Associations of Midpoint of Sleep and Night Sleep Duration with Type 2 Diabetes Mellitus in Chinese Rural Population: The Henan Rural Cohort

Zhihan Zhai
Zhengzhou University

Xiaotian Liu
Zhengzhou University

Haiqing Zhang
Zhengzhou University

Xiaokang Dong
Zhengzhou University

Yaling He
Zhengzhou University

Miaomiao Niu
Zhengzhou University

Mingming Pan
Zhengzhou University

Chongjian Wang
Zhengzhou University

Xiaoqiong Wang
Zhengzhou University

Yuqian Li (✉ liyuqian@zzu.edu.cn)
Zhengzhou University

Abstract

Background: The study aimed to explore the independent and combined associations of midpoint of sleep and night sleep duration with type 2 diabetes mellitus (T2DM) in areas with limited resources.

Methods: A total of 37,276 participants (14,456 men and 22,820 women) were derived from the Henan Rural Cohort. Information on sleep were collected using the Pittsburgh Sleep Quality Index. Logistic regression models and restricted cubic splines were used to estimate the relationship of the midpoint of sleep and night sleep duration with T2DM.

Results: Of the 37276 included participants, 3580 subjects suffered from T2DM. The mean midpoint of sleep among Early, Intermediate and Late groups were 1.09 ± 0.39, 1.93 ± 0.24 and 2.95 ± 0.56, respectively. Compared to Intermediate group, adjusted odd ratios (*ORs*) and 95% confidence interval (*CI*) of T2DM were 1.13 (1.04-1.22) and 1.16 (1.05-1.28) in Early group and Late group. Adjusted *OR* (95% *CI*) for T2DM compared with reference (7- h) was 1.27 (1.08-1.50) for longer (≥10 h) night sleep duration. The combination of late midpoint of sleep and night sleep duration (≥9 h) increased 39% (95% *CI*: 11%-75%) prevalence for T2DM. These associations were more obvious in women than men.

Conclusions: Late and early midpoint of sleep and long night sleep duration were all associated with the higher odds of T2DM. Meanwhile, midpoint of sleep and night sleep duration might be jointly associated with a higher prevalence of T2DM. Sleep may be a modifiable behavior that has potential health implications for T2DM.

Clinical Trail Registration: The Henan Rural Cohort Study has been registered at Chinese Clinical Trial Register (Registration number: ChiCTR-OOC-15006699). Date of registration: 2015-07-06.

Background

Type 2 diabetes mellitus (T2DM), a major chronic disease nowadays, has imposed enormous financial pressures on national health care systems and national economies worldwide. It was reported that the number of adults with diabetes worldwide aged 20−79 years reached 463 million, which will increase to 578.4 million by 2030 and 700.2 million by 2045 [1]. In 2019, diabetes was estimated to contribute to one in nine deaths among adults aged 20−79 [2, 3]. As the country with the largest number of diabetes patients, it is urgent to find out the determinants of T2DM to prevent this public health problem in China.

Large prospective studies have demonstrated the relationship between night sleep duration and T2DM [4−7], which showed that long or short night sleep duration were associated with increased risk of T2DM. Chronotype, a trait determining individual circadian preference, is reported to be associated with many lifestyle-related diseases [8−10]. In one analysis of 1620 middle-aged participants from the Korean Genome and Epidemiology Study, evening chronotype was independently associated with diabetes, metabolic syndrome, and sarcopenia [11]. A study of 1014 non-shift working adults in Bangkok with prediabetes reported a significant association between later chronotype and higher HbA1c levels [12]. A recent study from the UK Biobank also showed that late chronotype increase the risk of T2DM [13].

Midpoint of time, the midpoint between sleep and wake-up time, strongly correlates with both chronotype and dim light melatonin onset [14, 15]. Epidemiological studies have showed that late midpoint of sleep was associated dietary intake and dietary behavior [16−18], depression among adolescents [19], individuals' well-being [20]and higher risk of gestational diabetes [21]. However, evidences on the relationship between midpoint of sleep and T2DM in areas with limited resources were scarce and no previous studies explored jointly associations of midpoint of sleep and night sleep duration with T2DM.

Therefore, based on the Henan rural Cohort Study, the objectives of the present study were to explore the independent and combined associations of midpoint of sleep and night sleep duration with T2DM in rural Chinese adults.

Methods

Study Population

Data used in this study was drawn from the Henan Rural Cohort, which is an ongoing study that conducted in five counties (Suiping, Yuzhou, Yima, Tongxu and Xinxian) of Henan province and registered in Chinese Clinical Trial Register (Registration number: ChiCTR-OOC-15006699). Details of the study design, methods and participants characteristics have been previously described [22]. Briefly, during July 2015 and September 2017, 39,259 subjects aged 18−79 years were recruited in this cohort, which is being utilized for the present analysis.

We excluded participants: who were night shift workers (N = 1553); had type 1 diabetes mellitus (N = 4); were diagnosed with cancer (N = 327); had incomplete information on diagnoses of T2DM and sleep (N = 99). Finally, a total of 37,276 participants were remained in this analysis.

