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Original Article

The interactive effect of habitual midday napping and nighttime sleep duration on impaired fasting glucose risk in healthy adolescents

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ABSTRACT

Objectives: To investigate the association between habitual midday napping and impaired fasting glucose (IFG), and the interactive effect of napping and time in bed (TIB) at night on IFG among healthy adolescents.

Methods: The sample comprised 625 early adolescents (12.26 ± 0.63 years old) who self-reported good health status from Jintan, China. Midday napping and nighttime sleep were measured using the Youth Self-report Sleep Questionnaire. Fasting plasma glucose was dichotomized into normal (<5.6 mmol/L) and impaired (≥5.6 mmol/L) levels. The multivariate random-effect logistic regression examined the nap-glucose relationship and the interaction between nap and TIB. Marginal effects of napping were calculated when TIB was held constant at different values.

Results: Of the participants, 83.20% (n = 520) took naps and 62.28% reported average nap durations ≥31 min in the past month. Moreover, 16% (n = 101) of participants had IFG. After adjusting for covariates, early adolescents who napped 3–4 days/week (OR = 1.72, p < 0.001), 5–7 days/week (OR = 1.34, p = 0.02) or ≥31 min/nap (OR = 1.52, 1.56, p's < 0.05) were associated with increased likelihoods of IFG compared to non-nappers. There was an inverse relationship between TIB and IFG among non-nappers (OR = 0.45, p = 0.03). Interaction analyses also showed significantly increased likelihoods of IFG only among nappers with TIB ≥9 hours.

Conclusion: The relationship between midday napping and IFG is dependent on TIB. Midday naps may increase the risk for IFG among early adolescents who have sufficient nighttime sleep. However, further research is needed to confirm our preliminary findings.

1. Introduction

Up to 68.9% of adolescents' report insufficient nighttime sleep duration and impaired sleep quality [1,2], attributed to a combination of pubertal changes in intrinsic sleep regulation (eg, delayed melatonin onset phase) [3] and social-behavioral factors (eg, early school start time and screen time) [4,5]. As a response to nighttime sleep deficiencies, daytime napping behaviors are prevalent in between 53% and 89% of American adolescents [1,6]. Daytime napping, particularly midday napping, is even more prevalent in countries who have siesta cultures such as China. Specifically, midday napping is culturally perceived as a healthy lifestyle and public schools provide post-lunch napping opportunities for children and adolescents in mainland China [7].

Adolescents exhibit pubertal-related decreases in insulin sensitivity [8,9], thus at high risk for poor metabolic profile including impaired fasting glucose (IFG) compared with other populations [9–11]. Poor metabolic profile during childhood and adolescence exponentially increases the risk of adulthood obesity, diabetes, cardiovascular disease [12–14], and subsequent morbidity and mortality [15,16]. Sleep impairment has emerged as a non-traditional risk factor for a poor metabolic profile such as IFG [17]. A recent review indicated that the association between short sleep/poor sleep and negative metabolic indicators is most robust for obesity, followed by impaired fasting glucose and increased insulin sensitivity among children and adolescents [17]. There is also evidence that suggests an association between long nighttime sleep duration and increased risk of type 2 diabetes in adults [18],

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highlighting the importance of a moderate amount of sleep. While prior research has primarily focused on nighttime sleep, there is a lack of research on daytime napping and its association with IFG among adolescents.

Napping has been considered both as a health-promoting behavior [19] as well as a risk factor for cardio-metabolic diseases and all-cause mortality [20]. Emerging evidence has shown the benefits of experimentally imposed naps or habitual daytime naps on daytime vigilance [21], cognitive function [19,22] and emotional regulation [23,24]. In contrast, daytime naps, especially long duration naps in the late-afternoon, may interfere with nighttime sleep [6,25], thus posing risks for poor metabolic health. Midday napping may also exert an independent effect on poor metabolic health such as IFG, although this remains largely underexplored among adolescents. Cross-sectional [26] and longitudinal studies [27] have suggested that daytime napping was associated with an increased risk for IFG and type 2 diabetes in adults and older adults. A recent meta-analysis further indicates a "J-shaped" association between nap duration and the risk of type 2 diabetes in adults, with no effect of naps up to 60 minutes/day, followed by a sharp increase in risk at longer nap durations [28]. However, conflicting results were observed across studies. For example, a large-scale epidemiological study found that short naps (≤60 min) at least five times per week were estimated to protect against diabetes, while long naps (>60 min) increased the risk for diabetes in adults [29].

