	12.4±15.0	9.4±12.8	<0.001
T_{90}, %	3.6±10.6	6.4±15.2	2.8±8.6	<0.001
Follow-up time, y	10.7±3.0	6.9±3.2	11.9±1.7	<0.001

Results are presented as mean±SD or number (percentage). The *P* values represent the difference between the 2 groups. AHI indicates apnea-hypopnea index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; and T_{90}, oxygen desaturation <90%.

*White did not include Hispanic or Latino participants. Other race and ethnicity categories included Black, Native American or Alaskan Native, Asian or Pacific Islander, and Hispanic or Latino.

P<0.001), 5 to 6 hours (HR, 1.37 [95% CI, 1.10–1.71], *P*=0.005), and 6 to 7 hours (HR, 1.42 [95% CI, 1.15–1.76], *P*=0.001) were significantly associated with all-cause mortality compared with that of the reference (7–8 hours) (Table 2). In the restricted cubic spline analysis, an increasing objective sleep duration was accompanied by an overall downward trend in all-cause mortality ($P_{\text{overall association}}$<0.001; $P_{\text{nonlinear association}}$=0.016; Figure 2).In addition, individuals with a short objective sleep duration had high CVD mortality rates (Figure 1). Multivariable Cox regression analysis showed that a short objective sleep duration of ≤4 hours (HR, 2.31 [95% CI, 1.43–3.75], *P*=0.001) and 4 to 5 hours (HR, 1.57 [95% CI, 1.03–2.40], *P*=0.038) had a high rate of CVD mortality compared with those of 7 to 8 hours (Table 3). Moreover, an inverse linear association

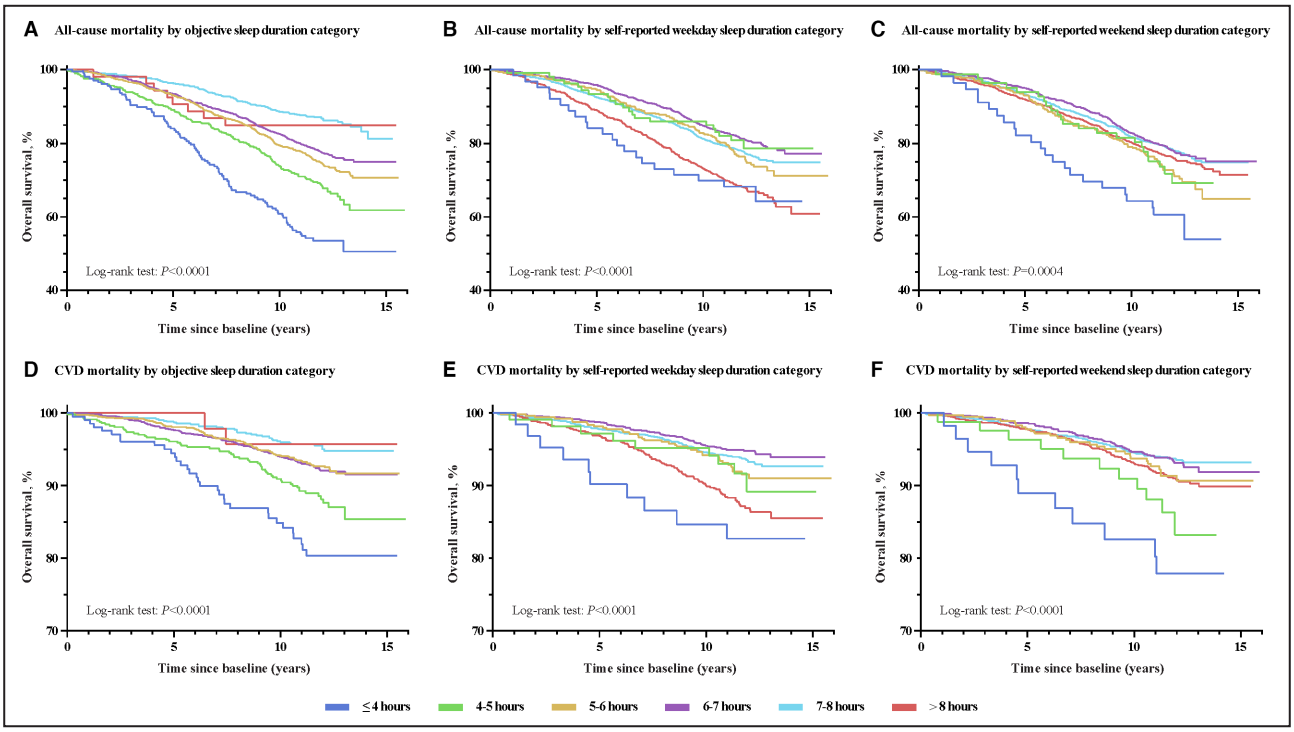

Figure 1. Kaplan–Meier plots of overall survival for all-cause and cardiovascular disease (CVD) mortality by objective and self-reported sleep duration.
A, Objective sleep duration category and all-cause mortality. **B**, Self-reported sleep duration category on weekdays and all-cause mortality. **C**, Self-reported sleep duration category on weekends and all-cause mortality. **D**, Objective sleep duration category and CVD mortality. **E**, Self-reported sleep duration category on weekdays and CVD mortality. **F**, Self-reported sleep duration category on weekends and CVD mortality.

between objective sleep duration and CVD death was observed in the restricted cubic spline analysis ($P_{\text{overall association}}$<0.001; $P_{\text{nonlinear association}}$=0.054; Figure 2).

