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Association of sleep duration and incidence of diabetes modified by tea consumption: a report from the Shanghai Men's Health Study

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Abstract

Objectives—To evaluate the association between sleep duration and the incidence of diabetes stratified by sleep-related factors among Chinese men.

Methods—This study included 34,825 men who provided information on sleep-related questions in the Shanghai Men's Health Study, a population-based cohort study conducted in Shanghai, China from 2002 to 2011. Participants were excluded who had a history of diabetes or who were diagnosed with diabetes within 2 years of recruitment. Cox regression was employed to evaluate the influence of sleep duration and its interaction with sleep-related factors on diabetes risk.

Results—A total of 1521 incident cases were documented during a median of 5.6 follow-up years. Adjusted hazard ratios and 95% confidence intervals were 1.0 (0.9–1.1) and 1.2 (1.0–1.3) for men who slept <7 and 8 hours per day, respectively, compared with those who slept 7 hours per day ($p_{\text{trend}}=0.01$). Stratified analyses revealed that the association between sleep duration and risk of diabetes was only statistically significant among current smokers and regular drinkers, never tea drinkers, men with a high body mass index, hypertension or comorbidity, and men who did not work nightshift or who snored. A statistically significant interaction between tea drinking and sleep duration was observed ($p_{\text{interaction}}=0.01$). The above association patterns remained when daytime nappers were excluded from the analyses.

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Conclusions—The data suggested that longer sleep duration, particularly among individuals already exhibiting factors linked to poor quality of sleep, was associated with diabetes. The association between sleep duration and diabetes may be modified by tea drinking, especially in older men or men with more sleep-related factors.

Keywords

Sleep duration and snoring; Diabetes incidence; Association; Lifestyle; Comorbidity

INTRODUCTION

Both sleeping quantity and quality play important roles in human health. The American Sleep Foundation has reported that a large majority (75%) of American adults complain of having had at least one symptom of a sleep problem [1] such as difficulty falling asleep, waking up too early and not being able to get back to sleep, or snoring. Both short and long sleep duration have been reported to be long-term risk factors for poor health, including obesity, diabetes, cardiovascular disease, and cancer [2–5].

However, data are inconsistent on the association between the duration and quality of sleep and the prevalence/incidence of diabetes. Results from cross-sectional studies and prospective studies have shown both short and long sleep duration, following a U-shaped pattern, to be associated with an increased risk of diabetes [6–8]. A Finish study reported this U-shaped association in women only [9]. Several other studies, however, found that either short sleep duration or long sleep duration, but not both, were associated with an incidence of diabetes [10–11]. Other studies have reported no association between sleep duration and diabetes [12–13].

Sleep duration may affect glucose metabolism by reducing glucose intolerance, insulin resistance, and acute insulin response to glucose [3]. The relationship between sleep duration and diabetes incidence may be influenced by many factors that influence the quality of sleep, such as body mass index (BMI), snoring and night shift work, and physical and economic conditions [2]. Furthermore, evidence suggests that the risk factors for diabetes may vary by ethnicity [14–15]. However, the vast majority of previous research studies on the association of sleep duration and diabetes risk have been conducted in developed countries, and few studies have focused on the effects of sleep-quality-related factors on this association.

Using data from the Shanghai Men's Health Study, a population-based cohort study of middle-aged Chinese men, a systematic evaluation was conducted of the association between sleep duration and diabetes risk, and its modification by sleep-quality-related factors.

METHODS

Study population

The Shanghai Men's Health Study (SMHS) is a population-based cohort study of 61,480 Chinese men aged 40–74 years and living in urban Shanghai, China. Participants were

recruited to the study from April 2002 to June 2006. A total of 83,033 eligible men from eight communities in urban Shanghai were invited to participate by trained interviewers through in-person contact, and 61,480 men who had no prior history of cancer were ultimately enrolled in the study (response rate 74.0%). Reasons for non-participation were refusal ($n=17,823$, 21.5%), out of area during enrollment ($n=2370$, 2.9%), and other miscellaneous reasons including poor health or hearing problems ($n=1360$, 1.6%). Sleep-related questions were added to the study after initiation of study enrollment. Thus, sleep information was unavailable for 16,776 SMHS participants, who were excluded from the current study.