The inconsistent findings on the association between daytime napping and metabolic outcomes may be due to varying nighttime sleep durations. A recent study suggested that midday naps among short nighttime sleepers (<5 h/night) tended to reduce the risk for poor glycemic control among adult patients with type 2 diabetes [30]. Cohen-Mansfield and Perach also reported that daytime napping significantly increased the mortality risk in older adults with long nighttime sleep (>9 h/night), while an opposite trend was observed in short nighttime sleepers (<7 h/night) [31]. While prior research predominantly focused on adults and older adults, it remains unknown whether the relationships among daytime napping, nighttime sleep and diabetes risks can be replicated in the adolescent population.

A better understanding of the relationship among nap, nighttime sleep and risk for IFG or diabetes among adolescents has important clinical implications. Thus, the primary aim of this study was to investigate the association between habitual midday napping (frequency & duration) and IFG among healthy adolescents in China. The secondary aim was to examine the interaction between midday napping and self-reported nighttime sleep duration on IFG. The siesta culture with a lunch break from 11:30 AM to 2:00 PM in schools whereby our sample was selected provides a research opportunity to study the health impact of habitual midday napping.

2. Materials and methods

2.1. Participants and procedure

The present study is an extension of the China Jintan child cohort, which was originally designed to investigate the predictive effect of early health factors on neurobehavioral development in children [32,33]. This longitudinal study used a multiple-stage sampling method and enrolled 1656 Chinese children (55.5% boys, 44.5% girls) in Jintan City in 2004. Participants were enrolled when they were 3–5 years old in three grades of preschool cohorts (upper, middle and bottom). When participants were in their last month of sixth grade in 2011–2013 (approximately 12 years old), they were invited to the Wave II data collection. These six graders studied in four elementary schools in three school districts (rural/suburb/urban) in Jintan city during Wave II data collection. The current study used a subsample of participants who were enrolled in Wave II and had complete cross-sectional data (n = 629) on napping behaviors (either frequency or duration) and fasting blood glucose concentrations. Four participants were excluded due to self-reported poor health status, yielding a final sample of 625 healthy early adolescents.

The Wave II data collection for the upper cohort was conducted in 2011 and the lower cohort in 2013. Sleep-related questionnaires were completed under the supervision of a research assistant in student classrooms. Furthermore, pediatric nurses conducted physical examinations for participants in each school, which included blood tests on fasting glucose, cholesterol, and height/weight measurement. Detailed sampling and research procedures of this cohort study have been described in Liu et al., [32]. The Jintan research team obtained written informed consent from parents and adolescents, and the Institutional Review Board (IRB) approval from the University of Pennsylvania and the ethical committee for research at Jintan Hospital in China. This secondary analysis also received IRB approval from the University of Delaware.

2.2. Measurements

2.2.1. Mid-day napping frequency and duration

Adolescents completed the Youth Self-report Sleep Questionnaire [34], which included self-report questions about habitual bedtime and rise time, napping frequency and duration and self-rated sleep quality during the past month. Napping frequency was assessed by asking "During the past month, how often did you usually take a post-lunch/midday nap in general?" Participants answered the question using a 5-point scale with frequency responses: never, <1 day/week, 1–2 days/week, 3–4 days/week, and 5–7 days/week. They were also asked to report the average duration of their naps on a 5-point scale: <15 min, 15–30 min, 31–60 min, 61 min–2 hours, and >2 hours. We recoded nap duration as 0 min if participants reported never-napped in the frequency question. Categories with small frequencies were merged into adjacent categories. Thus, we regrouped nap frequency into four categories as follows: never, ≤2 days/week, 3–4 days/week, and 5–7 days/week, and nap duration into four categories: never (0 min), <30 min, 31–60 min, and >60 min.

2.2.2. Nighttime sleep

Participants self-reported habitual bedtime and rise time on school days. Total time in bed (TIB) was calculated by the interval between habitual bedtimes and rise times on school days. Subjective sleep measures remain the most practical tools to characterize adolescent sleep in large-scale community research [35]. Given that the majority of self-report studies in children and adolescents operationalized sleep duration as self-report TIB [36,37], we used T1B as a proxy measure of nighttime sleep duration to ensure the comparability of our study results to other research. Nighttime sleep quality was assessed by asking "During the past month, how would you rate your sleep quality overall?" This question was answered using a four-point scale: excellent, good, poor and very poor.

2.2.3. Fasting plasma glucose

Research assistants provided fasting instructions to participants the day before data collection. Peripheral blood specimens were drawn between 7 and 8 AM in each school by pediatric nurses from the Jintan Hospital. Before blood draw, pediatric nurses verified fasting status by asking the question "did you eat or drink anything other than water after 9 PM last night?". The blood samples were sent to Jintan Hospital laboratory for plasma glucose concentration analysis using a strict research protocol. According to the reference

range recommended by the American Diabetes Association, fasting plasma glucose concentrations were dichotomized into normal (<5.6 mmol/L) and impaired (≥5.6 mmol/L) fasting glucose (IFG) levels [38].