Association of Self-Reported Sleep Duration With All-Cause and CVD Mortality

Unlike objective sleep, both short (≤4 hours) and long (>8 hours) self-reported sleep duration on weekdays had a high rate of all-cause mortality (Table 2; Figure 1). Compared with a self-reported weekday sleep duration of 7 to 8 hours, weekday sleep duration of ≤4 hours (HR, 1.63 [95% CI, 1.04–2.54], P=0.032) and >8 hours (HR, 1.26 [95% CI, 1.08–1.47], P=0.003) were associated with an increased risk of all-cause mortality. A J-shaped association was found between self-reported sleep duration on weekdays and all-cause mortality ($P_{\text{overall association}}$<0.001; $P_{\text{nonlinear association}}$<0.001; Figure 2).

The association of short (≤4 hours) and long (>8 hours) self-reported sleep duration on weekdays with a high CVD mortality rate was also observed. We also found a J-shaped curve between self-reported sleep duration on weekdays and all-cause mortality ($P_{\text{overall association}}$<0.001; $P_{\text{nonlinear association}}$<0.001; Figure 2). Moreover, self-reported sleep duration on weekends had a similar effect on all-cause and CVD mortality as that of weekday sleep duration.

The association of objective and self-reported sleep duration with all-cause and CVD mortality in men and women was also explored. There was an inverse association between the objective sleep duration and mortality in both men and women. A J-shaped association was found between self-reported sleep duration and mortality in both men and women (Figures S2 and S3). We further investigated the association between sleep duration based on morning survey and mortality. However, no significant association was found (Table S1).

DISCUSSION

In this large community-based study, we investigated the role of objective and self-reported sleep duration in all-cause and CVD mortality. The effects of objective and self-reported sleep duration on mortality differed. A J-shaped association of self-reported sleep duration on weekdays and weekends with all-cause and CVD mortality was observed. We also found that all-cause and CVD mortality rates decreased gradually with increasing objective sleep duration.

Table 2. HRs and 95% CIs for Objective and Self-Reported Sleep Duration Associated With All-Cause Mortality

Sleep duration	Patients, n	Events, n (%)	Person-years	Mortality*	Univariate model		Multivariable adjusted†		Multivariable adjusted‡	
					HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Objective sleep duration, h										
≤4	207	95 (45.9)	1934.2	49.1	4.29 (3.27–5.63)	<0.001	2.82 (2.15–3.71)	<0.001	2.43 (1.83–3.22)	<0.001
4–5	582	182 (31.3)	5876.4	31.0	2.65 (2.10–3.35)	<0.001	1.76 (1.39–2.23)	<0.001	1.66 (1.30–2.12)	<0.001
5–6	1396	349 (25.0)	14,905.9	23.4	1.92 (1.60–2.45)	<0.001	1.48 (1.19–1.83)	<0.001	1.37 (1.10–1.71)	0.005
6–7	1933	423 (21.9)	20,848.7	20.3	1.71 (1.39–2.10)	<0.001	1.43 (1.17–1.77)	0.001	1.42 (1.15–1.76)	0.001
7–8	855	115 (13.5)	9617.4	12.0	1 (Ref)		1 (Ref)		1 (Ref)	
>8	54	8 (14.8)	599.1	13.4	1.12 (0.55–2.30)	0.749	1.70 (0.83–3.48)	0.148	1.63 (0.79–3.34)	0.187
Self-reported weekday sleep duration, h										
≤4	63	21 (33.3)	630.2	33.3	1.71 (1.10–2.66)	0.017	1.74 (1.12–2.70)	0.014	1.63 (1.04–2.54)	0.032
4–5	108	21 (19.4)	1164.8	18.0	0.91 (0.59–1.42)	0.689	0.85 (0.55–1.31)	0.454	0.68 (0.43–1.08)	0.101
5–6	513	119 (23.2)	5465.3	21.8	1.11 (0.90–1.36)	0.322	1.08 (0.88–1.33)	0.471	1.02 (0.82–1.26)	0.866
6–7	1465	275 (18.8)	16,180.6	17.0	0.86 (0.74–1.00)	0.053	0.91 (0.78–1.06)	0.229	0.93 (0.79–1.09)	0.340
7–8	1791	384 (21.4)	19,437.9	19.7	1 (Ref)		1 (Ref)		1 (Ref)	
>8	986	313 (31.7)	9950.7	31.5	1.62 (1.40–1.88)	<0.001	1.37 (1.18–1.59)	<0.001	1.26 (1.08–1.47)	0.003
Self-reported weekend sleep duration, h										
≤4	57	23 (40.4)	534.6	43.0	2.21 (1.45–3.37)	<0.001	1.90 (1.25–2.90)	0.003	1.89 (1.23–2.89)	0.004
4–5	83	23 (27.7)	870.1	26.4	1.33 (0.87–2.02)	0.191	1.09 (0.72–1.67)	0.681	0.96 (0.62–1.50)	0.857
5–6	373	103 (27.6)	3916.2	26.3	1.32 (1.06–1.65)	0.012	1.17 (0.94–1.45)	0.169	1.10 (0.88–1.38)	0.421
6–7	1108	238 (21.5)	12,084.7	19.7	0.98 (0.83–1.16)	0.827	0.94 (0.79–1.10)	0.419	0.94 (0.80–1.12)	0.501
7–8	1704	369 (21.7)	18,390.2	20.1	1 (Ref)		1 (Ref)		1 (Ref)	
>8	1602	380 (23.7)	17,030.4	22.3	1.12 (0.97–1.29)	0.131	1.21 (1.05–1.39)	0.010	1.16 (1.01–1.35)	0.046

