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RESEARCH ARTICLE

Sleep duration and mortality, influence of age, retirement, and occupational group

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Summary

Previous work has shown that both long and short sleep duration is associated with increased mortality, with lowest risk around 7 hr. This has had widespread impact on views on the optimal sleep duration. However, age, being employed/retired, and blue-/white-collar status, may influence the time available for sleep and thus, confound the association. We investigated the role of these factors on the association between sleep duration and mortality. We used employed and retired participants (N = 25,430) from the Swedish National March Cohort and Cox proportional hazards regression to model the shape of the association. We found a significant U-shaped association in a multivariable model with a hazard ratio (HR) of 1.24 (95% confidence interval [CI] 1.10, 1.39) for <5-hr sleep duration, and a HR of 1.30 (95% CI 1.12, 1.51) for ≥9-hr sleep duration, with the lowest HR for 7 hr, but with a span of low HRs from 5 to 8 hr. Unadjusted values showed a pronounced U-shape. Adjusting for age accounted for most of the attenuation in the multivariable model. Stratification into five age groups showed a significant U-shape only in those aged >60.3 years at baseline. The shape of the association did not differ between blue-/white-collar workers, nor between employed and retired groups. We conclude that the U-shaped association between sleep duration and mortality is present only in older individuals.

KEYWORDS
blue-collar, cause of death registry, cohort, prospective, white-collar

1 | BACKGROUND

There is a concern surrounding what constitutes sufficient sleep to avoid disease and premature death. Several meta-analyses show that mortality increases with short sleep, but also with long sleep (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017). Two other meta-analyses found a J-shaped association (Liu et al., 2017; Ren et al., 2020), with highest risk for long sleep. Thus, the U-shape dominates the results. A recent, large, original study after the last published meta-analysis found a clear U-shape, with all sleep durations from 4 to 6 and 8–10 hr showing significantly increased hazard ratios (HRs) compared to 7 hr (Yang et al., 2021).

The lowest HR in the U-shaped association is 7 hr in most studies. Hence, 7 hr has been used as a reference value in statistical analyses, and been considered "optimal" for longevity, and used as a consensus recommendation by the American Academy of Sleep Medicine (Consensus Conference et al., 2015). This value is often cited in news media. However, a minority of studies have also used 8 or 6 hr, or even 6–8 hr, as reference (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017), suggesting a broad span of "optimal" sleep durations. Furthermore, short sleep has been defined as ≤5, ≤6, or ≤7 hr in four to six studies each (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017), and long sleep as >9 hr in most studies, but also >8 hr in four studies and >10 or 12 hr in three studies (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017).

Several possible causes have been put forth to explain the U-shaped association between sleep duration and mortality, including impaired glucose or lipid regulation, neurodegeneration, low grade inflammation, or depression (Grandner, 2017), all of which may be associated with short sleep duration and, by extrapolation, to mortality. In contrast, low-grade inflammation, or subclinical disease may cause both long sleep periods and increased mortality (Grandner, 2017); although, clear evidence for mortality is lacking.

The variability in results between studies may be due to factors that affect sleep duration, which, in turn, may affect the shape of its association with mortality. Ageing, being employed, or being a blue-collar worker may truncate sleep. Truncation of sleep should reduce the power to detect an association for long sleep (>8 hr) and reduce, or abolish, the upswing section of the U-shape. This might also make the identification of the reference point for the Cox regression analysis (lowest risk) less distinct, and, perhaps, place it at a longer sleep duration (because of a lack of a clear up-swing).

For employment status (working/being retired), working is likely to restrict sleep, while being retired is associated with longer sleep (Akerstedt et al., 2018; Groeger et al., 2004). However, little is known about the influence of employment status on the association between sleep duration and mortality. With respect to occupational group, blue-collar workers often have early starting times for their work shifts, have shift work (Statistics Sweden, www.scb.se), and have less influence over their work hours than white-collar workers (Ala-Mursula et al., 2006). However, the effect of occupational type on the association between sleep duration and mortality is unknown.

The duration of sleep decreases with age (Groeger et al., 2004), which might affect the probability of finding a significant link between long sleep and mortality in older individuals. The U-shaped associations have been significant, although rather modest, in most meta-analyses, despite the original studies being age adjusted in the basic model (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017; Liu et al., 2017; Ren et al., 2020). In some studies that were stratified by age, a U-shaped association between sleep duration and mortality was found in the older group, but not in the younger one (Gangwisch et al., 2008; Yeo et al., 2013), as well as in both groups (Svensson et al., 2020). However, the cut-off for age was only 50 or 60 years, respectively, in those studies, that is, the older groups in those studies were rather young. One study found a U-shape among the young only (Akerstedt et al., 2017), but had a restricted span of durations, <5-hr duration was combined with 5-hr duration and >8 hr of sleep was combined with 8-hr duration.