Approximately 91% of SMHS participants provided a spot urine sample for the study, on which a urine glucose test was conducted. Participants who had positive results to the urine glucose test or who did not complete a urine test ($n=7367$) were excluded from the current study. Additionally, the study excluded SMHS participants who reported a history of diabetes at the baseline survey or were possible diabetes cases ($n=1881$), who were diagnosed with diabetes within the first 2 years of study enrollment ($n=256$), or who had <2 years of follow-up ($n=375$) from the study. The final analytic data set comprised 34,825 men.

A structured questionnaire was used to collect information on demographic characteristics, disease history, and lifestyle factors, including physical activity level, smoking and drinking history, dietary intake, tea consumption and shiftwork. Anthropometric measurements (taken at the baseline survey by trained interviewers) included height, weight, and circumference of waist and hips. The BMI was calculated as weight (in kg) divided by the square of height (in m), and the waist hip ratio (WHR) was calculated as waist circumference divided by hip circumference.

Sleep-related information was collected by the following questions: “In the past year, how many hours on average did you sleep per day? (Including sleeping at night time and napping during the day time, but not including waking time during the sleep period)” and “In the past year, did you nap during the day at least once a week? (Not including time slept during the daytime if you worked nightshift).”

Ascertainment of type 2 diabetes

Information on type 2 diabetes (T2D) was self-reported and collected during the in-person follow-up surveys, which took place every 2–3 years after baseline enrollment. The current study considered individuals who reported having a diagnosis of T2D and who met at least one of the following criteria, recommended by the American Diabetes Association, as having the study outcome: 1) fasting glucose concentration ≥ 7 mmol/L on at least two separate occasions; 2) an oral-glucose-tolerance test (OGTT) performed at the doctor's office with a value ≥ 11.1 mmol/L; and/or 3) use of hypoglycemic medication (ie, insulin or oral hypoglycemic drugs). Twelve self-reported diabetes cases that did not meet the above criteria, and 30 men who died of diabetes but had no information on diabetes diagnosis were excluded from the current study.

Statistical analysis

Sleep duration was categorized into three groups in the analysis: <7 hours, 7 hours, and 8 hours. ANOVA was used for comparing continuous variables and Chi-squared test was used for dichotomous variables between T2D cases and healthy men. Cox regression was applied to calculate hazard ratios (HRs) and 95% CIs for each sleep duration group, adjusted for potential confounders at the baseline survey. The study used 7 hours of sleep duration as reference in the analysis because this group has been previously suggested to be associated with the lowest incidence of diabetes [8]. Covariates, including age at interview (continuous), smoking (pack-years), alcohol consumption (drinks per day), current tea drinking (yes/no), energy intake (continuous), and physical activity (met-hours/year), snoring (yes/no), self-reported nightshift work history (yes/no), BMI (continuous), family history of diabetes (yes/no), hypertension (yes/no), and comorbidity (yes/no) were included in the COX model.

Tests for linear trend were performed by using an ordinal value for each sleep category (1 for <7 hours, 2 for 7 hours, and 3 for 8 hours) as the continuous variable in the model. Sleep-quality-related factors, such as physical inactivity, smoking, drinking, high BMI (≥ 25), comorbidity (≥ 1), hypertension (yes) and snoring (yes), were treated as the risk factors, and the total number of risk factors for each participant was tallied to calculate a 'risk score'. The score was categorized to three categories: low risk (score=0–2), moderate risk (score=3–4) and high risk (score >4). All p -values were two-tailed and differences at $p<0.05$ were accepted as statistically significant. All analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

The average age of cohort participants was 55.0 years (standard deviation (SD)=9.6 years). Average sleep duration was 7.1 hours (SD=1.3 hours). About 26.3% of participants in the study reported sleep duration of 7 hours per day, and 18,651 participants reported no daytime napping (nocturnal sleep only).

Table 1 shows selected demographic characteristics, lifestyle factors, and anthropometric measurements, as well as daytime napping and snoring by diabetes status. All data presented in Table 1 are age-adjusted. Over an average of 5.6 years of follow-up, a total of 1521 diabetes cases were documented from 2 years after study enrollment. Participants who developed diabetes were older, had higher BMI and WHR, and were more likely to have higher energy intake, higher prevalence of coronary heart disease and hypertension, and a family history of diabetes and snoring, compared with diabetes-free participants. There were no significant differences in education, income, or lifestyle factors between diabetes cases and healthy men.