HR indicates hazard ratio.

*Crude event rate per 1000 person-years.

†Adjusted by age and sex.

‡Adjusted by age, race, body mass index, smoking status, alcohol use, diabetes, hypertension, history of major cardiovascular disease (myocardial infarction, congestive heart failure, and stroke), history of chronic respiratory disease (chronic obstructive pulmonary disease, chronic bronchitis), lipid-lowering medication use, benzodiazepine use, apnea-hypopnea index, and oxygen desaturation <90%.

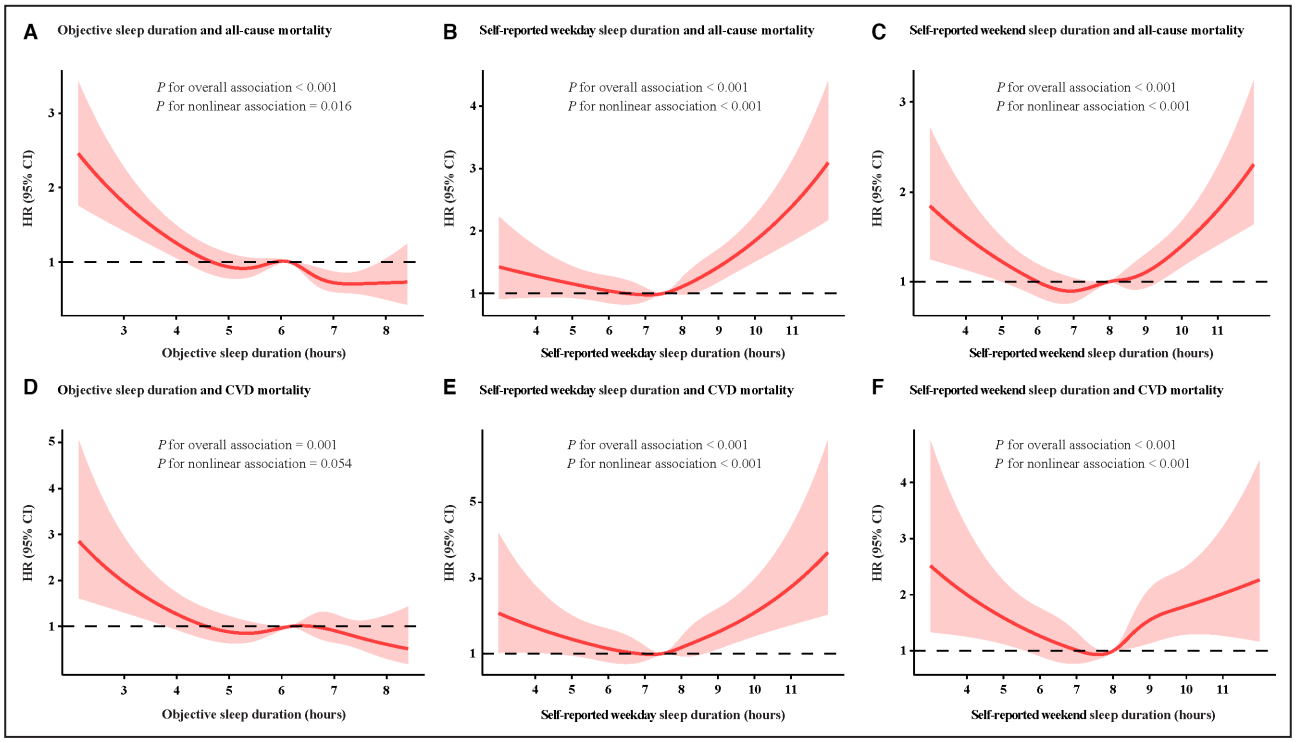

Figure 2. Multivariable Cox proportional hazard ratio (HR) for all-cause and cardiovascular disease (CVD) mortality based on restricted cubic spline analysis of sleep duration.
A, Objective sleep duration and all-cause mortality. **B**, Self-reported sleep duration on weekdays and all-cause mortality. **C**, Self-reported sleep duration on weekends and all-cause mortality. **D**, Objective sleep duration and CVD mortality. **E**, Self-reported sleep duration on weekdays and CVD mortality. **F**, Self-reported sleep duration on weekends and CVD mortality.