In addition, there is some evidence that adjusting for age strongly attenuates the association between sleep duration and mortality, even if long and short sleep still retain significant HRs (Akerstedt et al., 2021; Kronholm et al., 2011). It is possible that resilience to external demands decreases with age (Cosco et al., 2017), while the susceptibility to disease increases (Shetty et al., 2018). Hence, sensitivity to short sleep might increase with age. Long sleep, if resulting from age-related impaired health, might increase the HR for long sleep. This reverse causation might counteract the hypothesised effect of sleep truncation.

With respect to the association of sleep duration with mortality, one needs also to consider the possibly modifying influence of napping and sleep medication. Both are associated with increased mortality (Kripke, 2016; Wang et al., 2019), and could influence the association between sleep duration and mortality, although no prior work is available.

The purpose of the present study was to investigate the shape of the association between sleep duration and mortality across employment status, age groups, and occupational groups (white- and blue-collar workers). We hypothesised that the association might be stronger in older age groups, and that those at work, and blue-collar workers, would show weaker associations between long sleep and mortality.

2 | METHODS

2.1 | Design and participants

In this study we used The Swedish National March Cohort (SNMC), which is a prospective cohort study designed to investigate the association between lifestyle factors and chronic diseases (Trolle Lagerros et al., 2017). The cohort was empanelled in 1997 as a part of a fund-raising activity of the Swedish National Cancer Society. At 3,600 sites, all over Sweden, the participants were invited to complete a questionnaire regarding lifestyle, demographics, and health. In addition, they provided their individually unique national registration number, assigned to all Swedish residents. This number was subsequently linked to continuously updated and complete national databases.

A total of 43,865 subjects completed the questionnaire. We excluded those with an incorrect national registration number, those with inconsistent or absurd answers (e.g. pregnant men, or individuals with impossibly high alcohol consumption), wrong data on age, those who had emigrated or died before start of follow-up, and those who were aged <18 years. This left 42,063 subjects, which were followed prospectively for all-cause mortality. The follow-up started on October 1, 1997, and ended at death, emigration or on April 26, 2018, whichever occurred first (Figure 1). The mean (± *SD*) for follow-up time was 18.3 (4.1) years, with shortest

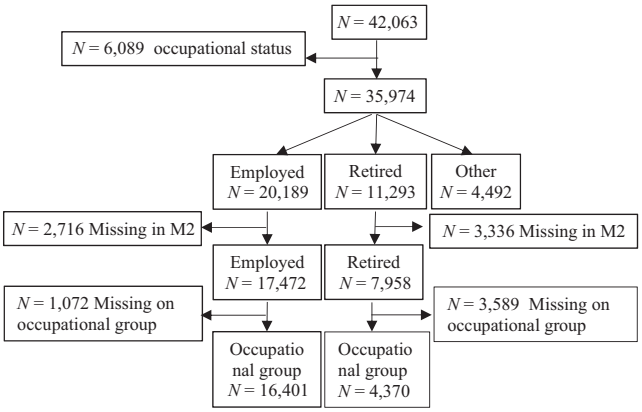

FIGURE 1 Flow diagram of exclusions. M2, Model 2 (adjusted); *N*, number of individuals

and longest follow-up time being 0.03 (11) days and 20.6 years, respectively. The response rate could not be determined as it is unknown how many subjects were originally given a questionnaire. In addition, 9,622 individuals did not have an occupational code. The code is used by Statistics Sweden (the national statistics authority) to classify the occupations of all Swedish citizens, but it was available only 5 years after start of the follow-up. Some participants had retired or died during that time and, therefore, did not receive an occupational code. Furthermore, a total of 6,089 individuals were excluded due to missing data on employment status. The initial number of subjects after excluding those with missing values on habitual sleep duration (n = 2,465) and covariates of interests was 25,432. The study was approved by the Regional Ethical Review Board of Karolinska Institutet. Informed consent was provided by all participants.

Subgroups for stratified analyses were employment status (employed or retired) and occupational group (high white-collar workers, low white-collar workers, and blue-collar workers). "High" here refers to managerial and professional occupations, such as heads of companies and organisations, lawyers, civil engineers, high school teachers, medical doctors, university teachers, etc.; Classes 1 and 2 in the official Swedish Classification System - SSYK of 1996 (Scb Standard för svensk yrkesklassificering [SSYK], Swedish Standard for Classification of Occupations, 1996). "Low" (Classes 3–5) refers to office workers, nurses, pilots, police officers, salespersons, etc., with a shorter post-high school education. "Blue-collar" (Classes 6–8) refers to manual workers, e.g. construction workers, metal workers, transport workers, assistant nurses, etc.