Sleep duration was positively associated with diabetes risk, with HRs (95% CIs) of 1.00 (0.87–1.14) and 1.16 (1.02–1.32) for men who slept <7 and 8 hours per day, respectively, compared with those who slept 7 hours per day ($p_{\text{for trend}}=0.01$) (Table 2). Analyses stratified by selected factors that are known to be associated with sleeping duration or quality showed that long sleep duration and diabetes risk were more apparent in men who

were smokers, drinkers, or never consumed tea, had a high BMI or comorbidity, who did not have nightshift work, or who snored. A significant interaction was observed between tea drinking and sleep duration. Specifically, among never tea drinkers, sleeping <7 hours per day was associated with a decreased risk of diabetes incidence [HR: 0.87 (95% CI: 0.69–1.10)], while sleeping 8 hours per day was associated with increased risk of diabetes incidence [HR: 1.23 (95% CI: 0.99–1.53)], compared with men who slept 7 hours per day ($p_{\text{for trend}} < 0.01$). Sleep duration was not associated with diabetes risk among tea drinkers.

The current study further evaluated sleep duration and diabetes risk excluding individuals who took naps. As shown in Table 3, the risk pattern between sleep duration and diabetes risk remained, with $p_{\text{for trend}} = 0.04$. Moreover, this association was also observed in men who did not exercise. However, the association was attenuated in men who had comorbidity, hypertension, who did not have nightshift work, or who snored when sleeping among those who had nocturnal sleep only. The interaction between tea drinking and sleeping duration remained, and the point estimate for both short and long sleeping duration changed: HRs were 0.89 (95% CI: 0.64–1.24) for sleep duration <7 hour per day and 1.32 (95% CI: 0.96–1.81) for sleep duration 8 hour per day ($p_{\text{for trend}} = 0.01$). Associations between sleep duration and diabetes were also found among those people with unhealthy lifestyles, such as smoking and drinking ($p_{\text{for trend}} < 0.05$). However, in the current study, HR was 1.13 (95% CI: 0.96–1.32) among non-exercisers with sleep duration 8 hours/day and this association remained among nocturnal sleepers [HR=1.28 (95% CI: 1.03–1.59), $p_{\text{for trend}} = 0.04$]. An association between sleep duration and diabetes was found among men who snored ($p_{\text{for trend}} = 0.02$) in the current study, but this association was attenuated among nocturnal sleepers only ($p_{\text{for trend}} = 0.07$). No association between sleep duration and diabetes was found among men who did not snore. The analysis was also performed among participants who did not have shift work, and association patterns among them were similar with the data of nocturnal sleepers (data not shown).

Since age, lifestyle, health condition, BMI and snoring are sleep-related factors, and these factors may influence the modification effect of tea consumption, the current study calculated ‘risk score’ by sum of the total number of sleep-related factors for each participant, and evaluated the possible modifying effect of tea consumption stratified by age and ‘risk score’ (Table 4). No associations of sleep duration and diabetes were found among participants aged <60 years or with low/moderate risk scores. However, sleep duration was associated with diabetes among non-tea drinkers aged 60 years: HRs were 0.78 (95% CI: 0.55–1.10) for sleep duration <7 hours per day and 1.24 (95% CI: 0.88–1.74) for sleep duration 8 hours per day ($p_{\text{for trend}} < 0.01$). This association was also found among non-tea drinkers with high ‘risk score’ ($p_{\text{for trend}} < 0.01$). These associations were modified by tea consumption ($p_{\text{for interaction}} < 0.01$ and 0.03, respectively).

DISCUSSION

In this population-based prospective cohort study it was found that sleep duration was positively associated with diabetes risk, particularly among men who had ever drank alcohol or smoked regularly, who never drank tea, who had a high BMI, comorbidity, men who did not work nightshift or who snored. The association pattern remained and some point

estimates increased when participants who napped during the day were excluded. A significant multiplicative interaction between tea consumption and sleep duration on diabetes risk was observed among participants aged 60 years or with a high-risk score.