Research on the relationship between sleep duration and all-cause and CVD mortality is inconsistent.[20–22] A growing number of studies have demonstrated a U-shaped or J-shaped association of self-reported sleep duration with all-cause and CVD mortality.[13,22,23] Both short and long self-reported sleep duration were associated with a high risk of all-cause and CVD mortality.[24–27] Moreover, a U-shaped association between self-reported sleep duration on weekdays and weekends and all-cause mortality was observed in a large population study.[28] In our study, we explored the association between self-reported sleep duration on both weekdays and weekends and all-cause and CVD mortality. A J-shaped association was observed between self-reported sleep duration on weekdays and weekends and all-cause and CVD mortality. Our findings indicate that self-reported weekday and weekend sleep duration of 7 to 8 hours were the nadir for associations with all-cause and CVD mortality.

Sleep questionnaires, commonly used to evaluate self-reported sleep duration in epidemiological studies, do not correspond closely to objectively measured sleep duration.[29,30] Several studies have demonstrated that self-reported sleep duration tends to overestimate objectively measured sleep duration, which may be attributable to sleep misperceptions.[10,11] We also found a higher self-reported sleep duration than objective sleep duration. Moreover, our findings show a weak correlation between objective and self-reported sleep duration. In the present study, we sought to observe the different effects of self-reported sleep duration and objective sleep duration on all-cause and CVD mortality. One observational study with a small sample size showed an inverse association between objective sleep duration and all-cause mortality in patients with chronic heart failure.[15] Bertisch et al demonstrated that insomnia or poor sleep with objective short sleep duration (<6 hours) was associated with higher risk of incident CVD but not with all-cause mortality.[31] We utilized restricted cubic spline analysis to investigate the dose–response association of objective sleep duration with all-cause and CVD mortality in a community-based population. Our findings reveal that the association between objective sleep duration and mortality was completely different from that of self-reported sleep duration. With an increase in the objective sleep duration, the rates of all-cause and CVD mortality showed a significant downward trend. Interestingly, the rates of all-cause and CVD mortality were lower in both objective and self-reported sleep duration of 7 to 8 hours.

The biological mechanisms underlying the potential association between sleep duration and all-cause

Table 3. HRs and 95% CIs for Objective and Self-Reported Sleep Duration Associated With CVD Mortality

Sleep duration	Patients, n	Events, n (%)	Person-years	Mortality*	Univariate model		Multivariable adjusted†		Multivariable adjusted‡	
					HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Objective sleep duration, h										
≤4	207	33 (15.9)	1934.2	17.1	4.49 (2.82–7.16)	<0.001	2.78 (1.74–4.44)	<0.001	2.31 (1.43–3.75)	0.001
4–5	582	60 (10.3)	5876.4	10.2	2.63 (1.75–3.95)	<0.001	1.63 (1.08–2.46)	0.019	1.57 (1.03–2.40)	0.038
5–6	1396	92 (6.6)	14,905.9	6.2	1.58 (1.08–2.30)	0.018	1.11 (0.76–1.63)	0.596	1.06 (0.72–1.58)	0.757
6–7	1933	134 (6.9)	20,848.7	6.4	1.63 (1.14–2.34)	0.008	1.32 (0.92–1.90)	0.132	1.35 (0.93–1.96)	0.112
7–8	855	38 (4.4)	9617.4	4.0	1 (Ref)		1 (Ref)		1 (Ref)	
>8	54	2 (3.7)	599.1	3.3	0.86 (0.21–3.54)	0.829	1.39 (0.34–5.76)	0.651	1.25 (0.30–5.22)	0.760
Self-reported weekday sleep duration, h										
≤4	63	10 (15.9)	630.2	15.9	2.91 (1.52–5.56)	0.001	2.98 (1.56–5.70)	0.001	2.56 (1.32–4.95)	0.005
4–5	108	9 (8.3)	1164.8	7.7	1.40 (0.71–2.77)	0.329	1.28 (0.65–2.54)	0.471	0.94 (0.45–1.94)	0.865
5–6	513	37 (7.2)	5465.3	6.8	1.24 (0.85–1.80)	0.260	1.20 (0.82–1.74)	0.345	1.07 (0.72–1.58)	0.749
6–7	1465	72 (4.9)	16,180.6	4.4	0.81 (0.60–1.09)	0.159	0.86 (0.64–1.16)	0.316	0.95 (0.70–1.29)	0.749
7–8	1791	107 (6.0)	19,437.9	5.5	1 (Ref)		1 (Ref)		1 (Ref)	
>8	986	108 (11.0)	9950.7	10.9	2.01 (1.54–2.62)	<0.001	1.66 (1.27–2.17)	<0.001	1.53 (1.16–2.02)	0.002
Self-reported weekend sleep duration, h										
≤4	57	11 (19.3)	534.6	20.6	3.92 (2.10–7.31)	<0.001	3.33 (1.79–6.22)	<0.001	3.12 (1.66–5.87)	<0.001
4–5	83	11 (13.3)	870.1	12.6	2.35 (1.26–4.38)	0.007	1.91 (1.03–3.57)	0.042	1.41 (0.71–2.81)	0.330
5–6	373	28 (7.5)	3916.2	7.1	1.34 (0.88–2.04)	0.174	1.16 (0.77–1.77)	0.480	1.08 (0.69–1.68)	0.743
6–7	1108	68 (6.1)	12,084.7	5.6	1.05 (0.77–1.43)	0.772	0.99 (0.73–1.35)	0.954	1.11 (0.81–1.52)	0.530
7–8	1704	99 (5.8)	18,390.2	5.4	1 (Ref)		1 (Ref)		1 (Ref)	
>8	1602	128 (8.0)	17,030.4	7.5	1.41 (1.08–1.83)	0.011	1.53 (1.18–1.99)	0.001	1.55 (1.18–2.03)	0.001

HR indicates hazard ratio.