2.2 | Variables

All-cause-mortality data was obtained by linkage of national registration numbers to the Swedish Cause of Death Registry, held by the National Board for Health and Welfare. A total of 7,655 deaths occurred during the follow-up period. Main causes of deaths were cardiovascular diseases (International Classification of Diseases [ICD]-10 codes I00-I99, n = 2,254) and cancer (ICD-10 codes C00-C97, n = 2,654).

Sleep duration was obtained from the Karolinska Sleep Questionnaire (KSQ) (Akerstedt et al., 2008). The question on sleep duration was formulated as "How many hours, approximately, do you usually sleep during a weekday night?". The response alternatives were <5, 5, 6, 7, 8 or >8 hr. The initial reference category was set to 7 hr as that is most commonly used but was subsequently changed depending on effects of stratification and of covariates.

The following variables served as covariates: age, sex, educational level (university versus high school and compulsory school [9 years]), Charlson Comorbidity Index (CCI; based on severity of major diseases; Charlson et al., 1987), body mass index (BMI; weight in kilograms divided by height in meters squared), smoking (current versus previous/never), exercise (4 hr/week versus less), coffee consumption (>4 cups/day versus less), and alcohol consumption (medium plus high versus low or none).

Furthermore, several of the following variables were used to either describe baseline characteristics or to adjust for in sensitivity analyses: taking naps (sometimes + mostly + always versus seldom/never), not feeling rested on awakening (never + seldom versus sometime + often + always), poor sleep (rather poor + very poor versus very good + god + neither good nor poor) use of sleep medication (sometimes + mostly + always versus never + seldom), sleep during weekends/days off and self-rated need for sleep (<5, 5, 6, 7, 8, ≥9 hr, for both the latter). The sleep variables correspond to those of the KSQ (Akerstedt et al., 2008).

2.3 | Statistical analysis

Summary characteristics of baseline variables are presented by categories of sleep duration and for stratified groups.

Cox proportional hazards models were fitted to estimate overall mortality HRs with 95% CIs for different categories of sleep duration. In addition, we used polynomial regression to study the shape of the association between sleep duration and mortality, using linear and quadratic components.

Participants were followed-up from baseline to death, emigration or end of the study whichever came first, yielding up to 21 years of follow-up time. The time scale used in Cox regression analysis was time from start of follow-up. Cox regression proportional hazard assumptions were tested through formal statistical tests based on the Schoenfeld residuals. In cases where the proportional hazards assumption was not correct, appropriate adjustments were performed (stratified Cox regression, or time varying effects).

The focus of the analyses was the association between sleep duration and mortality, and the influence of employment status (employed or retired), occupational group, and age. The main analysis approach was stratification by the three potential influences, with inclusion of interaction terms. The analyses used only complete cases, excluding individuals lacking data on a covariate included in the analysis.

Our analyses were a priori specified as follows:

1. The first analysis used the whole sample (employed + retired individuals) to study the association of sleep duration and mortality, and the effect of adjustment for age only. The question here is whether adjustment for age alone is the driving force behind the attenuated U-shape seen in most prior studies. In step (a) Model 1 was unadjusted (crude), and Model 2 was adjusted for all covariates: age, sex, BMI, daily exercise, education, smoking, alcohol consumption, and the CCI. In step (b) (evaluating the effects of adjusting for age) adjustment was made for age alone, and then for all other covariates, except age, in a separate model. In step (c) a sensitivity analysis was carried out through adding, one at a time, possible influences on sleep duration (napping, sleep medication, and shift work) to the total list of covariates.
2. In the second analysis, the whole sample was stratified by employment status (employed and retired), and analysed without any adjustment (Model 1), and with adjustment for all covariates (Model 2), with an interaction term for sleep duration and employment status computed for Model 2. To study the age aspect within each group, a further stratification on age was carried out (with age excluded from Model 2).
3. In the third analysis the whole sample was stratified into five age groups and analysed with and without adjustment (age was not included among the covariates, but employment status was added to adjust for being employed/retired).
4. In the fourth analysis the whole sample was stratified on occupational group and analysed with and without adjustment for all covariates, and with interaction term for occupational group and sleep duration. In addition, the same analysis was carried out on those employed and retired separately.

The difference in association between sleep duration and mortality across subgroups was tested through interaction terms, using the likelihood ratio test. The Wald test was used to test the interaction terms. To investigate possible reverse causality, the first 2 years of follow-up were excluded in a sensitivity analysis.

Missing data for the covariates were: age, 0%; sex, 0%; educational level, 0%; CCI, 0%; BMI, 3.7%; smoking, 8.7%; exercise, <1%; and coffee consumption, <1%. We assumed that data were missing at random. Multiple imputation (van Buuren et al., 1999) was used to impute missing data on covariates and sleep duration. Stata 16.1 was used for statistical analysis.