The association between sleep duration and diabetes is inconsistent in the literature. In the HIPOP-OHP study, a prospective cohort study conducted in Japan with a median of 4.2 years follow-up time, a null association between risk of developing diabetes and sleep duration was found [13]. A report from 23,620 middle-aged participants of the European Prospective Investigation into Cancer and Nutrition (EPIC)-Potsdam study reported a similar result: sleep duration was not associated with the risk of diabetes [12]. However, a literature review that included 36 cohort studies (1,061,555 participants) reported pooled RRs for sleep 5 hours and 9 hours per day of 1.48 (95% CI: 1.25–1.76) and 1.36 (1.12–1.65), respectively, and concluded that the risk of developing diabetes associated with sleep duration is comparable to that of traditional risk factors [16]. A recent cross-sectional study of 18,121 Chinese participants aged 40 years found that only long sleep duration (>9 hours per day), not short duration, was associated with high HbA1c, impaired glucose regulation (IGR), and diabetes in China [17]. A cohort study conducted in China also reported similar findings [18]. The results from the current study are in line with those findings.

It is worth mentioning that the positive sleep and diabetes association persisted among those only sleeping at night, presumably for whom there was a better exposure assessment. In addition, to minimize the potential for reverse causation, diabetes cases that were diagnosed within 2 years of follow-up, along with all first 2-year observations were excluded. Further excluding the first 5 years of observation showed a similar risk pattern, although some of the statistics lost significance due to the reduced statistical power (data not shown).

The mechanisms underlying the association between sleep duration and diabetes risk is unclear. One possible explanation of the association is that participants with longer sleep duration were more likely to snore, compared with short sleepers. This sleep problem could have played a part in the association [10,19]. In the current study, proportions of snoring and daytime napping in long sleepers was 45.1% and 50.9%, respectively, and significantly higher than in short sleepers, which is consistent with the data in the Finish diabetes prevention study [20]. Thus, long sleep duration could also be reflective of sleep problems, such as sleep-disordered breathing, which were associated with insulin resistance and diabetes in the current study. Another possible explanation is that sleep duration is highly correlated with obesity, the latter of which has been found to have deleterious effects on both glucose homeostasis and β -cell function, and with inducing insulin resistance [21]. Both BMI and WHR of long sleepers were significantly higher than in short sleepers in the current study, suggesting that obesity could be a mediation factor between sleep duration and diabetes risk.

Tea is the most widely consumed non-alcoholic beverage in the world, with especially high consumption in Asian countries [22]. Several studies have reported the beneficial effects of tea, not only on cardiovascular diseases but also on diabetes and other chronic diseases [23]. A retrospective study performed in Japan found a 33% risk reduction of developing diabetes among participants who consumed six or more cups of green tea daily, compared to those

consuming less than one cup per week [24]. A big cohort study conducted in eight European countries reported that people who drink at least four cups of tea per day might have a 16% lower risk of developing diabetes than non-tea drinkers [25]. However, a limited number of clinical trials using tea and tea extracts, or its main ingredient catechin, have shown inconsistent results in controlling hyperglycemia in diabetes patients. MacKenzie et al. showed no significant difference in glucose control after 3 months of ingestion of decaffeinated green tea extracts in diabetes patients [26]. However a recent study concluded that chamomile tea has some beneficial effects on glycemic control and serum lipid profile in T2D patients [27].

The effect of tea on sleep duration and diabetes risk is complicated. On one hand, tea consumption, especially green tea, has been shown to be associated with a significantly reduced risk of diabetes [28], due to its high flavonoid content, which may act as an antioxidant and anti-inflammatory agent to reduce the oxidative stress and inflammation that is often associated with the progressive impairment of pancreatic b-cell function in the development of diabetes [29–30]. On the other hand, tea consumption is negatively associated with sleep duration, due to its caffeine content, which can increase sleep onset latency and decrease total sleep time [31]. These functions could attenuate the association between sleep duration and diabetes risk among tea drinkers. The current study found that sleep duration was only associated with risk of diabetes among men who were not tea drinkers. The interaction effect of tea consumption and sleep duration on diabetes risk was statistically significant.