The protocol of this study was approved by the ethic committee of the Zhengzhou University Life Science Ethics Committee. Informed consent was obtained from all participants.

Data collection and assessment of covariates

Information on demographic characteristics (age, gender, educational levels, incomes and marital status), lifestyles characteristics (smoking, alcohol drinking, diet habits and physical activity), family history of disease (diabetes, hypertension, dyslipidemia, etc.) were collected by a structured questionnaire. Education levels was divided into primary school or below, junior high school and senior high school or above. Average income per month was categorized into three groups (< 500, 500-, and ≥ 1000 RMB). Marital status was grouped into married/cohabitating and unmarried/divorced/widowed. Smoking and alcohol

drinking were grouped into never, former, current. High-fat diet was defined as > 75 g/day of meat from livestock and poultry. Consumption of vegetables and fruits > 500 g/day was defined as high vegetables and fruits intake. Physical activity was grouped into low, moderate and high level based on International Physical Activity Questionnaire (IPAQ) [23].

Anthropometric variables were measured in light clothing and without shoes. Weight and height were measured twice for each person to the nearest 0.1 kg and 0.1 cm separately, according to a standard protocol. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2).

Sleep variables

Information about night sleep duration and sleep timing was evaluated by the Pittsburgh Sleep Quality Index (PSQI) [24]. In the present study, the subjects reported bedtime and wake-up time (the time they usually went to bed and got up) and sleep latency (the minutes it took to fall asleep) during the past month. Using these data, sleep time was computed as bedtime plus sleep latency. The midpoint of sleep was calculated as the halfway point between sleep time and wake-up time and was classified into three categories by the 25th and 75th percentile according to the distribution: Early, Intermediate (reference) and Late [25]. Sleep duration was also calculated from sleep time and wake-up time and grouped as < 5 h, 5- h, 6- h, 7- h (reference), 8- h, 9- h and ≥ 10 h[26]. In addition, information on napping frequency and napping duration were also obtained.

Definition of T2DM

The determination of T2DM was based on the American Diabetes Association (ADA) diagnostic criteria (2009). Participants were defined as having T2DM if the fasting blood glucose > 7.0 mmol/L or having a self-reported previous diagnosis of diabetes by a physician after excluding type 1 diabetes mellitus, gestational diabetes mellitus, and diabetes due to other causes.

Statistical Analyses

All continuous variables were presented as the mean ± SD. All categorical variables were presented as the number (proportion). Baseline characteristics of the study population were compared among different T2DM groups. The t-test and chi-square test were used for comparing continuous and categorical variables, respectively. Potential gender interactions were found (P < 0.05) by performing a multiplicative interaction term with midpoint of sleep and night sleep duration. Hence the analyses stratified by gender (men and women) were presented. Moreover, to explore the associations of midpoint of sleep and night sleep duration with T2DM, logistic regression models were performed by controlling age, gender, physical activity, marital status, smoking status, drinking status, educational levels, average income per month, BMI, high fat diet, adequate vegetable and fruit intake, napping duration, family history of diabetes, midpoint of sleep or night sleep duration. Restricted cubic spline was used to explore the dose-response relationship between midpoint of sleep and night sleep duration with T2DM, with three knots located at 25th, 50th, and 95th percentiles of midpoint of sleep and 15th, 50th, and 85th percentiles of night sleep duration according to the distribution. In addition, a series of stratified analyses were performed to estimate the underlying modification effects. Furthermore, night sleep duration was regrouped into < 6 h, 6- h, 7- h, 8- h, ≥ 9 h to investigate the combined effects of midpoint of sleep and night sleep duration on T2DM by taking Intermediate group and 7- h as the reference category. All statistical analyses were performed by running the SAS V.9.1 (SAS Institute) and R Language software (version 4.0.2) software packages. Statistical significance was based on two tailed P < 0.05.

Results

Characteristics of participants

Baseline characteristics of the study participants according to T2DM were present in Table 1. Of the 37,276 included participants, 3580 subjects suffered from T2DM. Compared with those without T2DM, individuals with T2DM were older, and more likely to be women, unmarried, lower education level, lower income, less physical activity, higher BMI, and have a family history of T2DM. Meanwhile, they tend to have longer night sleep and napping duration and early midpoint of sleep. The study participants according to midpoint of sleep showed all significant differences for baseline characteristics. The mean night sleep duration for Early, Intermediate and Late groups were 8.19 ± 1.24, 7.72 ± 1.09, and 7.32 ± 1.45 and the mean midpoint of sleep among 3 categories were 1.09 ± 0.39, 1.93 ± 0.24 and 2.95 ± 0.56, respectively. Details of the baseline characteristics of participants were provided in Supplementary table1.