3 | RESULTS

Table 1 describes the baseline characteristics for the six groups of sleep duration among those employed plus retired. Short sleepers (<5 hr) had a high prevalence of sleep medication use and perceived poor sleep. Both long and short sleepers had a high prevalence of disease at baseline, napping, not being well rested, and of being retired.

Table S1 describes baseline characteristics across employment status (separately for the employed and retired), and across occupational groups (combined employed and retired groups). Notably, the retired group was less healthy, reported shorter sleep, shorter need for sleep, and more napping. Shift work, high workload and napping were more prevalent in blue-collar workers. Table S2 describes baseline characteristics for the five age groups. The older age groups reported worse health, shorter education, more use of sleep medication, more napping, but also a *lower* prevalence of not being rested on awakening.

The first analysis (Table 2, Model 1, entire sample) shows a significant U-shape (quadratic component) for the association between sleep duration and mortality in the combined group of employed and retired individuals. There is a clearly defined low risk duration at 7 hr (with significant HRs for all other durations), and a pronounced increase in HR from 7 hr towards highest HR values at <5- and ≥9-hr sleep duration, respectively. The pattern was strongly attenuated in Model 2 (adjusted), but the HRs for the shortest and longest sleep duration remained significant.

To investigate the effect of adjusting for age, we carried out an analysis with only age as a covariate in Model 1 and all other covariates in Model 2. For Model 1, the results were HR of 1.27 (95% CI 1.13, 1.42) for sleep of <5-hr duration and HR of 1.41 (95% CI 1.22, 1.63) for ≥9-hr duration. The HRs are similar to those of the multivariable adjusted Model 2 in Table 1, entire sample. Adjustment for all other covariates yielded HR of 2.56 (95% CI 2.29, 2.88) for <5 hr and HR of 2.25 (9%% CI 1.94, 2.61) for ≥9 hr of sleep.

As a sensitivity analysis of variables that might affect sleep duration, and possibly mortality, we added employment status, napping, shift work, and use of sleep medication as covariates one at a time to Model 2. This did not change the results; nor did entering these variables in interaction analyses with sleep duration. Eliminating the first 2 years of follow-up did not affect the main results appreciably (data not shown).

In the second analysis, we stratified by employment status, and found that the employed group showed (Table 2) a significant U-shaped association between sleep duration and mortality in both models, and a significant HR for <5-hr sleep duration. Lowest risk in the adjusted model was at 6 hr, but 5 hr also had a low HR. Retirees showed a strongly significant U-shape for both models, with significant HRs for sleep durations of <5 and ≥9 hr for both models, but with attenuation in the adjusted model (Table 2). Most of the effect of adjustment was due to age. Optimal sleep duration was 8 hr in the adjusted model, but the span of non-significant HRs ranged between 5 and 8 hr. The interaction term between employment status and sleep duration was not significant.

To study the effect of age within employment status groups, we stratified by age (two categories) within the employed and retired groups, respectively. We found no significant association between sleep duration and mortality (multivariable model) in the younger, employed half (aged 18.0–48.1 years). For the older half (aged 48.2–68.9 years) a significant U-shape was found for the association between sleep duration and mortality, but only the <5-hr sleep duration showed a significant HR of 1.94 (95% 1.35, 2.81). In

TABLE 1 Baseline characteristics by sleep duration during weekdays

	Sleep duration					
	<5 hr	5 hr	6 hr	7 hr	8 hr	≥9 hr
N	722	1,298	6,158	11,303	5,507	442
Age, years, mean (*SD*)	62.4 (14.4)	56.1 (14.4)	52.7 (13.9)	52.0 (13.8)	54.7 (15.1)	59.3 (15.8)
Female, %	60.0	61.2	59.7	61.4	63.7	58.6
BMI, kg/m^2, mean (*SD*)	25.2 (3.5)	25.2 (3.8)	24.8 (3.5)	24.5 (3.3)	24.6 (3.4)	25.0 (3.6)
Exercise, %	56.8	55.0	55.1	53.8	57.3	57.2
University education, %	21.2	32.4	39.1	42.8	36.9	31.3
Smoking: current, %	7.9	7.2	8.6	6.8	5.9	4.7
Coffee: >4 cups/day, %	14.2	22.1	21.0	17.1	13.8	11.8
Alcohol (medium-high), %	36.8	43.0	44.4	43.6	39.8	40.6
Sleep duration weekdays, hr, mean (*SD*)	4.0 (1.3)	5.0 (1.1)	6.0 (0.9)	7.0 (0.6)	8.0 (0.5)	9.0 (0.5)
Sleep duration weekends/days off, hr, mean (*SD*)	4.8 (1.5)	6.2 (1.3)	7.2 (1.0)	7.8 (0.8)	8.2 (0.7)	8.8 (0.6)
Sleep need, hr, mean (*SD*)	6.6 (1.2)	6.4 (1.0)	7.0 (0.8)	7.5 (0.6)	8.0 (0.4)	8.6 (0.6)
Retired, %	62.0	37.8	26.3	25.6	40.5	62.4
Hypnotics (sometimes-always), %	20.9	15.1	6.3	3.5	2.9	5.9
Napping (sometimes-always), %	53.9	37.2	36.2	37.0	45.8	65.6
Not well rested (sometimes-always), %	39.0	22.5	30.1	41.3	55.0	57.2
Bad sleep (rather bad-very bad), %	34.2	32.6	10.0	2.3	1.3	1.3
Charlson Comorbidity index >0, %	19.9	14.6	9.8	9.0	12.3	17.4