2.2.4. Covariates

Socio-demographic variables, including age, sex, parental education levels and school districts (rural/suburb/urban) were assessed and treated as covariates. Since body mass index (BMI) and plasma cholesterol concentrations have been linked to daytime napping and/or risk for elevated glucose levels and type 2 diabetes [39–41], we also considered them as covariates in this study. BMI was calculated using the formula self-report weight (kg) divided by height in meters squared (m) as an indirect measure of body fat. Fasting plasma cholesterol samples were collected and analyzed using a similar procedure of plasma glucose measurement. We reported the detailed data-collection procedures for covariates elsewhere [32].

2.3. Statistic analyses

We used descriptive statistics to present socio-demographic factors, nap frequency and duration. At the bivariate level, we tested the differences between nap groups using the analysis of variance (ANOVA) for age, BMI, plasma cholesterol concentrations, nighttime TIB and sleep quality; and chi-squared tests for categorical variables such as sex, parental education, and school district. For bivariate analyses that showed overall differences, post hoc analyses were followed using pairwise comparisons with a Tukey–Kramer adjustment. We performed two multivariate random-effect logistic models to estimate the odds ratio (95% CI) of having impaired fasting glucose, with participants' original cohort set as a random effect to account for clustering of observations across cohorts. Models used the never-napped group as the reference category and adjusted for age, sex, school district, education in mother and father, night time in bed, nighttime sleep quality, BMI and plasma cholesterol concentrations. Nap frequency and duration were analyzed separately due to their collinearity. To examine the interaction between TIB and napping behaviors, we further added TIB-nap frequency interaction term and TIB-nap duration term into two separate random-effect logistic regression models, controlling for studied covariates. Using the STATA's Margins function, we further estimated the marginal effect of nap frequency/duration on the probability of having IFG, when TIB was held constant at different values. Since linear prediction is the default for marginal effect in random-effect logistic regression in STATA, we reported coefficients (β), p values and 95% CI for the interaction effects. The significance level was set at $\alpha = 0.05$ level.

3. Results

3.1. Sample characteristics

The final dataset comprised of 625 early adolescents (12.26 ± 0.63 years old) with 54.37% (n = 342) boys. Only 105 (16.80%) early adolescents reported having never napped in the past month. Among nappers, about 30.56% (n = 116) were routine nappers defined as naps of 5–7 days/week. Moreover, 68% of our sample (n = 423) had an average nap length greater than 30 minutes each day. In terms of nighttime sleep, respondents reported TIB as 8.86 ± 0.81 hours per night on school days, with 45.01% having nighttime sleep less than recommended 9 hours. In addition, 100 (16.15%) participants self-reported poor or very poor sleep quality. The average fasting glucose concentration was 5.14 ± 0.55 mmol/L, with 101 (16.06%) participants classified as having impaired fasting glucose levels.

Table 1 shows sample characteristics by nap groups. Nap frequencies ($\chi 2 = 14.70$, $p = 0.01$) and nap lengths ($\chi^2 = 16.24$, $p = 0.004$) statistically differed between boys and girls, with boys having a higher frequency in the never-napped condition (21% VS 12%). There were significant overall differences among nap-duration groups with respect to age ($F = 4.21$, $p = 0.02$), mother ($\chi^2 = 16.49$, $p = 0.02$) and father ($\chi^2 = 24.23$, $p < 0.001$) education levels and school district ($\chi^2 = 14.25$, $p = 0.02$). Specifically, participants whose parents received up to middle-school education had the highest frequencies of long naps >60 min, while participants whose father received college education reported the highest frequencies of moderate naps (31–60 min). Participants whose school district was located in rural/suburb areas showed higher frequencies of routine naps (5–7 days/week) than those in urban areas. The mean age of participants who reported naps of >60 min was slightly older than those who never napped (Tukey $t = 2.55$, $p = 0.05$). At the bivariate level, the mean BMI, blood cholesterol concentrations and frequency of impaired fasting glucose were similar across napping groups (p's > 0.05).

3.2. Nighttime sleep associated with midday napping

As shown in Table 1, self-reported TIB (hours) was significantly different across nap-frequency ($F = 3.03$, $p = 0.03$) and nap-duration groups ($F = 2.69$, $p = 0.045$). The post-hoc comparison indicated that compared with those who had never napped, frequent nappers (5–7 d/w) or those who reported 1–60 min per nap significantly slept longer at night as indicated by TIB (ps < 0.05). There was a trend toward better sleep quality, suggested by lower sleep quality score, with increasing nap frequency ($F = 3.09$, $p = 0.02$) and duration ($F = 3.16$, $p = 0.02$). Post-hoc analyses showed that participants with naps ≤60 min or 5–7 days/week were significantly associated with better nighttime sleep quality (ps < 0.05) than the never-napped group.