Variables	Total			Men			Women	
	Non-T2DM	T2DM	*P*	Non-T2DM	T2DM	*P*	Non-T2DM	T2DM
N	33696	3580		13128	1328		20568	2252
Age(year), mean ± SD	55.51 ± 12.23	60.58 ± 9.12	< 0.001	56.92 ± 12.29	59.74 ± 9.7	< 0.001	54.61 ± 12.11	61.08 ± 8.73
Marital status, n (%)			0.018			0.011		
Married/cohabitation	30210(89.65)	3164(88.38)		11747(89.48)	1218(91.72)		18463(89.77)	1946(86.41)
Unmarried/divorced/widowed	3486(10.35)	416(11.62)		1381(10.52)	110(8.28)		2105(10.23)	306(13.59)
Educational levels, n (%)			< 0.001			0.561		
Primary school or below	15129(44.90)	2013(56.23)		4573(34.83)	459(34.56)		10556(51.32)	1554(69.01)
Junior high school	13498(40.06)	1161(32.43)		6063(46.18)	601(45.26)		7435(36.15)	560(24.87)
Senior high school or above	5069(15.04)	406(11.34)		2492(18.98)	268(20.18)		2577(12.53)	138(6.13)
Average income per month, n (%)			< 0.001			0.535		
< 500 RMB	12125(35.98)	1430(39.94)		4880(37.17)	509(38.33)		7245(35.22)	921(40.90)
500- RMB	11147(33.08)	1154(32.23)		4176(31.81)	426(32.08)		6971(33.89)	728(32.33)
≥ 1000 RMB	10424(30.94)	996(27.82)		4072(31.02)	393(29.59)		6352(30.88)	603(26.78)
High vegetables and fruits intake, n (%)	14363(42.63)	1271(35.51)	< 0.001	5732(43.67)	506(38.13)	< 0.001	8631(41.96)	765(33.97)
High fat diet, n (%)	6482(19.24)	573(16.01)	< 0.001	3291(25.07)	310(23.34)	0.166	3191(15.51)	263(11.68)
Smoker, n (%)	6428(19.08)	499(13.94)	< 0.001	6375(48.56)	491(36.97)	< 0.001	53(0.26)	8(0.36)
Drinker, n (%)	6033(17.90)	514(14.36)	< 0.001	5470(41.67)	484(36.45)	< 0.001	563(2.74)	30(1.33)
Physical activity, n (%)			< 0.001			< 0.001		
Light	10545(31.29)	1414(39.50)		4564(34.77)	580(43.67)		5981(29.08)	834(37.03)
Moderate	12823(38.05)	1261(35.22)		3618(27.56)	357(26.88)		9205(44.75)	904(40.14)
Vigorous	10328(30.65)	905(25.28)		4946(37.68)	391(29.44)		5382(26.17)	514(22.82)
Family history of diabetes, n (%)	1181(3.50)	346(9.66)	< 0.001	374(2.85)	133(10.02)	< 0.001	807(3.92)	213(9.46)
Body mass index	24.68 ± 3.53	26.15 ± 3.68	< 0.001	24.35 ± 3.43	26 ± 3.54	< 0.001	24.89 ± 3.57	26.25 ± 3.76
Night sleep duration, mean ± SD	7.75 ± 1.27	7.87 ± 1.36	< 0.001	7.74 ± 1.28	7.88 ± 1.24	< 0.001	7.76 ± 1.26	7.87 ± 1.42
Napping duration, mean ± SD	57.06 ± 50.38	61.00 ± 50.5	< 0.001	62.85 ± 49.91	65.4 ± 49.17	0.075	53.37 ± 50.33	58.4 ± 51.1
Midpoint of sleep, mean ± SD	1.93 ± 0.79	1.83 ± 0.80	< 0.001	1.92 ± 0.84	1.85 ± 0.85	0.003	1.94 ± 0.75	1.81 ± 0.77

Associations of midpoint of sleep and night sleep duration with T2DM

To further explore the associations of midpoint of sleep and night sleep duration with T2DM, logistic regression models were performed for odd ratios (*ORs*) and 95% confidence intervals (*CIs*) (Table 2). Compared with Intermediate group, people with early midpoint of sleep and late midpoint of sleep had higher odds of T2DM, the *ORs* (95% *CIs*) were 1.13 (1.04–1.22) and 1.16 (1.05–1.28) after adjustment for age, gender, marital status, educational levels, average income per month, high vegetables and fruits intake, high fatty diet, smoking status, drinking status, physical activity, body mass index, family history of diabetes, napping duration and night sleep duration. Stratified by gender revealed that the association between late midpoint of sleep and T2DM was significant in women (*OR*:1.13, 95%*CI* 1.00-1.28) but not in men (*OR*:1.15, 95%*CI* 0.98–1.34) in adjusted model.