*Crude event rate per 1000 person-years.

†Adjusted by age and sex.

‡Adjusted by age, race, body mass index, smoking status, alcohol use, diabetes, hypertension, history of major cardiovascular disease (myocardial infarction, congestive heart failure, and stroke), history of chronic respiratory disease (chronic obstructive pulmonary disease, chronic bronchitis), lipid-lowering medication use, benzodiazepine use, apnea-hypopnea index, and oxygen desaturation <90%.

and CVD mortality are not yet fully understood. Our findings reveal that objectively measured and self-reported short sleep duration had an obviously high rate of all-cause and CVD mortality. It may be because short sleep duration has been linked to 7 (including CVD, malignant neoplasm, cerebrovascular disease, accidents, diabetes, septicemia, and hypertension) of the 15 leading causes of death in America.[32] Moreover, short sleep duration is related to reduced leptin and elevated ghrelin levels.[33] Perturbation of leptin and ghrelin levels may be related to increased appetite and calorie intake, which could lead to the development of obesity and diabetes, ultimately increasing mortality. Furthermore, increased all-cause and CVD mortality was observed only in the long self-reported sleep duration group. This may be attributable to the fact that individuals with long self-reported sleep duration had significantly increased sleep latency, wake after sleep onset, and arousal index (Table S2). These findings remind us that self-reported long sleep duration may include more wakefulness time in bed. In addition, wake after sleep onset was also found to be associated with both all-cause and CVD mortality (Table S3). Increased wake after sleep onset may be the underlying cause of higher mortality in people who had self-reported long sleep duration. Moreover, long sleep duration may be related to fatigue, immune function, photoperiodic abnormalities, depression, and some underlying diseases.[34]

The current study, based on a community-based population, reported the association of objective and self-reported sleep duration with all-cause and CVD mortality that may be available to the general population. We highlight the different characteristics of the effects of objective and self-reported sleep duration on mortality. This study had several limitations. Most of the individuals were of White race and middle-aged or older; our findings may not apply to other ethnic groups or younger individuals. We did not include socioeconomic status because of a lack of relevant information in SHHS data sets. Moreover, the objective sleep duration in this study was monitored using single-night in-home polysomnography. Nocturnal variability in sleep duration may exist and affect the strength of observed associations.

CONCLUSIONS

The current study indicates that the effects of objective and self-reported sleep duration on mortality are different in middle-aged and older people. Objective sleep duration tended to have an inverse association with all-cause and CVD mortality. A J-shaped association was observed between self-reported sleep duration and mortality. A short sleep duration in both objectively measured and self-reported data was associated with increased all-cause and CVD mortality. Insufficient sleep is an important public health concern. Self-reported long sleep duration is also a concern, especially if it is caused by sleep fragmentation and underlying diseases. Importantly, self-reported sleep duration is the most practical and cost-effective research method, but it may not fully reflect real sleep duration. Long-term monitoring of objective sleep duration can reflect the true level and fluctuation of sleep duration, and the development and popularization of smart wearable devices may provide a convenient means of collecting these data for studies in the near future.

ARTICLE INFORMATION

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Affiliations

Department of Psychiatry, The First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China (B.Z., X.J., W.X., Q.M., J.Y., X.M., B.Y.); Department of Brain Sciences, Imperial College London, London, UK (Y.M.); and Department of Clinical Research Center, The First Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China (Y.M., J.Y., B.Y.).

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Disclosures

All of the authors declare no conflicts of interest.

Supplemental Material

Data S1
Tables S1–S3
Figures S1–S3

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SUPPLEMENTAL MATERIAL

Data S1. Supplemental Methods

All the participants in the Sleep Heart Health Study (SHHS) underwent in-home polysomnography (PSG) to collect data of sleep parameters. Objective sleep duration was obtained from PSG records. The Compumedics sleep monitor was set up by a team of two individuals (one sleep technician and one helper) who have been specifically trained and certified. The sleep monitor is battery operated so the participant is not potentially in connection with electrical outlets. PSG records were obtained in an unattended setting. The next morning a technician returned to the participant's home at a pre-arranged time to collect the sleep monitor and self-administered surveys. The PSG data were then sent to the Reading Center for processing and the paper forms submitted for local data entry. The trained technicians completed manual analysis of monitoring results to obtain accurate information. If the study was inadequate, a repeat study request is initiated. The entire monitoring process tried to make participants consistent with their usual sleep. The each stage of sleep was clearly defined which could be found at https://sleepdata.org/datasets/shhs/pages/mop/6-626-mop-rules-for-assigning-sleep-stages.md.