3.3. Midday napping, self-report time in bed and impaired fasting glucose

Table 2 shows odds ratios of nap frequency/duration and TIB after adjusting for age, sex, school district, parental education levels, BMI, plasma cholesterol, and nighttime sleep quality. Controlling for TIB, adolescents who napped 3–4 days/week (OR = 1.72, $p < 0.001$) and 5–7 days/week (OR = 1.34, $p = 0.02$) were associated with an increased likelihood of having IFG compared with the never-napped group. In the model using nap duration as an independent variable, adolescents who napped 31–60 min (OR = 1.52, $p = 0.04$) and >60 min (OR = 1.56, $p < 0.001$) were estimated to increase the odds of having IFG by about 50% compared with non-nappers. In both models, longer TIB at night demonstrated a small decrease in the likelihood of IFG (OR = 0.91 and 0.87) but the associations were not statistically significant (ps > 0.05). Worse sleep quality was significantly associated with increased odds of having IFG (OR = 1.08, $p = 0.04$) in the model controlling for nighttime TIB, nap durations and other covariates.

Regarding the interaction between nap and TIB, the coefficients of interaction terms between nap frequency/duration groups and TIB showed positive signs, suggesting that napping behaviors dampened the inverse relationship between TIB and IFG compared with the never-napped condition. Specifically, among non-nappers, every one-hour increase in TIB at night tended to significantly decrease the odds of having IFG by about 55% ($\beta = -0.80$/OR = 0.45, $p = 0.03$) (Table 3). The differences in the mean marginal effect of TIB on the odds of IFG between frequent nappers and non-nappers

Table 1
Sample characteristics by nap groups in early adolescents in sixth grade (n = 625).

	Nap Frequency					Nap Length				
	Never	≤2 d/w	3–4 d/w	5–7 d/w	χ^2/F^a	Never	≤30 min	31–60 min	>60 min	χ^2/F^a
Sex										
Male	72 (21.24%)	76 (22.42%)	95 (28.02%)	96 (28.32%)	14.70**	72 (21.49%)	52 (15.52%)	105 (31.34%)	106 (31.64%)	16.24**
Female	33 (11.54%)	53 (18.53%)	105 (36.71%)	95 (33.22%)		33 (11.62%)	39 (13.73%)	126 (44.37%)	86 (30.28%)	
Age (years)	12.17 ± 0.44	12.23 ± 0.51	12.30 ± 0.72	12.27 ± 0.69	0.93	12.17 ± 0.44	12.17 ± 0.46	12.23 ± 0.57	12.39 ± 0.82	4.21*[b]
Mother's education										
≤Middle school	44 (18.26%)	45 (18.67%)	69 (28.63%)	83 (34.44%)	7.32	44 (18.26%)	33 (13.69%)	73 (30.29%)	91 (37.76%)	16.49*
High school	18 (13.24%)	26 (19.12%)	51 (37.50%)	41 (30.15%)		18 (13.33%)	21 (15.56%)	51 (37.78%)	45 (33.33%)	
≥College	41 (17.23%)	56 (23.53%)	77 (32.35%)	64 (26.89%)		41 (17.60%)	37 (15.88%)	102 (22.75%)	53 (22.75%)	
Father's education										
≤Middle school	35 (20.11%)	37 (21.26%)	39 (22.41%)	63 (36.21%)	11.63	35 (19.89%)	21 (11.93%)	49 (27.84%)	71 (40.34%)	24.23**
High school	28 (16.37%)	32 (18.71%)	62 (36.26%)	49 (28.65%)		28 (16.57%)	21 (12.43%)	62 (36.69%)	58 (34.32%)	
≥College	40 (14.76%)	58 (21.40%)	96 (35.42%)	77 (28.41%)		40 (15.09%)	49 (18.49%)	116 (43.77%)	60 (22.64%)	
School district										
Rural	19 (16.96%)	26 (23.21%)	28 (25.00%)	39 (34.82%)	14.25*	19 (16.52%)	12 (10.43%)	41 (35.65%)	43 (37.39%)	12.18
Suburb	43 (16.29%)	48 (18.18%)	78 (29.55%)	95 (35.98%)		43 (16.48%)	37 (14.18%)	89 (34.10%)	92 (35.25%)	
Urban	43 (17.27%)	55 (22.09%)	94 (37.75%)	57 (22.89%)		43 (17.70%)	42 (17.28%)	101 (41.56%)	57 (23.46%)	
Blood cholesterol (mmol/L)	4.02 ± 0.83	3.99 ± 0.68	4.01 ± 0.67	3.96 ± 0.64	0.23	4.02 ± 0.83	3.98 ± 0.70	4.01 ± 0.65	3.97 ± 0.66	0.19
Body Mass Index	19.16 ± 3.29	19.28 ± 3.94	19.48 ± 3.93	19.12 ± 3.36	0.33	19.16 ± 3.29	19.98 ± 3.55	19.14 ± 3.60	19.09 ± 3.55	1.26
Time in bed (hours)	8.68 ± 0.91	8.89 ± 0.77	8.80 ± 0.84	8.97 ± 0.74	3.03*[c]	8.68 ± 0.91	8.76 ± 0.76	8.92 ± 0.75	8.92 ± 0.84	2.69*[d]
Nighttime sleep quality	2.01 ± 0.88	1.87 ± 0.75	1.82 ± 0.72	1.71 ± 0.72	3.09*[e]	2.01 ± 0.88	1.89 ± 0.83	1.80 ± 0.72	1.73 ± 0.75	3.16*[f]
Blood glucose levels										
Normal	87 (16.60%)	106 (20.23%)	164 (31.30%)	167 (31.87%)	2.66	87 (16.73%)	80 (15.38%)	188 (36.15%)	165 (31.73%)	2.85
IFG	18 (17.82%)	23 (22.77%)	36 (35.64%)	24 (23.76%)		18 (18.18%)	11 (11.11%)	43 (43.43%)	27 (27.27%)	