	Total			Men			Women		
	Case/N	Model 1	Model 2	Case/N	Model 1	Model 2	Case/N	Model 1	Model 2
Midpoint of sleep									
Early	1324/11560	1.10(1.01–1.19)	1.13(1.04–1.22)	482/4664	1.11(0.97–1.26)	1.14(1.00-1.31)	842/6896	1.09(0.98–1.20)	1.11(1.00-1.23)
Intermediate	1483/16456	1.00	1.00	540/6220	1.00	1.00	943/10236	1.00	1.00
Late	773/9260	1.14(1.04–1.25)	1.16(1.05–1.28)	306/3572	1.16(0.99–1.35)	1.15(0.98–1.34)	467/5688	1.09(0.97–1.23)	1.13(1.00-1.28)
Night sleep duration									
< 5	71/619	1.16(0.90–1.50)	1.15(0.88–1.50)	15/247	0.62(0.37–1.06)	0.64(0.37–1.10)	56/372	1.49(1.10-2.00)	1.52(1.11–2.07)
5-	137/1662	0.87(0.72–1.04)	0.87(0.72–1.06)	44/689	0.68(0.49–0.94)	0.68(0.49–0.94)	93/973	0.98(0.78–1.23)	1.01(0.80–1.28)
6-	496/5995	0.89(0.80-1.00)	0.89(0.79-1.00)	199/2482	0.87(0.73–1.04)	0.87(0.73–1.05)	297/3513	0.09(0.78–1.04)	0.90(0.77–1.04)
7-	1144/12505	1.00	1.00	456/4979	1.00	1.00	688/7526	1.00	1.00
8-	1027/10621	1.02(0.93–1.11)	1.01(0.92–1.11)	375/3861	1.03(0.89–1.19)	1.02(0.88–1.18)	652/6760	1.02(0.91–1.15)	1.01(0.90–1.14)
9-	491/4373	1.10(0.98–1.23)	1.10(0.98–1.24)	169/1621	1.06(0.88–1.28)	1.08(0.88–1.31)	322/2752	1.13(0.98–1.31)	1.13(0.98–1.31)
≥ 10	214/1501	1.32(1.13–1.55)	1.27(1.08–1.50)	70/577	1.22(0.93–1.60)	1.23(0.93–1.63)	144/924	1.37(1.12–1.68)	1.31(1.06–1.61)

Model 1: adjusted for age, gender (only for total participants);

Model 2: adjusted for age, gender (only for total participants), marital status, educational levels, average income per month, high vegetables and fruits intake, high fatty diet, smoking status, drinking status, physical activity, body mass index, family history of diabetes, napping duration, night sleep duration or midpoint of sleep

Compared with individuals of 7- h night sleep duration, longer (≥ 10 h) night sleep duration was associated with increased prevalence of T2DM in adjusted model, the *OR* was 1.27 (1.08−1.50). After being stratified by gender, the relationship was more evident in women but not significant in men. The *ORs* and 95%*CI* were 1.52 (1.11−2.07) and 1.31 (1.06−1.61) for women who slept < 5 h and ≥ 10 h per night.

Furthermore, potential associations between midpoint of sleep and night sleep duration and T2DM were also assessed by restricted cubic spline (Fig. 1). A U-shaped dose-response relationship between midpoint of sleep and T2DM was found after controlling for potential confounders (P for nonlinearity < 0.001). After being stratified by gender, the U-shaped relationship was significant in both men and women (P for nonlinearity < 0.05). As for night sleep duration, the U-shaped dose-response relationship only found in women (P for nonlinearity < 0.05). In total participants and men, restricted cubic spline showed that P for overall association < 0.05 and P for nonlinearity > 0.05.

Subgroup analysis of the association of midpoint of sleep and night sleep duration with T2DM

The results of the associations of midpoint of sleep and night sleep duration with T2DM stratified by age, BMI, family history of diabetes, physical activity, smoking status and drinking status were presented in Supplementary table 2. The effects of midpoint of sleep on T2DM were significantly modified by age. Participants less than 60 years had statistically stronger associations than the others with early midpoint of sleep (*OR* 1.33, 95%*CI* 1.16−1.52 vs. *OR* 1.11, 95%*CI* 1.00-1.23), but participants ≥ 60 years had statistically stronger associations than the others with late midpoint of sleep (*OR* 1.24, 95%*CI* 1.07−1.43 vs. *OR* 0.95, 95%*CI* 0.83−1.08). However, there were none statistically significant interactions between midpoint of sleep and other stratification factors.

Combined effects of midpoint of sleep and night sleep duration on T2DM

Figure 2 displays combined analysis of midpoint of sleep and night sleep duration with T2DM. Compared with those with intermediate midpoint of sleep and 7- h of night sleep duration, individuals with combined late midpoint of sleep and longer night sleep duration had the highest prevalence of T2DM. The corresponding risk was 1.39 (1.11−1.75). Further analysis stratified by gender manifested that this combined relationship was enhanced in women, which showed a notably U relationship with T2DM.

Discussion

This study provided new evidence between midpoint of sleep and T2DM in rural population, which had implications for better understanding of chronotype with T2DM. The current study found a U-shaped relationship between midpoint of sleep and T2DM, which means that early and late midpoint of sleep may increase the prevalence of T2DM. Besides, late midpoint of sleep and longer night sleep duration might be jointly associated with a higher likelihood of T2DM. Moreover, gender and age might influence the health effects of sleep which should be taken into consideration when making strategies to improve public health in rural areas.

On the basis of precious studies, we found late midpoint of sleep was related to increased odds of T2DM. For instance, former studies showed that late chronotype assessed by chronotype questionnaire was associated with increased risk of T2DM [27]. Moreover, chronotype acquired by free-day mid-sleep time also showed similar results. A survey of large sample of diverse US Hispanics/Latino adults found that later sleep timing based on sleep midpoint was significantly associated with higher estimated insulin resistance (HOMA-IR) in individuals with and without diabetes combined independent of sleep duration [28]. Furthermore, late chronotype was associated with poorer glycemic performance in individuals who were prediabetes and T2DM [12]. In addition, consistent with other findings [29], long night sleep duration was associated higher risk of T2DM.