In studies published since 1990, current smokers were found to have a 1.2–2.6 times higher risk of diabetes than nonsmokers [32–33]. Smoking not only impairs insulin action in both diabetes patients and healthy people, through enhancing ethanol-induced pancreatic injury, but also increases lipase activity, which is linked with increased insulin resistance [34–35]. Several epidemiological studies have reported obesity as a key player in diabetes development and an elevated FFA level as a risk marker for long-term development of glucose intolerance and progression to diabetes [36]. Drinking is also a complex factor in the association with diabetes: moderate alcohol consumption reduces the risk of diabetes by 20–40% [37], while high alcohol consumption is associated with higher diabetes risk [38]. Meanwhile, smoking, drinking and obesity are related to the quality of sleep [2,4,6], and thus could modify the association between sleep duration and diabetes risk. In the current study, however, no modification effect of these factors was found on the association.

Day napping is a more common lifestyle habit in China than in other countries [39]. The prevalence of habitual day napping has been reported to be 61.7% among Chinese men aged 60 years [40]. In the current study, the percentage of napping was 53.6%. Picarsic et al. observed no difference between nappers and non-nappers in terms of reported nighttime sleep duration, sleep-onset latency, or sleep efficiency [41]. However, the current study found that the proportion of nappers was higher among participants who slept 9 hours per day compared with those who slept <6 hours (56.1% vs 42.8%, $p<0.001$), and napping was associated with diabetes risk. The current data were in line with another prospective study in which it was reported that duration of day napping from 1996–1997 was associated with a higher risk of diabetes after the year 2000 in a dose-response manner [42]. And among

participants who reported no napping, only short sleepers had a higher risk of diabetes, whereas among those napping >1 hour/day, both long and short sleeping was associated with higher risk of diabetes. This evidence suggests that napping could be an independent risk factor for diabetes, and napping habits may modify the association between nocturnal sleep duration and diabetes [42]. However, the current study also detected a relationship between night sleep duration and diabetes risk in the group of men who had only nighttime sleep. There was no difference in association of sleep duration with risk of diabetes between all participants and participants who slept only at night.

Snoring is a sleep problem, and a common and early symptom of obstructive sleep apnea [43]. Snoring affected 43.7% men in the current study, which is a similar proportion reported by Stradling [44]. The current study found an association between sleep duration and diabetes risk (OR=1.23, 95% CI: 1.01–1.49) among snorers with sleep duration ≥ 9 hours per day, but this association was not found among non-snorers. A recent study of 6522 participants aged ≥ 20 years from the National Health and Nutrition Examination Survey 2005–2008 reported that snoring was associated with diabetes risk with OR of 1.44 (95% CI: 1.16–1.79), an association that was also found in a meta-analysis [45–46]. The mechanisms underlying this association have not been elucidated completely. It could be that nocturnal intermittent hypoxia and hypercapnia contribute to increased sympathetic nervous activity and increased oxidative stress, which ultimately lead to insulin resistance, or relate to activation of pro-inflammatory cytokine production [47]. The current study found no reports on the relation of snoring and sleep duration to diabetes risk. However, snoring and longer sleep duration could have an additive effect on diabetes risk among the Chinese population. Further studies need to be conducted on this topic.

Strengths of the current study include its large sample size, and prospective and population-based design. In addition, a wide range of factors related to sleep duration and quality were incorporated into the study. The study also had several limitations. First, the information about sleep duration was self-reported, which may have lead to misclassification. However, a reasonable agreement between self-reported and actigraph-measured sleep duration has been previously reported [48]. Second, although snoring was included in the study, there were no other direct measurements of quality of sleep, such as obstructive sleep apnea or insomnia, which could have provided more information to help understand the association between sleep duration and risk of diabetes. Third, due to lack of information on length of afternoon napping time, the current study was unable to evaluate the relationship between napping duration and diabetes risk.

In conclusion, the current study found that sleeping duration was positively associated with diabetes risk, particularly among overweight individuals, but also those with comorbidity, hypertension, and snoring. The results suggest that targeting these higher-risk individuals for more rigorous diabetes screening and preventive interventions could provide a public health benefit.

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Highlights

The Shanghai Men's Health Study, a large population-based cohort study, was used to assess association between sleep duration and risk of type 2 diabetes incidence. The study found a J-shaped association between sleep duration and diabetes risk (ie, higher risk of diabetes was associated with longer sleep duration). This association was also observed among people who already had factors linked to poor quality of sleep, such as smoking, drinking, obesity, hypertension and comorbidity. Tea drinking could modify this association. The results suggest that targeting these higher-risk individuals for more rigorous diabetes screening and prevention could provide public health benefits.