Employed plus retired group. Groups were compared using analysis of variance or chi-square test depending on type of data.

the retired group, the younger half (aged 55.1–69.1 years) showed a significant U-shape, with a HR of 1.45 (95% CI 1.15, 1.83) for <5-hr duration and a HR of 1.40 (95% CI 1.20, 1.62) for the ≥9-hr duration. For the older half (aged 69.2–94.1 years) of the retired group, the U-shape was significant, with a HR of 1.40 (95% CI 1.20, 1.62) for <5-hr duration, and a HR of 1.40 (95% CI 1.14, 1.73) for ≥9-hr duration. Analyses using Schoenfeld's criterion showed that the assumption of proportional hazards was violated in the adjusted model of the analysis of the employed and retired groups, with age as a cause.

In the third analysis, we stratified by age in five age groups for the entire sample, with and without adjustment for covariates (age was not included, but employment status was added as a covariate to adjust for retirement). In the adjusted model (Model 2), the three youngest groups lacked a significant quadratic component, but in the 51.6–60.3-year age group the <5-hr duration showed a significant HR (Table 3). Both older groups (aged 60.4–68.8 and 68.9–94.3 years) showed significant quadratic components and significant HRs for both <5- and ≥9-hr sleep durations. No linear components were significant. The unadjusted results showed similar results. The interaction term for sleep duration/employment status was not significant.

In the fourth analysis (Table 4) white-collar workers showed a significant U-shape for the association between sleep duration and mortality, and significant HRs for <5- and ≥9-hr sleep durations for both models. Low white-collar workers showed a significant U-shape for the unadjusted model, but this was not seen in the adjusted model. Still, ≥9-hr sleep duration showed a significant HR. Blue-collar workers showed a significant U-shape for both models, but the adjusted model showed a significant HR for short sleep (<5 hr) only. The interaction term between occupational groups in the fully adjusted model (Model 2) was not significant. Table S3 shows that there was no significant U-shape for any occupational group among the employed, but the U-shape was significant for high white-collar workers and blue-collar workers among the retired.

Multiple imputations of missing data (15) did not affect the results in the tables.

To study the role of follow-up time, we repeated the analysis in Table 2 (multivariable model) with 15 and 10 years of follow-up. This yielded for 15 years a HR of 3.42 (95% CI 1.12, 1.53) for <5 hr and a HR of 2.49 (95% CI 1.06, 1.58) for ≥8 hr. For 10 years, the results were a HR of 3.08 (95% CI 1.13, 1.74) for <5 hr and a HR of 1.81 (95% CI 0.97, 1.73) for ≥8 hr.

To determine the association between sleep duration, age and retirement, an exploratory regression analysis was carried out on the combined employed and retired groups. This showed significant beta coefficients for age/10 years ($\beta = -0.07$ hr, 95% CI −0.08, −0.06), and for retirement (0/1 for employed/retired) ($\beta = 0.18$ hr, 95% CI 0.15, 0.22), with a constant of 7.11 hr. The results correspond to a decrease in sleep duration by 0.07 hr (4.2 min) per 10 years, and an increase with retirement of 0.18 hr (10.8 min).

4 | DISCUSSION

In the present study, the U-shape of the association between sleep duration and mortality was pronounced without adjusting for covariates. However, age adjustment strongly attenuated the effects,

TABLE 2 Hazard ratio (HR) with 95% confidence interval (CI) for the association between sleep duration and all-cause mortality, by employed and retired groups