Note. Data were provided as n(%) or mean ± standard deviation. [a] $\chi 2$ test was used for dichotomous variables and ANOVA was used for continuous variables. Post-hoc analyses results: [b.] ">60min" VS "Never": p = 0.05; [c.]"5-7d/w" VS "Never": p = 0.01; [d]"≤ 30 min" VS "Never": p = 0.03, "31–60 min" VS "Never": p = 0.05; [e] "5-7d/w" VS "Never": p = 0.002; [f] "≤ 30 min" VS "Never": p = 0.04, "31–60 min" VS "Never": p = 0.01; *p < 0.05, **p < 0.01.

Table 2
Results of logistic regression models of IFG on napping behaviors among Early Adolescents in Sixth Grade.

Model 1	OR (robust se)	95% CI
Nap frequency		
≤2/wk	1.45 (0.36)	(0.89,2.36)
3–4/wk	1.72 (0.16) **	(1.43,2.07)
5–7/wk	1.34 (0.16) *	(1.05,1.70)
Time in bed (TIB, hours)	0.91 (0.09)	(0.75,1.10)
Self-rated sleep quality	1.05 (0.05)	(0.97,1.70)
Model 2	**OR (robust se)**	**95% CI**
Nap duration		
≤30 min	1.01 (0.24)	(0.63,1.62)
31–60 min	1.52 (0.31) *	(1.02,2.28)
>60 min	1.56 (0.18) **	(1.25,1.94)
Time in bed (TIB, hours)	0.87 (0.09)	(0.71,1.08)
Self-rated sleep quality	1.08 (0.04) *	(1.01,1.17)

Note. In each model, the reference level was the never-napped group. Models controlled for age, sex, parental education, residence, BMI, plasma cholesterol and self-rated nighttime sleep quality and considered cohorts as a random effect. OR = odds ratio, se = standard error, CI = confidence interval. *p < 0.05, **p < 0.01.

Table 3
Results of logistic regression models of IFG with an interaction term among Early Adolescents in Sixth Grade.

Model 1	β (robust se)	95% CI
Nap frequency		
≤2/wk	−8.34 (6.48)	(−21.04,4.36)
3–4/wk	−4.95 (3.12)	(−11.06,1.15)
5–7/wk	−7.63 (3.81) *	(−15.10,-0.15)
Time in bed (TIB, hours)	−0.80 (0.38) *	(−1.55,-0.06)
Interaction		
1–2/wk # TIB	1.02 (0.74)	(−0.43,2.47)
3–4/wk # TIB	0.66 (0.37)	(−0.07,1.39)
5–7/wk # TIB	0.93 (0.43) *	(0.09,1.76)
Model 2	**β (robust se)**	**95% CI**
Nap duration		
≤30 min	−6.54 (1.13) **	(−8.75, −4.33)
31–60 min	−6.98 (6.05)	(−18.84, 4.89)
>60 min	−5.21 (1.74) **	(−8.62, −1.80)
Time in bed (TIB, hours)	−0.78 (0.35) *	(−1.47, −0.09)
Interaction		
≤30 min # TIB	0.77 (0.13) **	(0.53, 1.02)
31–60 min # TIB	0.87 (0.68)	(−0.46, 2.20)
>60 min# TIB	0.67 (0.21) **	(0.26, 1.09)

Note. In each model, the reference level was the never-napped group. Models control for age, sex, parental education, residence, BMI, plasma cholesterol and self-rated nighttime sleep quality and considered cohorts as a random effect. se = standard error, CI = confidence interval. *p < 0.05, **p < 0.01.