Table 1

Comparison of baseline characteristics of diabetes cases and diabetes-free men in the SMHS.*

Characteristics	Diabetes (n=1521)	Healthy men (n=33,304)	p
Age (years, $\bar{x} \pm SE$)	55.63 $\pm$ 0.25	54.93 $\pm$ 0.05	<0.01
BMI (kg/m ² , $\bar{x} \pm SE$)	25.76 $\pm$ 0.08	23.53 $\pm$ 0.02	<0.01
WHR ($\bar{x} \pm SE$)	0.9294 $\pm$ 0.0014	0.8979 $\pm$ 0.0003	<0.01
Energy intake (kcal/day, $\bar{x} \pm SE$)	1964.06 $\pm$ 12.24	1915.40 $\pm$ 2.62	<0.01
Education (%)			
Primary school or less	6.38	6.33	0.18
Middle school	36.87	34.48	
High school	36.83	37.54	
College or more	19.91	21.65	
Income (yuan/per capita/year, %)			
<6000	14.07	12.92	0.29
6000	77.56	77.91	
10,000	8.37	9.17	
Occupation (%)			
Professional	23.51	23.72	0.61
Clerical	22.50	21.33	
Manual workers	53.99	54.95	
Disease history			
Hypertension (%)	43.44	27.00	<0.01
Coronary heart disease (%)	6.40	4.17	<0.01
Myocardial infarction (%)	1.02	0.69	0.16
Comorbidity score 1 (%)	28.64	26.88	0.13
Family history of diabetes (%)	28.13	16.10	<0.01
Current smoker (%)	60.63	61.00	0.77
Ever drank alcohol (%)	33.19	34.51	0.29
Current tea drinker (%)	65.86	64.46	0.28
Regular exercise participation (%)	34.01	34.36	0.75
Nightshift work (%)	35.59	34.61	0.51
Daytime napping (%)	49.17	46.33	0.03
Snoring (%)	59.55	43.00	<0.01

* Means and proportions were adjusted for age at interview

Table 2

Associations between sleep duration and diabetes risk by selected lifestyles factors. *

Sleep duration	<7 hours <i>n</i> =11,608		7–7.9 hours <i>n</i> =9149		8 hours <i>n</i> =14,068		<i>P</i> _{linear}	<i>P</i> _{interaction}
	cases	HR (95% CI)	cases	HR	cases	HR CI (95%)		
Total	506	1.00 (0.87, 1.14)	382	1.00	633	1.16 (1.02, 1.32)	0.01	
Age (years)								
40-	175	0.93 (0.74, 1.16)	141	1.00	225	1.18 (0.95, 1.46)	0.02	0.54
50-	157	1.05 (0.82, 1.33)	120	1.00	219	1.12 (0.89, 1.41)	0.49	
60-	174	1.03 (0.82, 1.31)	121	1.00	189	1.18 (0.93, 1.48)	0.23	
Currently drink tea								
Yes	339	1.07 (0.91, 1.27)	250	1.00	406	1.12 (0.96, 1.31)	0.54	0.01
No	167	0.87 (0.69, 1.10)	132	1.00	227	1.23 (0.99, 1.53)	<0.01	
Regular exercise participation								
Yes	179	1.04 (0.83, 1.30)	134	1.00	222	1.23 (0.99, 1.53)	0.09	0.70
No	327	0.99 (0.84, 1.17)	248	1.00	411	1.13 (0.96, 1.32)	0.07	
Current smokers								
Yes	288	0.92 (0.77, 1.09)	239	1.00	377	1.08 (0.92, 1.27)	0.04	0.75
No	218	1.11 (0.90, 1.38)	143	1.00	256	1.27 (1.03, 1.57)	0.15	
Ever alcohol drank								
Yes	173	0.80 (0.64, 1.02)	122	1.00	207	1.00 (0.80, 1.26)	0.04	0.65
No	333	1.08 (0.91, 1.27)	260	1.00	426	1.21 (1.04, 1.42)	0.09	