	Whole sample		Employed		Retired	
	HR (95% CI) Model 1	HR (95% CI) Model 2	HR (95% CI) Model 1	HR (95% CI) Model 2	HR (95% CI) Model 1	HR (95% CI) Model 2
N and deaths (D)	*N* = 25,430 D = 5,610	*N* = 25,430 D = 5,610	*N* = 17,473 D = 1,274	*N* = 17,473 D = 1,274	*N* = 7,957 D = 4,336	*N* = 7,957 D = 4,336
Quadratic term *p*	<0.001	<0.001	<0.01	<0.05	<0.001	<0.001
Sleep duration, hr						
<5	**3.25 (2.90, 3.64)[c]**	**1.24 (1.10, 1.39)[c]**	**2.03 (1.44, 2.88)[c]**	**1.74 (1.16, 2.60)[c]**	**1.65 (1.46, 1.87)[c]**	**1.22 (1.08, 1.39)[b]**
5	**1.50 (1.34, 1.68)[c]**	1.02 (0.91, 1.14)	1.13 (0.86, 1.50)	1	**1.15 (1.01, 1.31)[b]**	1.06 (0.93, 1.21)
6	**1.08 (1.01, 1.16)[a]**	1.00 (0.93, 1.07)	1.05 (0.88, 1.24)	1.03 (0.79, 1.35)	1.08 (0.99, 1.18)	1.04 (0.96, 1.14)
7	1	1	1.02 (0.88, 1.19)	1.12 (0.86, 1.45)	1	1.02 (0.94, 1.10)
8	**1.44 (1.35, 1.54)[c]**	1.00 (0.94, 1.07)	1	1.14 (0.86, 1.51)	1.03 (0.96, 1.11)	1
≥9	**2.78 (2.40, 3.22)[c]**	**1.30 (1.12, 1.51)[c]**	1.13 (0.65, 1.97)	1.22 (0.67, 2.21)	**1.43 (1.22, 1.66)[c]**	**1.34 (1.13, 1.57)[c]**

Model 1, unadjusted; and Model 2, adjusted for all covariates: age, sex, body mass index, daily exercise, education, smoking, alcohol, and Charlson Comorbidity Index. Also, *p* value for quadratic component. Note that the reference value may differ between groups and models, as the lowest HR is modified by group or covariates.

[a], $p < 0.05$; [b], $p < 0.01$; [c], $p < 0.001$; D, number of deaths; *N*, number of participants.

Bold = significant HRs. Q = Quadratic components. 1: linear term $p = 0.001$. Individuals with missing data on covariates in Model 2 have been excluded.

and the U-shape was present only in older age groups. Furthermore, being retired (or working) did not affect the association, nor did occupational group.

The clear U-shape of the association between sleep duration and mortality agrees with previous findings (Cappuccio et al., 2010; da Silva et al., 2016; Yin et al., 2017). However, the associations are rather modest possibly because virtually all previous work has presented results adjusted for age. The present study, together with two other studies (Akerstedt et al., 2021; Kronholm et al., 2011), indicate that adjustment for age will dramatically attenuate the association of sleep duration and mortality. This includes a widening of the range of sleep durations with low mortality to 5–8 hr. The observation suggests that statements referring to 7 hr sleep duration (or sometimes 8 hr) as the sleep duration with low mortality risk are too conservative.

The present study also shows that the U-shape becomes discernible with increasing age. However, there are no similar studies to compare with, as previous studies only used dichotomised data, with one high and one low age group. In two of these studies, the authors found U-shaped associations only in the older half of their samples (Gangwisch et al., 2008; Yeo et al., 2013). In another study, which examined retired individuals only, a U-shaped association was also found (Akerstedt et al., 2021). Finally, another study uncovered a U-shaped association in both young and old groups (Svensson et al., 2020). However, the young group in that study used 40 years as the lowest age (rather than the 18 years used in the present study); thus, young adults were excluded. Taken together, the results suggest that the U-shape of the association between sleep duration and mortality is only present in older individuals. Thus, the null hypothesis of no age effect is rejected. However, it is conceivable that the association between sleep duration and mortality in younger groups may be clearer if follow-up time is extended, as suggested by the increase in strength of the U-shape with increased follow-up time in the present study. This possibility should be considered in future studies.

The reason for the stronger association between sleep duration and mortality with increasing age is not clear. However, the number of deaths is, for natural reasons, low in the younger age groups, which reduces statistical power. Any organism becomes more vulnerable to different type of challenges with increasing age (Cosco et al., 2017; Shetty et al., 2018). Shortened sleep may be such a challenge, with effects on mortality via impaired cerebral waste removal, disturbed lipid metabolism, and disturbed glucose metabolism (Grandner, 2017). However, a causative link has not been proven. The role of long sleep for premature death has less plausible explanations, but one notion suggests that increased immune activation would increase sleep duration, as well as mortality (Grandner, 2017). Also, subclinical depression could be hypothesised to work in the same way (Grandner, 2017). One might also consider the fact that sleep duration decreases with age (Groeger et al., 2004), making long sleep an anomaly in older age groups.

Diseases that appear during follow-up time, may not only contribute to increased mortality, but may also reflect reverse causality due to subclinical disease at baseline, affecting sleep duration at that time. However, this issue would need very elaborate designs to address. It is also noteworthy that the <5- and ≥9-hr sleep duration groups in the present study both contained the largest proportions of retired individuals (and the oldest age), of nappers, of those not being well rested, and of those with major diseases. Even if these factors were included as covariates in the main analyses, or in sensitivity analyses, the results give an impression of fragility in the long- and short-duration sleepers.