However, associations between midpoint of sleep and T2DM remained inconsistent with previous studies. This study suggested that early midpoint of sleep also increased the T2DM risk. A cross-sectional study involving 821 participants reported that M-type was associated with diabetes in middle-aged and elderly people [30]. One possibility explanation for differences observed between these studies is that there are large differences in circadian patterns between rural and urban populations [31]. The rural population presented a more predominantly early sleep pattern, as determined by the mid-sleep phase. In present study, people might have early midpoint of sleep due to work schedule, suggesting that mismatch between internal circadian rhythms and social factors could play a significant role for development of diabetes [32]. Though there were no objective parameters of chronotype in the present study, the association between chronotype and rural population should be addressed in future studies.

Two studies previously explored the combined effect of sleep behaviors and T2DM. Liu et al. showed that longer napping and night sleep duration were jointly associated with T2DM [6]. and Lou et al. presented that combined effect of sleep duration and sleep quality on the risk T2DM, which highlighted that both shorter sleep duration and poor sleep quality were jointly associated with T2DM [33]. The present study found that midpoint of sleep and long night sleep duration might be jointly associated with a higher prevalence of T2DM. Investigating combined associations of midpoint of sleep and night sleep duration simultaneously with T2DM might have important implications for understanding the impact of sleep on T2DM.

Gender and age can modify these detrimental effects of midpoint of sleep on T2DM. Consistent with our results, Fabbian et al. reported that Eveningness may impact general health especially in women [34]. However, one analysis of 1620 middle-aged Korean men and women (age range 47–59 years), stronger associations of Evening Chronotype with T2DM were presented among men [35]. Consistent with Liu et al. [35] that women were more susceptive to the adverse effects of night sleep duration, we also found that short and long night sleep duration had more effects on women. Different biological and lifestyle characteristics may attribute to the gender differences. Besides, participants less than 60 years with early midpoint of sleep had statistically stronger associations than the others in present study which consistent with former findings [36]. Individuals with younger age tend to under a mismatch between circadian and social activities such as working and studying and have adverse health outcome [32, 37].

All these above findings supported that disruption of circadian clock was associated to adverse changes on T2DM. There are several potential explanations of the biological mechanisms underlying the association between midpoint of sleep and night sleep duration with T2DM. One possibility is that circadian misalignment leads to fluctuation in the metabolic and endocrine function, including lower glucose tolerance and thyrotrophic concentration, increased evening cortisol concentrations and elevated activity of the sympathetic nervous system, which might accelerate the development of diabetes [38]. Another is that melatonin secretion at night might have been disrupted by short sleep duration, circadian misalignment and/or light exposure, which may one of the endocrine mediators of circadian regulation of insulin sensitivity [39]. Additionally, circadian rhythm was associated dietary intake and dietary behavior. An animal experiment showed that the Clock gene mutant mice have an attenuated diurnal rhythm of feeding behavior, and develop obesity, hyperphagia, reduced energy expenditure and visceral adiposity, as well as dysregulation of glucose and lipid metabolism [40].

There are several limitations needed to address in this study. First, the midpoint of sleep was calculated using sleep time and wake-up time of previous one month, but the midpoint of sleep was different between free days and work days and it is reported that free day midpoint of sleep was correlated better with chronotype scores assessed by chronotype questionnaire. However, because of the hot weather and any other reason (i.e. farming), most of the participants were on vacation during baseline assessment. Therefore, the participants probably had free time during the past month. Second, there were no objective parameters of chronotype in the present study which should be addressed in future studies. Third, the midpoint of sleep was classified into three categories by the 25th and 75th percentile based on previous study [25] and might lead to misclassification. Fourth, this study was a cross-sectional which was unlikely to yield a clear cause-effect conclusion and the information of sleep was self-reported which might suffer recall bias.

Conclusion

In conclusion, Late and early midpoint of sleep and long night sleep duration were all associated with the higher odds of T2DM. Meanwhile, midpoint of sleep and long night sleep duration might be jointly associated with a higher prevalence of T2DM. These results suggest that chronotype may be predictive of disease outcomes and further support to the role of the circadian system in metabolic regulation in rural population. Further studies regarding the potential role of chronotype in diabetes prevention should be explored.