Sleep duration	<7 hours		7-7.9 hours		8 hours		<i>p</i> _{linear}	<i>p</i> _{interaction}
	<i>n</i> =11,608		<i>n</i> =9149		<i>n</i> =14,068			
	cases	HR (95% CI)	cases	HR	cases	HR CI (95%)		
BMI								
<25 (kg/m ²)	220	1.10 (0.89, 1.36)	145	1.00	264	1.24 (1.01, 1.52)	0.19	0.52
25 (kg/m ²)	286	0.94 (0.79, 1.12)	237	1.00	369	1.13 (0.96, 1.34)	0.02	
Comorbidity 1								
Yes	153	1.13 (0.87, 1.46)	98	1.00	190	1.43 (1.12, 1.83)	0.03	0.45
No	353	0.94 (0.80, 1.10)	284	1.00	443	1.07 (0.92, 1.24)	0.07	
Hypertension								
Yes	221	0.89 (0.73, 1.09)	177	1.00	278	1.08 (0.89, 1.31)	0.03	0.68
No	285	1.09 (0.91, 1.31)	205	1.00	355	1.25 (1.05, 1.48)	0.08	
Shift work								
Yes	187	0.95 (0.75, 1.19)	128	1.00	222	1.13 (0.91, 1.41)	0.08	0.98
No	319	1.01 (0.85, 1.19)	254	1.00	411	1.17 (1.00, 1.37)	0.04	
Snoring								
Yes	435	1.02 (0.88, 1.17)	329	1.00	554	1.18 (1.02, 1.35)	0.02	0.99
No	71	0.91 (0.62, 1.32)	53	1.00	79	1.09 (0.76, 1.56)	0.28	

* Adjusted for age, BMI, energy intake, smoking (pack-years), drinking (drinks per day), current tea drinking, exercise (met-hours/year), hypertension, family history of diabetes, shiftwork, snoring, comorbidity, and napping (stratifying variable was not adjusted in the model). Excludes those cases that were diagnosed within 2 years of recruitment.

Table 3

Association of nocturnal sleep duration and diabetes incidence by selected lifestyles.*

Nocturnal sleep duration	<7 hours <i>n</i> =6553		7–7.9 hours <i>n</i> =4940		8 hours <i>n</i> =7158		<i>P</i> _{linear}	<i>P</i> _{interaction}
	cases	HR (95% CI)	cases	HR	cases	HR (95% CI)		
Total	264	1.01 (0.84, 1.22)	192	1.00	310	1.20 (1.00, 1.44)	0.04	
Age (years)								
40-	103	0.95 (0.70, 1.29)	77	1.00	134	1.25 (0.93, 1.66)	0.04	0.43
50-	84	0.96 (0.69, 1.34)	64	1.00	103	1.19 (0.87, 1.64)	0.15	
60-	77	1.08 (0.76, 1.56)	51	1.00	73	1.25 (0.87, 1.80)	0.43	
Currently drink tea								
Yes	180	1.08 (0.86, 1.36)	127	1.00	206	1.16 (0.92, 1.45)	0.48	0.05
No	84	0.89 (0.64, 1.24)	65	1.00	104	1.32 (0.96, 1.81)	0.01	
Regular exercise participation								
Yes	83	0.95 (0.67, 1.34)	59	1.00	87	1.08 (0.77, 1.52)	0.41	0.45
No	181	1.05 (0.84, 1.32)	133	1.00	223	1.28 (1.03, 1.59)	0.04	
Current smokers								
Yes	152	0.93 (0.73, 1.18)	125	1.00	196	1.18 (0.94, 1.49)	0.02	0.27
No	112	1.12 (0.82, 1.52)	67	1.00	114	1.24 (0.91, 1.68)	0.49	
Ever alcohol drank								
Yes	92	0.83 (0.59, 1.16)	58	1.00	110	1.14 (0.82, 1.57)	0.03	0.32
No	172	1.08 (0.86, 1.36)	134	1.00	200	1.21 (0.97, 1.50)	0.29	