For employment status, the retirees showed a significant U-shape, whereas that of the employed was weaker with a significant

TABLE 3 Hazard ratio (HR) with 95% confidence interval (CI) for the association between sleep duration and all-cause mortality, by age group

	Age group				
	18–41.7 years HR (95% CI)	**41.8–51.5 years HR (95% CI)**	**51.6–60.3 years HR (95% CI)**	**60.4–68.8 years HR (95% CI)**	**68.9–94.3 years HR (95% CI)**
N and deaths (D)	*N* = 5,606 D = 98	*N* = 5,491 D = 284	*N* = 5,331 D = 608	4,954 D = 1,701	*N* = 4,048 D = 2,919
Unadjusted (Model 1)					
Quadratic term *p*	>0.05	>0.05	>0.05	<0.001	<0.001
Sleep duration, hr					
<5	3.24 (0.45, 22.97)	1.81 (0.21, 15.41)	**2.82 (1.20, 3.01)[b]**	**1.55 (1.22, 1.97)[c]**	**1.35 (1.17, 1.56)[c]**
5	1	1.39 (0.18, 10.37)	1.15 (0.82, 1.63)	1.07 (0.85, 1.34)	1.01 (0.87, 1.18)
6	1.95 (0.46, 8.25)	1.63 (0.23, 11.70)	1	1	1.04 (0.93, 1.15)
7	1.84 (0.45, 7.60)	1.43 (0.20, 10.26)	1.00 (0.81, 1.24)	1.00 (0.88, 1.14)	1.00 (0.88, 1.09)
8	2.16 (0.51, 9.15)	1.97 (0.27, 14.28)	1.02 (0.82, 1.28)	**1.11 (0.97, 1.28)[a]**	1
≥9	2.76 (0.39, 19.59)	1	1.17 (0.55, 2.47)	**1.64 (1.27, 2.14)[c]**	**1.35 (1.11, 1.64)[a]**
Adjusted (Model 2)					
Quadratic term *p*	>0.05	>0.05	>0.05	<0.001	<0.001
Sleep duration, hr					
<5	3.79 (0.53, 27.11)	1.53 (0.18, 13.21)	**2.01 (1.19, 3.41)**	**1.46 (1.16, 1.84)[c]**	**1.39 (1.20, 1.61)[c]**
5	1	1.14 (0.15, 8.91)	1.32 (0.90, 1.92)	1.05 (0.85, 1.31)	1.14 (0.97, 1.33)
6	2.13 (0.50, 9.06)	1.35 (0.19, 9.42)	1.01 (0.79, 1.30)	1.00 (0.88, 1.14)	1.11 (1.00, 1.24)
7	2.26 (0.54, 9.42)	1.25 (0.17, 9.01)	1.15 (0.91, 1.44)	1	1.03 (0.93, 1.13)
8	2.59 (0.60, 11.19)	1.73 (0.24. 12.60)	1	1.05 (0.93, 1.19)	**1**
≥9	4.32 (0.60, 31.17)	1	1.10 (0.51, 2.36)	**1.50 (1.16, 1.93)[b]**	**1.35 (1.11 1.64)[b]**

Model 1, unadjusted; and Model 2 adjusted for all covariates except age, including sex, body mass index, daily exercise, education, smoking, alcohol, and Charlson Comorbidity index. Also, *p* value for quadratic components. Employed plus retired group. Note that the reference value often differs between groups and models, as the lowest HR is modified by group and/or covariates.

[a], $p < 0.05$; [b], $p < 0.01$; [c], $p < 0.001$; D, number of deaths; *N*, number of participants.

Bold = significant HRs. Also, *p* value for quadratic component. Missing data on covariates in Model 2 have been removed. No linear component significant.

HR only for the <5-hr duration. The sensitivity analyses (whole sample), with employment status entered as a covariate or with an interaction term, did not affect the association between sleep duration and mortality. Hence, employment status does not influence the association between sleep duration and mortality. While there are no comparable data in the literature, the explanation for the lack of effect of employment status may be because an association between sleep duration and mortality exists only in older individuals, as discussed above.

The lack of significant interaction between occupational groups indicates that patterns of association between sleep duration and mortality were not different, which was in contrast to the hypothesis. Still, both blue- and high white-collar workers showed significant U-shapes (although the latter group did not show a significant HR for ≥9 hr of sleep), and low white-collar workers showed a significant HR for ≥9 hr of sleep. With multivariable adjustment, the span of sleep with low risk of mortality is quite wide for all groups. Therefore, it is not possible to draw any conclusions about differences in shape or low-risk duration between occupational groups. It should also be noted that the findings refer to the combined groups of employed and retired (whole sample). In the employed group alone, no significant U-shape was found, but it was present in the retired group for both high white- and blue-collar workers.