(β = 0.93, p = 0.03), and between nappers with nap lengths ≤ 30 min (β = 0.77, p<0.001) or >60 min (β = 0.67, p = 0.002) and non-nappers, were statistically significant (Table 3). These results indicated that compared with non-nappers, the magnitudes of TIB-IFG association significantly decreased in groups who napped frequently (5–7 days/week) or napped ≤ 30 min or >60 min and the direction of the TIB-IFG association even altered in the frequent napping group (Table 3 and Fig. 1). Fig. 1 shows the average marginal effect of TIB on IFG among nap frequency/duration groups.

Table 4 further reports the contrasts of marginal effects of napping groups versus non-nappers on IFG when TIB is held constant at different values. Specifically, when adolescents reported at least nine hours for TIB at night, nappers with nap frequencies ≥3 d/week showed a significant increase in the likelihood of having IFG compared with non-nappers (ps < 0.05). There was a similar trend for nap-duration groups. While nappers with any nap length who reported TIB≥9 hours were significantly associated with an increased likelihood of having IFG versus non-nappers (ps < 0.05), there was an opposite trend for those who had TIB <9 hours.

4. Discussion

The present study is one of the first to examine the relationship among habitual midday napping, nighttime sleep duration and impaired fasting glucose risk using an early adolescent sample. Over 80% of our sample reported midday napping behaviors in the

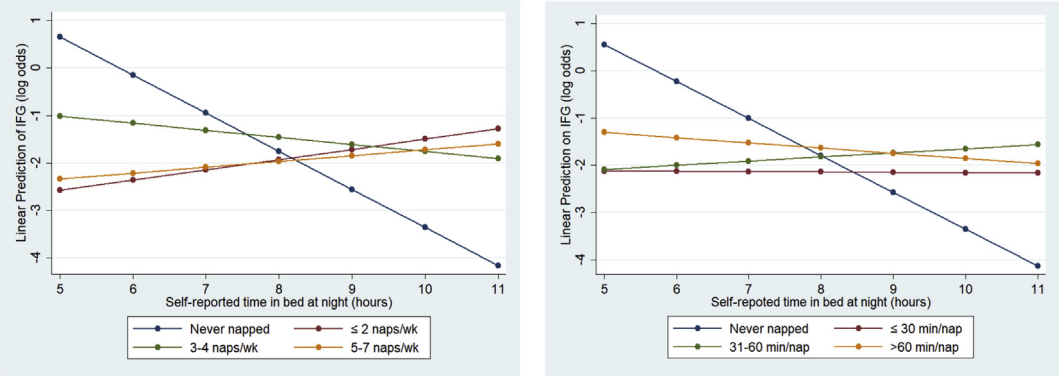

Fig. 1. The marginal effect of time in bed (β) on IFG for each nap frequency/duration group.

Table 4
The marginal effect of napping on log odds of IFG at different values of TIB at night: difference with non-nappers.

Time in bed	Model 1 (β of nap frequency)			Model 2 (β of nap duration)		
	≤2 naps/wk	3–4 naps/wk	5–7 naps/wk	≤30 min/nap	31–60 min/nap	>60 min/nap
5 hours	−3.24	−1.67	−2.99	−2.67**	−2.64	−1.86**
6 hours	−2.22	−1.02	−2.07	−1.90**	−1.77	−1.19**
7 hours	−1.20	−0.36	−1.14	−1.13**	−0.90	−0.51
8 hours	−0.18	0.29*	−0.21	−0.35	−0.03	0.16
9 hours	0.85*	0.95**	0.71**	0.42*	0.83**	0.83**
10 hours	1.87	1.61*	1.64**	1.19**	1.70**	1.50**
11 hours	2.89	2.26*	2.57**	1.97**	2.57	2.17**

Note. Data presented was predictive margins (β = log odds) of each nap group minus that of non-nappers. Contrasts of predictive margins and p values were produced by the post option (margins command) of random effect logistic regression with interaction terms in the Stata.