A total of 6441 men and women aged 40 years or older completed the baseline examination (1995–1998). Institutional Review Board approval was obtained at all participating institutions, and all participants signed informed consent. Of the 6441 participants enrolled in SHHS, 637 withdrew their consent due to sovereignty issues

(Strong Heart Study participants are not included in the shared SHHS data). Therefore, SHHS dataset only includes the remaining 5804 participants. We also acquired 5804 participants from the SHHS datasets. The data could be found at https://doi.org/10.25822/ghy8-ks59.

Table S1. HRs and 95% CIs for self-reported sleep duration in morning survey associated with all-cause and CVD mortality

	All-cause mortality		CVD mortality	
Sleep duration, hours*	HR (95% CI)	*P*	HR (95% CI)	*P*
⩽4	1.26 (0.97-1.62)	0.080	1.14 (0.71-1.82)	0.586
4-5	0.87 (0.69-1.11)	0.259	0.86 (0.57-1.32)	0.497
5-6	1.08 (0.91-1.30)	0.381	1.12 (0.81-1.54)	0.494
6-7	0.89 (0.75-1.06)	0.179	0.87 (0.64-1.18)	0.359
7-8	1 (Ref)		1 (Ref)	
>8	1.02 (0.83-1.25)	0.849	0.91 (0.63-1.32)	0.614

AHI, apnea hypopnea index; BMI, body mass index; 95% CI, 95% confidence interval; CVD, cardiovascular disease; HR, hazard ratio; T90, percent time below oxygen desaturation 90%.

***** Adjusted by age, sex, race, BMI, smoking status, alcohol use, diabetes mellitus, hypertension, history of major CVD, history of chronic respiratory disease, lipid-lowering medication use, benzodiazepine use, AHI and T90

Table S2. Sleep latency, wake after sleep onset and arousal index in self-reported and objective long sleep duration (> 8 hours)

	Objective SD (n=54)	Weekday SD (n=986)	Weekend SD (n=1602)
SL	2.1±4.2	13.7±21.5*	13.4±20.2*
WASO	26.1±10.5	75.1±50.0*	66.1±46.5*
ArI	14.3±7.2	20.7±11.6*	19.6±11.0*

ArI, arousal index; SD, sleep duration; SL, sleep latency; WASO, wake after sleep onset.

* $p<0.05$, compared with objective SD

Table S3. HRs and 95% CIs for WASO, SL and ArI associated with all-cause and CVD mortality

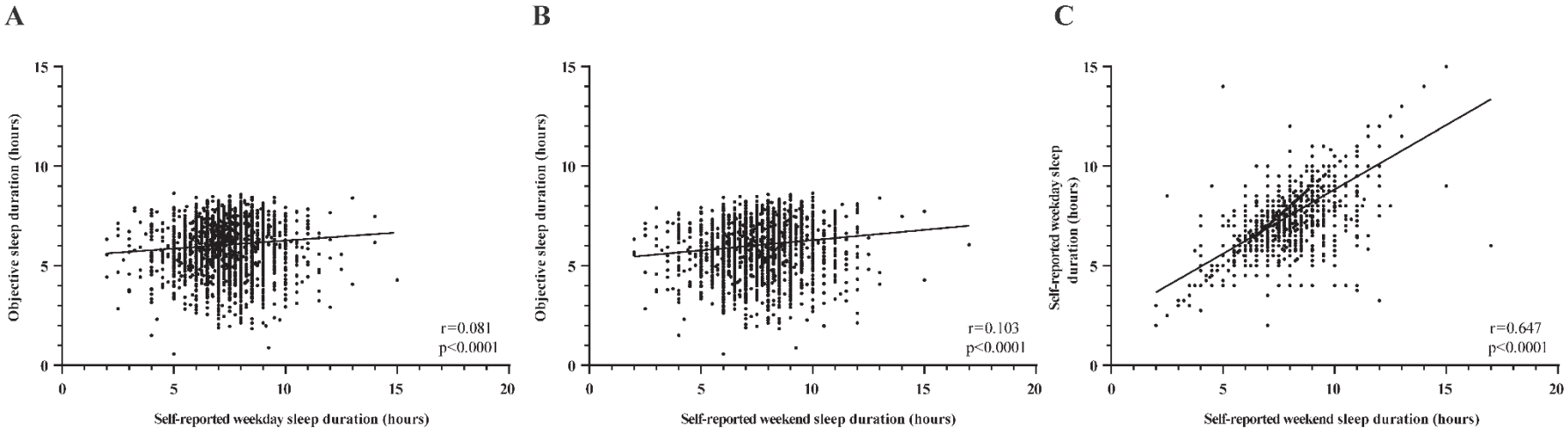
	Univariate model		Multivariable adjusted*	
	HR (95% CI)	**P**	**HR (95% CI)**	**P**
All-cause mortality				
WASO*	1.04 (1.03-1.05)	<0.001	1.02 (1.01-1.03)	<0.001
SL*	1.02 (1.01-1.04)	0.001	1.02 (1.01-1.03)	0.009
ArI*	1.09 (1.06-1.11)	<0.001	1.02 (0.99-1.05)	0.201
CVD mortality				
WASO*	1.04 (1.03-1.05)	<0.001	1.02 (1.01-1.03)	<0.001
SL*	1.01 (0.99-1.04)	0.341	1.01 (0.98-1.03)	0.692
ArI*	1.08 (1.03-1.13)	0.001	1.02 (0.96-1.07)	0.549

AHI, apnea hypopnea index; ArI, arousal index; BMI, body mass index; CHF, congestive heart failure; 95% CI, 95% confidence interval; COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; HR, hazard ratio; MI, myocardial infarction; SL, sleep latency; T90, percent time below oxygen desaturation 90%; WASO, wake after sleep onset.