Overall, it appears that the hypothesis of the role of sleep truncation as a modifier of the association between sleep duration and mortality, was not supported. Possibly, the restrictions on sleep were too modest, and sleep duration was very similar between employment status groups and occupational groups.

Among the strengths of the present study is the size, the virtually complete set of registry data on mortality, and the long follow-up time. We also used curve-fitting to determine if there was U-shaped association between sleep duration and mortality, in addition to establishing whether HRs for long and short sleep significantly deviated from the reference value. We also systematically used the lowest HR as reference for sub-analyses, as it varied with covariates and stratifications. One limitation of the present study is the large loss of data in the occupational group due to occupational codes being obtained only 5 years after start of the study. The main consequence was a substantial loss of mainly older participants, who retired or died before the code could be obtained. This may have

TABLE 4 Hazard ratio (HR) with 95% confidence interval (CI) for the association between sleep duration and all-cause mortality, by occupational groups

	High white-collar		Low white-collar		Blue-collar	
	HR (95% CI) Model 1	HR (95% CI) Model 2	HR (95% CI) Model 1	HR (95% CI) Model 2	HR (95% CI) Model 1	HR (95% CI) Model 2
N and deaths (D)	*N* = 6,880 D = 825	*N* = 6,880 D = 825	*N* = 7,663 D = 1106	*N* = 7,663 D = 1,106	*N* = 6,228 D = 962	*N* = 6,228 D = 962
Quadratic term *p*	<0.001[1]	<0.01	<0.001[1]	>0.05	<0.001[1]	<0.001[2]
Sleep duration, hr						
<5	**3.22 (2.08, 4.97)[c]**	**1.70 (1.09, 2.63)[a]**	**2.09 (1.49, 2.92)[c]**	1.08 (0.77, 1.93)	**2.58 (1.89, 3.51)[c]**	**1.52 (1.03, 2.23)[c]**
5	**1.54 (1.10, 2.16)[a]**	1.21 (0.86, 1.70)	**1.38 (1.04, 1.83)[a]**	1.09 (0.92, 1.29)	1.06 (0.78, 1.44)	1
6	1	1	**1.20 (1.03, 1.39)[a]**	1.09 (0.92, 1.29)	1	1.01 (0.74, 1.36)
7	1.13 (0.94,1.36)	1.11 (0.93, 1.34)	1	1.01 (0.87, 1.18)	1.07 (0.90, 1.27)	1.02 (0.77, 1.37)
8	**1.46 (1.19, 1.80)[c]**	1.09 (0.89, 1.35)	**1.41 (1.21, 1.64)[c]**	1	**1.47 (1.23, 1.77)[d]**	1.20 (0.89 1.62)
≥9	**4.08 (2.76, 6.05)[c]**	**1.72 (1.15, 2.56)[b]**	**2.91 (2.04, 4.15)[c]**	**1.51 (1.05, 2.17)[a]**	**1.95 (1.27, 2.99)[b]**	1.27 (0.78, 2.08)

Also, *p* value for quadratic components. Employed plus retired group. Note that the reference value often differs between groups and models, as the lowest HR is modified by group and/or covariates.

Model 1, unadjusted; Model 2, adjusted for age, sex, body mass index, daily exercise, smoking, alcohol, Charlson Comorbidity index.

[a], $p < 0.05$; [b], $p < 0.01$; [c], $p < 0.001$; D, number of deaths; *N*, number of participants.

Education not entered as a covariate because of collinearity with occupational group. 1: linear term $p < 0.001$. 2: linear term $p < 0.01$. Individuals with missing data on covariates in Model 2 have been removed.

attenuated the effects of age on the association between sleep duration and mortality. A second limitation is the missing data on employment status (employment/retirement). A third limitation is that only self-reported sleep duration was available, but objective sleep data are, as yet, not feasible in large cohorts. A fourth limitation is that the study lacked repeated measurement of exposure. Reverse causality may have been present but should have been handled through the prospective design and the removal of the first 2 years of follow-up.

In conclusion, the present study has shown that that the U-shape of the association between sleep duration and mortality was present only in older age groups, with no influence of retirement or occupational group, and that the span of sleep durations with low risk was quite wide.

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CONFLICT OF INTEREST

None of the authors have reported any conflicts of interest.

AUTHOR CONTRIBUTIONS

TA conceived of the study and wrote the first draft. LW analysed the data. YTL, RB, HOA, and WY provided the cohort and critically commented on the design and manuscript.

DATA AVAILABILITY STATEMENT

The data underlying this article may be shared after application to YTL, RB and WY.

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