Abbreviations

BMI: Body mass index; CI: Confidence interval; TDM: type 2 diabetes mellitus; SD: Standard deviation

Declarations

References

1. Ling C, Ronn T. Epigenetics in Human Obesity and Type 2 Diabetes. Cell Metab. 2019;29(5):1028–44.
2. Saeedi P, Salpea P, Karuranga S, Petersohn I, Malanda B, Gregg EW, Unwin N, Wild SH, Williams R. Mortality attributable to diabetes in 20–79 years old adults, 2019 estimates: Results from the International Diabetes Federation Diabetes Atlas, 9(th) edition. Diabetes Res Clin Pract. 2020;162:108086.
3. Williams R, Karuranga S, Malanda B, Saeedi P, Basit A, Besancon S, Bommer C, Esteghamati A, Ogurtsova K, Zhang P, et al: Global and regional estimates and projections of diabetes-related health expenditure: Results from the International Diabetes Federation Diabetes Atlas, 9th edition. *Diabetes Res Clin Pract* 2020, 162:108072.
4. Beihl DA, Liese AD, Haffner SM. Sleep Duration as a Risk Factor for Incident Type 2 Diabetes in a Multiethnic Cohort. Ann Epidemiol. 2009;19(5):351–7.
5. Knutson KL, Ryden AM, Mander BA, Van Cauter E. Role of sleep duration and quality in the risk and severity of type 2 diabetes mellitus. Arch Intern Med. 2006;166(16):1768–74.
6. Liu R, Li Y, Mao Z, Liu X, Zhang H, Yang K, Zhang H, Tu R, Qian X, Jiang J, et al. Gender-specific independent and combined dose-response association of napping and night sleep duration with type 2 diabetes mellitus in rural Chinese adults: the RuralDiab study. Sleep Med. 2018;45:106–13.
7. Yaggi HK, Araujo AB, McKinlay JB. Sleep duration as a risk factor for the development of type 2 diabetes. Diabetes Care. 2006;29(3):657–61.
8. Knutson KL, von Schantz M. Associations between chronotype, morbidity and mortality in the UK Biobank cohort. Chronobiol Int. 2018;35(8):1045–53.
9. Wong PM, Hasler BP, Kamarck TW, Muldoon MF, Manuck SB. Social Jetlag, Chronotype, and Cardiometabolic Risk. Journal of Clinical Endocrinology Metabolism. 2015;100(12):4612–20.
10. Fabbian F, Zucchi B, De Giorgi A, Tiseo R, Boari B, Salmi R, Cappadona R, Gianesini G, Bassi E, Signani F, et al. Chronotype, gender and general health. Chronobiol Int. 2016;33(7):863–82.
11. Yu JH, Yun C-H, Ahn JH, Suh S, Cho HJ, Lee SK, Yoo HJ, Seo JA, Kim SG, Choi KM, et al. Evening Chronotype Is Associated With Metabolic Disorders and Body Composition in Middle-Aged Adults. Journal of Clinical Endocrinology Metabolism. 2015;100(4):1494–502.
12. Anothaisintawee T, Lertrattananon D, Thamakaison S, Knutson KL, Thakkinstian A, Reutrakul S. Later chronotype is associated with higher hemoglobin A1c in prediabetes patients. Chronobiol Int. 2017;34(3):393–402.
13. Tan X, Ciuculete DM, Schioth HB, Benedict C. Associations between chronotype, MTNR1B genotype and risk of type 2 diabetes in UK Biobank. J Intern Med. 2020;287(2):189–96.

14. Zavada A, Gordijn MCM, Beersma DGM, Daan S, Roenneberg T. Comparison of the Munich Chronotype Questionnaire with the Horne-Ostberg's Morningness-Eveningness Score. Chronobiol Int. 2005;22(2):267–78.

15. Kantermann T, Sung H, Burgess HJ. Comparing the Morningness-Eveningness Questionnaire and Munich ChronoType Questionnaire to the Dim Light Melatonin Onset. J Biol Rhythms. 2015;30(5):449–53.

16. Sato-Mito N, Shibata S, Sasaki S, Sato K. Dietary intake is associated with human chronotype as assessed by both morningness-eveningness score and preferred midpoint of sleep in young Japanese women. Int J Food Sci Nutr. 2011;62(5):525–32.

17. Sato-Mito N, Sasaki S, Murakami K, Okubo H, Takahashi Y, Shibata S, Yamada K, Sato K. Freshmen Dietetic Courses S, II: The midpoint of sleep is associated with dietary intake and dietary behavior among young Japanese women. Sleep Med. 2011;12(3):289–94.

18. Kleiser C, Wawro N, Stelmach-Mardas M, Boeing H, Gedrich K, Himmerich H, Linseisen J. Are sleep duration, midpoint of sleep and sleep quality associated with dietary intake among Bavarian adults? Eur J Clin Nutr. 2017;71(5):631–7.

19. de Souza CM, Loayza Hidalgo MP. Midpoint of sleep on school days is associated with depression among adolescents. Chronobiol Int. 2014;31(2):199–205.

20. de Souza CM, Loayza Hidalgo MP. The midpoint of sleep on working days: A measure for chronodisruption and its association to individuals' well-being. Chronobiol Int. 2015;32(3):341–8.

21. Facco FL, Grobman WA, Reid KJ, Parker CB, Hunter SM, Silver RM, Basner RC, Saade GR, Pien GW, Manchanda S, et al: Objectively measured short sleep duration and later sleep midpoint in pregnancy are associated with a higher risk of gestational diabetes. *American Journal of Obstetrics and Gynecology* 2017, 217(4).

22. Liu X, Mao Z, Li Y, Wu W, Zhang X, Huo W, Yu S, Shen L, Li L, Tu R, et al. Cohort Profile: The Henan Rural Cohort: a prospective study of chronic non-communicable diseases. Int J Epidemiol. 2019;48(6):1756-+.

23. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381–95.

24. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry research. 1989;28(2):193–213.

25. Liu B, Song L, Zhang L, Wang L, Wu M, Xu S, Wang Y. Sleep patterns and the risk of adverse birth outcomes among Chinese women. Int J Gynaecol Obstet. 2019;146(3):308–14.

26. Zhang H, Zhao X, Li Y, Mao Z, Huo W, Jiang J, Wang Y, Liu X, Abdulai T, Tian Z, et al. Night sleep duration and sleep initiation time with hypertension in Chinese rural population: the Henan Rural Cohort. Eur J Public Health. 2020;30(1):164–70.

27. Merikanto I, Lahti T, Puolijoki H, Vanhala M, Peltonen M, Laatikainen T, Vartiainen E, Salomaa V, Kronholm E, Partonen T. Associations of chronotype and sleep with cardiovascular diseases and type 2 diabetes. Chronobiol Int. 2013;30(4):470–7.

28. Knutson KL, Wu D, Patel SR, Loredo JS, Redline S, Cai J, Gallo LC, Mossavar-Rahmani Y, Ramos AR, Teng Y, et al: Association Between Sleep Timing, Obesity, Diabetes: The Hispanic Community Health Study/Study of Latinos (HCHS/SOL) Cohort Study. *Sleep* 2017, 40(4).

29. Tan X, Chapman CD, Cedernaes J, Benedict C. Association between long sleep duration and increased risk of obesity and type 2 diabetes: A review of possible mechanisms. Sleep Med Rev. 2018;40:127–34.

30. Sasaki N, Ozono R, Yamashita H, Teramen K, Kihara Y. Chronotype and diabetes in middle-aged and elderly people: Importance of mismatch between chronotype and actual lifestyle. Eur Heart J. 2018;39:878–8.

31. Carvalho FG, Hidalgo MP, Levandovski R. Differences in circadian patterns between rural and urban populations: an epidemiological study in countryside. Chronobiol Int. 2014;31(3):442–9.

32. Vetter C, Devore EE, Ramin CA, Speizer FE, Willett WC, Schernhammer ES. Mismatch of Sleep and Work Timing and Risk of Type 2 Diabetes. Diabetes Care. 2015;38(9):1707–13.

33. Lou P, Chen P, Zhang L, Zhang P, Yu J, Zhang N, Wu H, Zhao J. Relation of sleep quality and sleep duration to type 2 diabetes: a population-based cross-sectional survey. *BMJ Open* 2012, 2(4).

34. Fabbian F, Zucchi B, De Giorgi A, Tiseo R, Boari B, Salmi R, Cappadona R, Gianesini G, Bassi E, Signani F, et al. Chronotype, gender and general health. Chronobiol Int. 2016;33(7):863–82.

35. Yu JH, Yun CH, Ahn JH, Suh S, Cho HJ, Lee SK, Yoo HJ, Seo JA, Kim SG, Choi KM, et al. Evening chronotype is associated with metabolic disorders and body composition in middle-aged adults. J Clin Endocrinol Metab. 2015;100(4):1494–502.

36. Koopman ADM, Rauh SP, van 't Riet E, Groeneveld L, van der Heijden AA, Elders PJ, Dekker JM, Nijpels G, Beulens JW, Rutters F. The Association between Social Jetlag, the Metabolic Syndrome, and Type 2 Diabetes Mellitus in the General Population: The New Hoorn Study. J Biol Rhythms. 2017;32(4):359–68.

37. Henson J, Rowlands AV, Baldry E, Brady EM, Davies MJ, Edwardson CL, Yates T, Hall AP, Investigators C. Physical behaviors and chronotype in people with type 2 diabetes. *BMJ Open Diabetes Res Care* 2020, 8(1).

38. Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. Lancet. 1999;354(9188):1435–9.