Nocturnal sleep duration	<7 hours		7–7.9 hours		8 hours		<i>p</i> _{linear}	<i>p</i> _{interaction}
	<i>n</i> =6553		<i>n</i> =4940		<i>n</i> =7158			
	cases	HR (95% CI)	cases	HR	cases	HR (95% CI)		
BMI								
<25 (kg/m ²)	117	1.20 (0.90, 1.62)	76	1.00	141	1.44 (1.08, 1.91)	0.15	0.98
25 (kg/m ²)	147	0.91 (0.71, 1.16)	116	1.00	169	1.13 (0.89, 1.43)	0.06	
Comorbidity 1								
Yes	74	1.04 (0.71, 1.52)	48	1.00	83	1.36 (0.95, 1.96)	0.10	0.92
No	190	0.98 (0.79, 1.22)	144	1.00	227	1.17 (0.94, 1.44)	0.08	
Hypertension								
Yes	106	1.00 (0.74, 1.35)	80	1.00	115	1.16 (0.87, 1.55)	0.29	0.61
No	158	0.99 (0.77, 1.26)	112	1.00	195	1.21 (0.96, 1.53)	0.06	
Shift work								
Yes	109	1.00 (0.73, 1.38)	63	1.00	115	1.26 (0.92, 1.74)	0.09	0.83
No	155	0.99 (0.78, 1.25)	129	1.00	195	1.16 (0.93, 1.45)	0.14	
Snoring								
Yes	224	1.00 (0.82, 1.22)	172	1.00	269	1.18 (0.97, 1.43)	0.07	0.92
No	40	1.17 (0.65, 2.10)	20	1.00	41	1.52 (0.87, 2.64)	0.25	

* Adjusted for age, BMI, energy intake, smoking (pack-years), drinking (drinks per day), current tea drinking, exercise (met-hours/year), hypertension, family history of diabetes, shiftwork, snoring, and comorbidity (stratifying variable was not adjusted in the model). Excludes those cases that were diagnosed within 2 years of recruitment.

Modification effect of tea intake on association of sleep duration and diabetes incidence by age and risk score.*

Table 4

Sleep duration	<7 hours <i>n</i> =7351		7–7.9 hours <i>n</i> =6213		8 hours <i>n</i> =9185		<i>P</i> _{linear}	<i>P</i> _{interaction}
	cases	HR CI (95%)	cases	HR	cases	HR CI (95%)		
Age <60 (years)								
Currently drink tea								
Yes	241	0.97 (0.80,1.17)	190	1.00	297	1.08 (0.89, 1.30)	0.22	0.37
No	91	1.01 (0.74,1.39)	71	1.00	147	1.26 (0.94, 1.69)	0.10	
Age ≥60 (years)								
Currently drink tea								
Yes	98	1.34 (0.97,1.85)	60	1.00	109	1.18 (0.86, 1.63)	0.41	<0.01
No	76	0.78 (0.55,1.10)	61	1.00	80	1.24 (0.88, 1.74)	<0.01	
Low risk (score: 0–2)								
Currently drink tea								
Yes	82	1.08 (0.75, 1.56)	50	1.00	78	1.20 (0.84, 1.73)	0.54	0.43
No	50	1.06 (0.65, 1.72)	27	1.00	54	1.49 (0.92, 2.41)	0.10	
Moderate risk (score: 3–4)								
Currently drink tea								
Yes	132	1.07 (0.82, 1.39)	102	1.00	182	1.14 (0.89, 1.46)	0.54	0.34
No	67	0.95 (0.66, 1.37)	62	1.00	95	1.22 (0.87, 1.72)	0.12	
High (score: >4) risk								

Sleep duration	<7 hours <i>n</i> =7351		7–7.9 hours <i>n</i> =6213		8 hours <i>n</i> =9185		<i>P</i> _{linear}	<i>P</i> _{interaction}
	cases	HR CI (95%)	cases	HR	cases	HR CI (95%)		
Currently drink tea								
Yes	125	1.00 (0.77, 1.31)	98	1.00	146	1.08 (0.84, 1.41)	0.51	0.03
No	50	0.68 (0.45, 1.04)	43	1.00	78	1.17 (0.80, 1.72)	<0.01	

* Adjusted for age, BMI, energy intake, smoking (pack-years), drinking (drinks per day), current tea drinking, exercise (met-hours/year), hypertension, family history of diabetes, shiftwork, snoring, and comorbidity (stratifying variable was not adjusted in the model). Excludes those cases that were diagnosed within 2 years of recruitment.