* per 5-unit increased

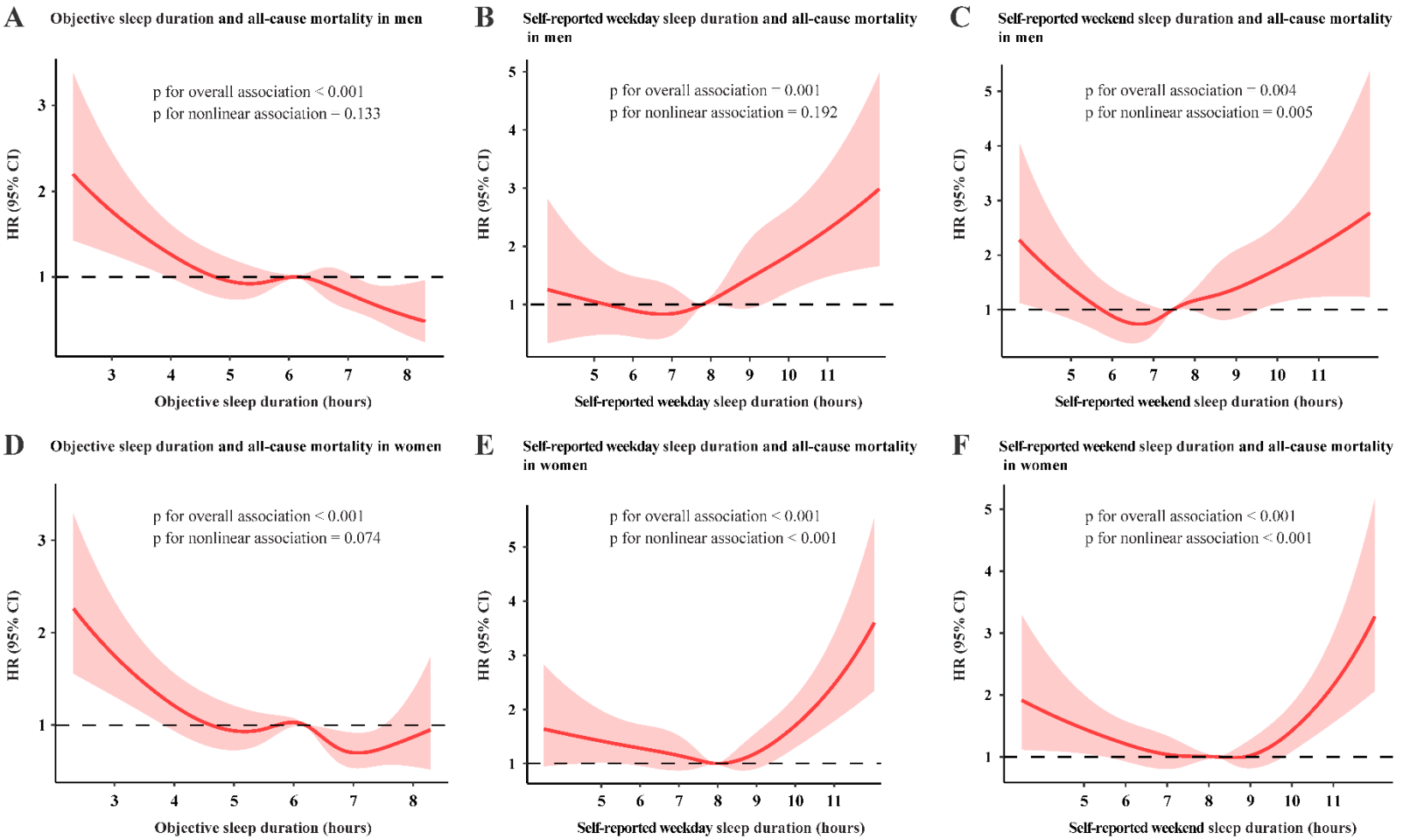
Each individual sleep variable including WASO, SL and ArI was adjusted by age, sex, race, BMI, smoking status, alcohol use, diabetes mellitus, hypertension, history of major CVD (MI, CHF and stroke), history of chronic respiratory disease (COPD, chronic bronchitis), lipid-lowering medication use, benzodiazepine use, AHI and T90

Figure S1. Correlation between objective sleep duration and self-reported sleep duration