39. Larcher S, Benhamou PY, Pepin JL, Borel AL. Sleep habits and diabetes. Diabetes Metab. 2015;41(4):263–71.

40. Turek FW, Joshu C, Kohsaka A, Lin E, Ivanova G, McDearmon E, Laposky A, Losee-Olson S, Easton A, Jensen DR, et al. Obesity and metabolic syndrome in circadian Clock mutant mice. Science. 2005;308(5724):1043–5.
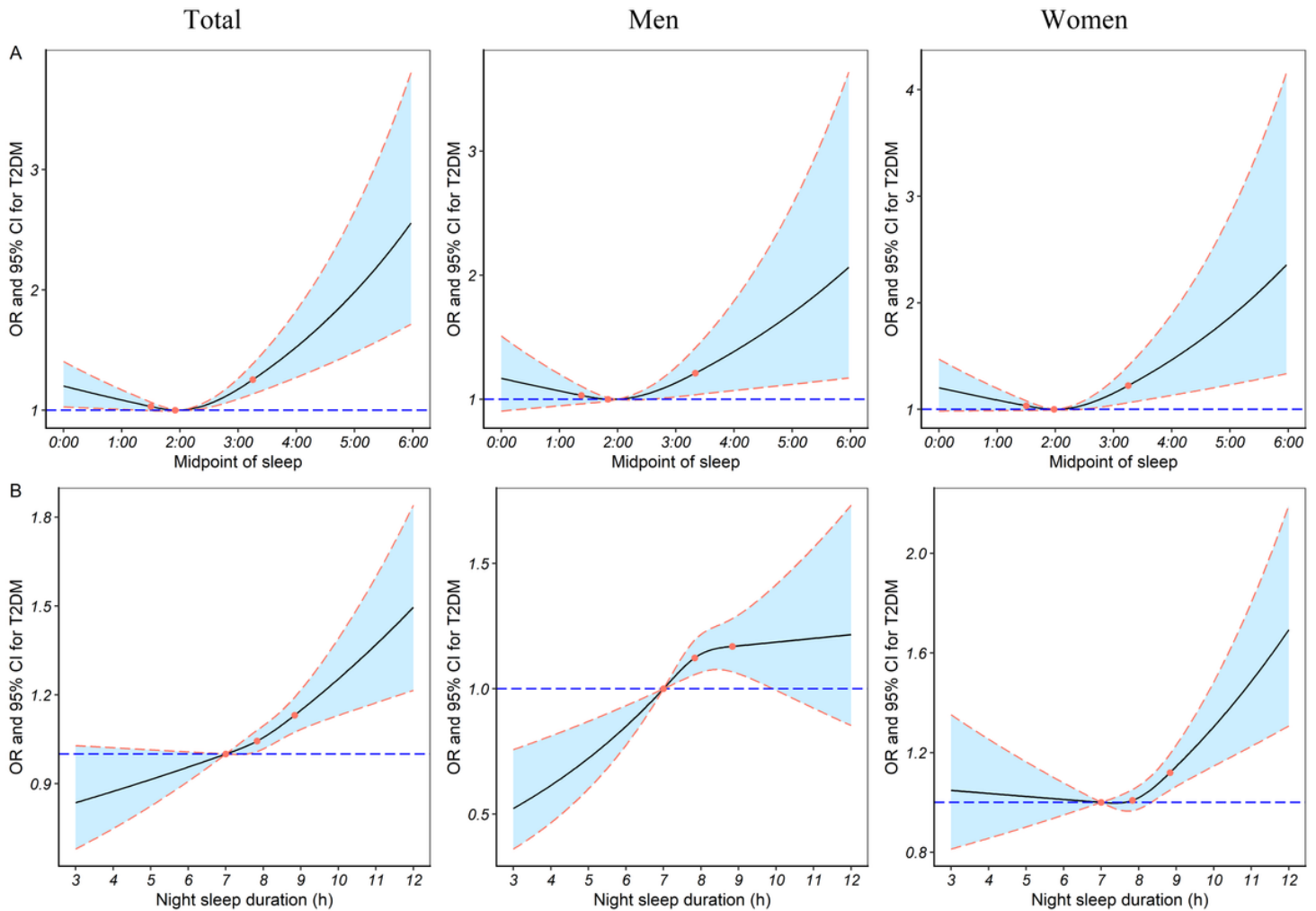
Figures

Figure 1

Associations of midpoint of sleep (A) and night sleep duration (B) with T2DM. Adjusted for age, gender (only for total participants), marital status, educational levels, average income per month, high vegetables and fruits intake, high fatty diet, smoking status, drinking status, physical activity, body mass index, family history of diabetes, napping duration, night sleep duration or midpoint of sleep.
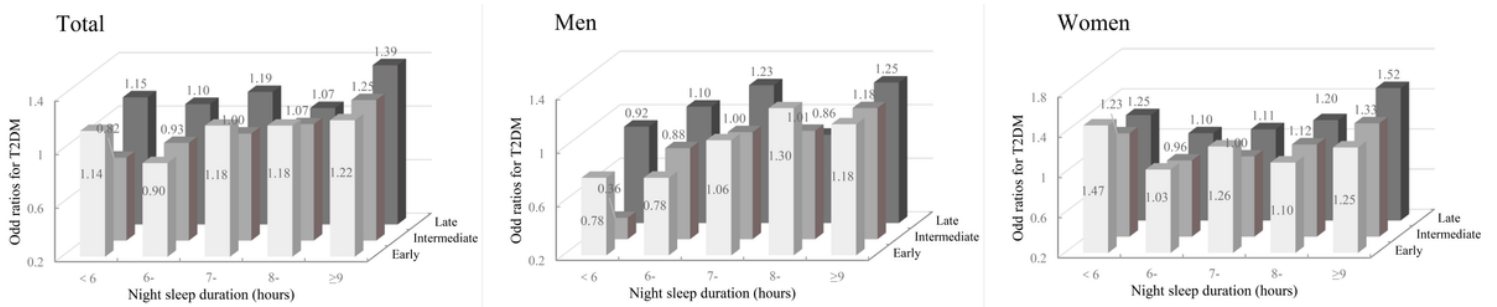

Figure 2

Joint effects of midpoint of sleep and night sleep duration on T2DM. Adjusted for age, gender (only for total participants), marital status, educational levels, average income per month, high vegetables and fruits intake, high fatty diet, smoking status, drinking status, physical activity, body mass index, family history of diabetes, napping duration.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementary.docx