past month and girls napped more than boys. Midday naps ≥3 days/week or ≥31 min were significantly associated with better nighttime sleep quality and longer TIB. Compared with non-nappers, routine midday nappers (5–7 days/week) and nappers with average durations ≥ 31 min were significantly associated with an increased likelihood of IFG, independent of self-reported TIB and sleep quality at night. After controlling for napping frequency/duration, there were no significant associations between TIB and IFG. However, we found interactive effects between midday napping and TIB on odds of developing IFG. Non-nappers with an increased TIB significantly predicted decreased odds of IFG. Compared with the never-napped condition, napping behaviors weakened or reversed the relationship between TIB and IFG. TIB also moderated the association between midday napping and IFG. Midday nappers with nocturnal TIB ≥9 hours, particularly those who averagely napped ≥3 days/week or of any nap-duration, were estimated to have an increased likelihood of IFG compared with the never-napped group.

The nap-IFG relationship was most pronounced among nappers with ≥3 naps/week or ≥31 min/nap. Whereas habitual naps (≥3 days/week) and moderate/long naps (≥31 min) were estimated to increase the odds of having IFG independent of TIB and sleep quality at night, there was no significant association of IFG with less frequent naps and short naps. IFG indicates early metabolic abnormalities that precede diabetes, and up to 70% of individuals with prediabetes indicators eventually develop diabetes [42]. Although evidence is sparse in the adolescent population, our findings are in line with previous epidemiological studies that reported a dose-dependent relationship between midday napping and risk for prediabetes and diabetes in adults and older adults [26,27,43]. Among Chinese adults aged 50 years or older, those who reported frequent midday naps (≥4 days/week) were associated with small increases in the odds of having IFG and diabetes versus the never-napped group [44]. The risk level of nap duration varied in prior findings. Consistent with our findings, white postmenopausal women in the US who napped ≥30 min/day had 74% higher odds of diabetes compared to non-nappers after controlling for covariates including nighttime sleep duration [43]. Two cross-sectional studies in China observed increased odds of IFG and diabetes only among older adults with naps greater than 60 min [26] or 90 min [45], respectively. Notably, empirical evidence on habitual napping and risk for IFG/diabetes is mixed. Dragano et al., found that diabetes was less prevalent among daily short napper (≤60 min) than in no/irregular nappers in Germany [29]. The inconsistent findings may result from discrepancies in selected covariates, characteristics of daytime napping such as planned/unplanned naps and the timing of naps, and the statistical treatment of nighttime sleep duration and quality.

The average TIB (8.86 hours) in our sample was higher than the average TIB among early adolescents aged 12 years (8.24 hours) in Asia but slightly shorter than the same age group in the US (8.97 hours) [36]. Despite a less sleep-deprived sample, nearly half of early adolescents did not meet the nine-hour recommendation for age 12 [46]. There was no significant relationship between TIB at night and odds of IFG after controlling for nap duration/frequency and sleep quality. Our findings contradict with previous studies that have linked short sleep duration with elevated fasting plasma glucose levels and risk of type 2 diabetes across age groups [17,47]. While the majority of previous findings did not consider the role of naps and/or sleep quality, the current study adjusted for the potential confounding effect of midday napping behaviors and self-reported sleep quality. The interaction analyses further suggested that the TIB-IFG association was dependent on napping behaviors. Non-nappers showed a trend towards decreasing odds of IFG with increasing TIB. In contrast, the magnitudes of this association significantly decreased among frequent (5–7 days/week) and long (>60 min/nap) nappers and the direction of the TIB-IFG association even altered in the frequent-napping group. The current study

partially replicate a prospective study by Xu et al. [48], which found that only short nighttime sleep was associated with a higher risk of diabetes among non-nappers, whereas both short and long nighttime sleep were associated with a higher risk of diabetes among those with one-hour naps. Our findings and those reported previously consistently indicate that napping behaviors dampened the protective effect of nighttime sleep on the risk for IFG.

Midday napping, especially regular naps at least three times per week, may be a risk factor for IFG and diabetic risk among adolescents who had sufficient nighttime sleep (TIB ≥9 hours). Our findings support a prospective study in Israel, which showed increased mortality in 20-year follow-up among elderly nappers who had nighttime sleep longer than nine hours [31]. A recent study in Japanese patients with type 2 diabetes further suggested that taking midday naps reduced the risk of poor glycemic control associated with short nighttime sleep (<5 hours) [30]. In contrast, in a British sample, participants who took daytime naps and shortened nighttime hours slept showed the highest risk for type 2 diabetes [27]. In Western society, daytime napping is viewed as a sleep behavior driven by pre-existing health conditions and insufficient nighttime sleep [27]. However, napping may be a planned behavior determined by cultural ritual in our sample. Since cultural differences in napping behaviors may influence research findings, the current findings may not be generalizable to Western cultures. More research is warranted to examine the association between midday naps and diabetes risk with different nighttime sleep hours in Western cultures.