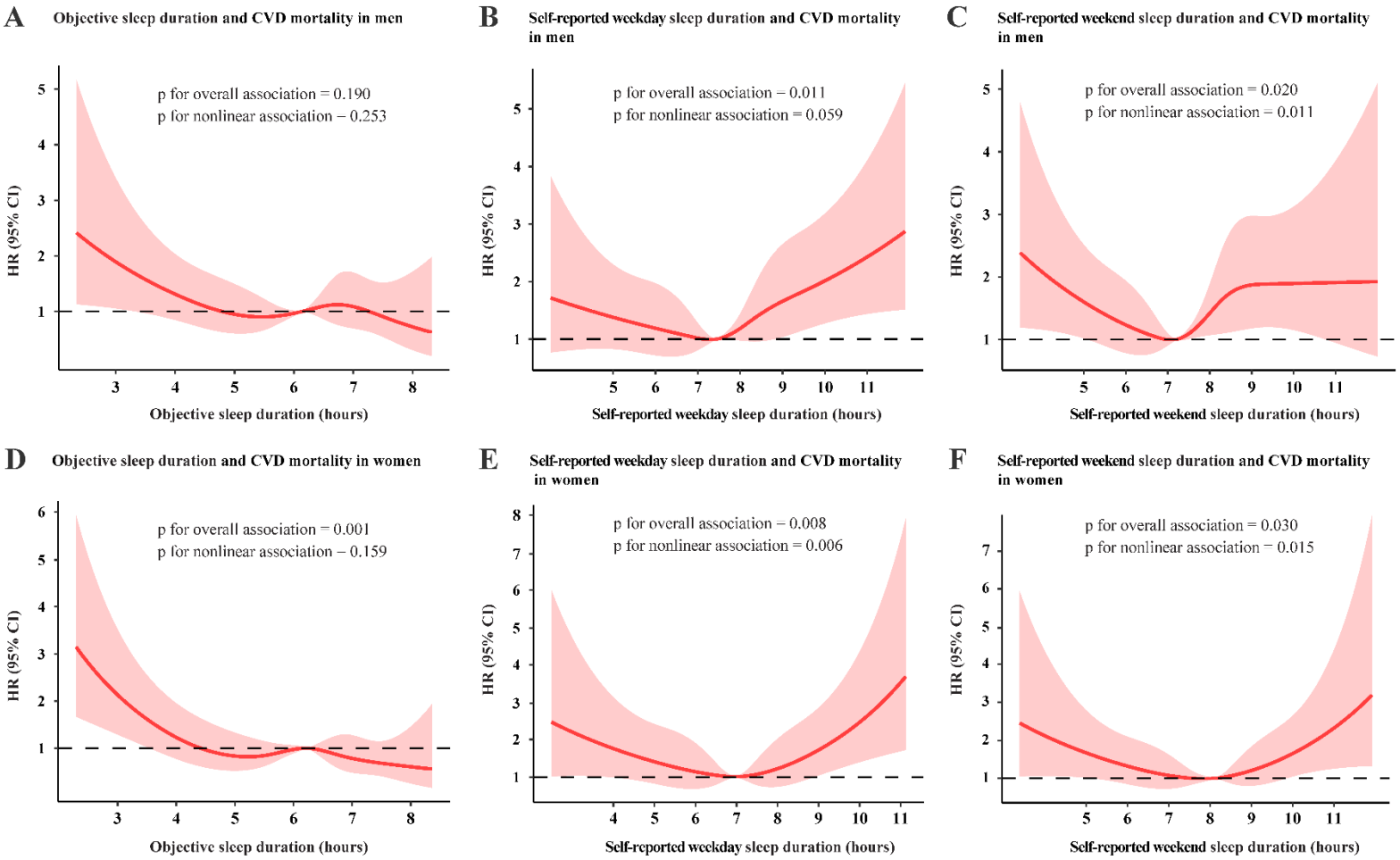
A. objective sleep duration and self-reported sleep duration on weekdays; **B.** objective sleep duration and self-reported sleep duration on weekends; **C.** self-reported sleep duration on weekdays and self-reported sleep duration on weekends.

Figure S2. Multivariable Cox proportional hazard ratio for all-cause mortality based on restricted cubic spline analysis of sleep duration in men and women



A. objective sleep duration and all-cause mortality in men; **B.** self-reported sleep duration on weekdays and all-cause mortality in men; **C.** self-reported sleep duration on weekends and all-cause mortality in men; **D.** objective sleep duration and all-cause mortality in women; **E.** self-reported sleep duration on weekdays and all-cause mortality in women; **F.** self-reported sleep duration on weekends and all-cause mortality in women.
CI, confidence interval; HR, hazard ratio.

Figure S3. Multivariable Cox proportional hazard ratio for all-cause mortality based on restricted cubic spline analysis of sleep duration in men and women



A. objective sleep duration and cardiovascular disease (CVD) mortality in men; **B.** self-reported sleep duration on weekdays and CVD mortality in men; **C.** self-reported sleep duration on weekends and CVD mortality in men; **D.** objective sleep duration and CVD mortality in women; **E.** self-reported sleep duration on weekdays and CVD mortality in women; **F.** self-reported sleep duration on weekends and CVD mortality in women.

CI, confidence interval; HR, hazard ratio.