The underlying mechanism whereby midday napping may predict the risk of IFG and diabetes is underexplored. Midday napping may affect sleep homeostatic and circadian processes, which further expert negative influences on physiological functions including metabolic hormones [49–51]. Prior research found that daytime napping was associated with impaired glucose regulation, insulin resistance and glycated hemoglobin in Chinese adults, who share the same napping culture with our sample [52]. Daytime napping may be associated with elevated inflammatory biomarkers (eg, C-reactive protein and evening cortisol levels) [53,54] which predispose to insulin resistance and type 2 diabetes. Prior research also suggests that obesity indicators associated with habitual napping may partially explain the nap-IFG relationship [45]. However, BMI values did not differ by nap groups in the present study. Additionally, nighttime sleep duration and sleep quality have been hypothesized as potential mediators [6,55]. In contrast, midday napping in our sample did not function as compensation for sleep deficiencies or a risk factor for impaired nocturnal sleep. Thus, the nap-IFG relationship is less likely mediated by TIB in our study. Regarding the moderate effect of TIB on the nap-IFG association, there is no clear mechanism underlying the aforementioned dose–response relationship. One possible explanation may be the importance of moderate sleep hours within a 24-hour period. Research shows that both short and long sleep duration are associated with insulin resistance, thus mediating the risk for IFG and diabetes [56]. Further research is needed to understand the biological mechanism underlying the interaction between daytime napping and nighttime sleep on metabolic health.

The present study used an early adolescent sample living in siesta culture and included important covariates, such as nighttime sleep quality and BMI, thereby ensuring robust estimates of the relationship among habitual midday napping, TIB and the presence of IFG. Several potential limitations of this study should be taken into consideration. First, midday napping and nighttime sleep were assessed using self-reported measures, which may be subjected to recall bias. Despite potential weekday-weekend discrepancies, we did not distinguish napping and nighttime sleep on school days and weekends. Future research should employ objective measures of weekday and weekend sleep (eg, actigraphy) to validate our findings. Second, a single measurement of fasting glucose concentrations may not capture the insulin-resistant states [42], and future research should consider more robust measures of insulin sensitivity such as homeostasis model assessment of insulin resistance (fasting insulin × fasting glucose/22.5), glucose tolerance test, hyperinsulinemic-euglycemic clamp technique [57]. Third, given that the sample size for the IFG group is small, we did not re-categorize napping frequency and duration groups (10 subgroups) to examine their joint effect. Nevertheless, our findings contribute to an understanding of the nap-IFG relationship with frequency and duration as separate behavioral dimensions of midday naps. Fourth, a cross sectional-study design cannot confirm a causal relationship between midday napping and IFG. Whereas IFG may function as a consequence of midday napping, IFG may also increase daytime sleepiness, thus resulting in midday napping behaviors. In addition, midday napping in our sample was driven by social norms of daytime sleep practice. Due to cultural differences, our findings may be not generalizable to napping behaviors in non-siesta countries, especially “compensational” napping behaviors. The association among napping, nighttime sleep and IFG should be examined in other populations in future research. Finally, we did not collect data on medication use, clinical sleep disorders such as obstructive sleep apnea and other health conditions (eg, depression) that may confound the association among midday napping, nighttime sleep and IFG [58-60]. Although we excluded early adolescents who self-reported poor health status, there is a possibility that napping may be a marker of these confounders that increase the risk of IFG and diabetes.

5. Conclusions

Regular (≥3 times/week) and long (≥31 min) midday napping are associated with IFG, thus increasing the risk for diabetes among early adolescents in a siesta culture. Our study also suggests a complex interactive effect between midday napping frequency/duration and TIB on IFG, with the potential negative effect of midday napping present only among sufficient nighttime sleepers (TIB ≥ 9 hours). Given that midday napping is a custom ritual in Chinese society and schools provide nap opportunities, our findings warrant the need for future research on the optimal amount of daytime nap and nighttime sleep in diabetes prevention and management among adolescents in China. Although the current study suggests potential health detriments related to midday napping, the clinical implication of the interaction between midday nap and nighttime sleep is not fully understood. Moreover, our previous findings using the same sample implicate the cognitive and emotional benefits of midday naps [19,61]. Thus, there is insufficient evidence to inform different sleep routines and policy changes to school schedules in China. Further cohort studies with objective sleep measures are needed to examine the role of midday naps in multiple health outcomes in countries with and without a siesta culture.

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Conflict of interest

None of the authors declare any conflict of interest that may be relevant to the materials presented in this paper.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2019.06.016.

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