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Research article

U-shaped relationship between lights-out time and nocturnal oxygen saturation during the first trimester: An analysis based on the nuMOM2b-SDB data

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ABSTRACT

Objective: Preventing adverse events due to unstable oxygen saturation (SpO2) at night in pregnant women is of utmost importance. Poor sleep has been demonstrated to impact SpO2 levels. Nowadays, many gravida have a habit of prolonged exposure to light before sleep, which can disrupt their sleep. Therefore, this study aimed at investigate the relationship between lights-out time, sleep parameters and SpO2, exploring the underlying mechanisms.

Methods: The data of 2881 eligible subjects from the Nulliparous Pregnancy Outcomes Study Monitoring Mothers-to-be and Sleep Disordered Breathing (nuMOM2b-SDB) database were analyzed. Multiple linear regression models were used to investigate the relationship between lights-out time and SpO2. In addition, restricted cubic splines (RCS) were employed to fit the nonlinear correlation between the two variables. The smoothing curve method was further utilized to depict the relationship between lights-out time and SpO2 based on various subgroup variables.

Results: All participants were categorized according to race/ethnicity. A negative correlation was observed between nighttime lights-out time and average value of SpO2 (Avg-SpO2) ($\beta = -0.05$, $p = 0.010$). RCS revealed a U-shaped relationship between lights-out time and Avg-SpO2, with the turning point at 22:00. The subcomponent stratification results indicated that the Avg-SpO2 and minimum value of SpO2(Min-SpO2) of advanced maternal age decreased as the lights-out time was delayed. Furthermore, overweight and obese gravida showed lower Avg-SpO2 and Min-SpO2 levels than normal weight.

Abbreviations: nuMOM2b-SDB, Nulliparous Pregnancy Outcomes Study Monitoring Mothers-to-be and Sleep Disordered Breathing; NSRR, National Sleep Research Resource; nuMOM2b, Nulliparous Pregnancy Outcomes Study Monitoring Mothers-to-Be; SpO2, oxygen saturation; Min-SpO2, minimum value of oxygen saturation; Max-SpO2, maximum value of oxygen saturation; Avg-SpO2, average value of oxygen saturation; AHI, Apnea Hypopnea Index; SDB, Sleep Disordered Breathing; SCN, suprachiasmatic nucleus; BMI, body mass index; RCS, restricted cubic spline.

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Conclusions: A U-shaped relationship was identified between lights-out time and nocturnal Avg-SpO2 during early pregnancy, with the inflection at 22:00. Notably, later lights-out times are associated with lower levels of Min-SpO2 for advanced maternal age. The findings suggest that appropriately adjusting the duration of light exposure before sleep and maintaining a relatively restful state may be more beneficial for the stability of SpO2 in pregnant women. Conversely, deviations from these practices could potentially lead to pathological alterations in SpO2 levels.

1. Introduction

Oxygen saturation (SpO2) reflects the oxygen content in human blood. The reference range for SpO2 in the general population is 95%–100 % (https://www.nccn.org, 2023) [1], and low SpO2 could negatively impact health. During pregnancy, women experience an increased physiological demand for oxygen compared to the general population [2]. Maintaining stable SpO2 levels throughout gestation, particularly during nighttime hours, is critical for both maternal and fetal well-being [3]. Research has demonstrated a correlation between decreased maternal SpO2 during sleep and reduced birth weight and head circumference in newborns [4]. Furthermore, unstable SpO2 levels can manifest as headaches, palpitations, and other discomforting symptoms for pregnant women. In severe cases, it may even contribute to pregnancy complications [5]. It is now understood that hypoxia during pregnancy poses a significant threat to fetal development [6], particularly during the first trimester when the neural tube is forming, a process highly dependent on adequate oxygen supply. Therefore, prioritizing stable SpO2 levels during the first trimester, especially at night, holds significant importance.

Chronic nocturnal exposure to artificial light may have a effect on SpO2 levels, potentially leading to adverse health consequences [7,8]. Some studies on gravidas have reported various negative effects resulting from long-time exposure to artificial light at night [9]. Chronic exposure to low-intensity light immediately before bedtime significantly affects sleep homeostasis, circadian phase, and cycle duration [10], poor sleep may also lead to changes in SpO2 levels [11]. Compared with the general population, pregnant women require good sleep to maintain their health and that of the fetus [12]. However, poor sleep quality is common during the first trimester [13], and various sleep-related parameters such as sleep duration, sleeping position, and snoring, can affect sleep quality [14]. Therefore, this study hypothesized that maternal nocturnal SpO2 during the first trimester might be influenced by the duration of exposure to artificial light before sleep and different sleep status.

This study aimed at investigate the association between lights-out time, sleep status-related variables, and maternal nocturnal SpO2, further exploring the influencing factors for maternal nocturnal SpO2.

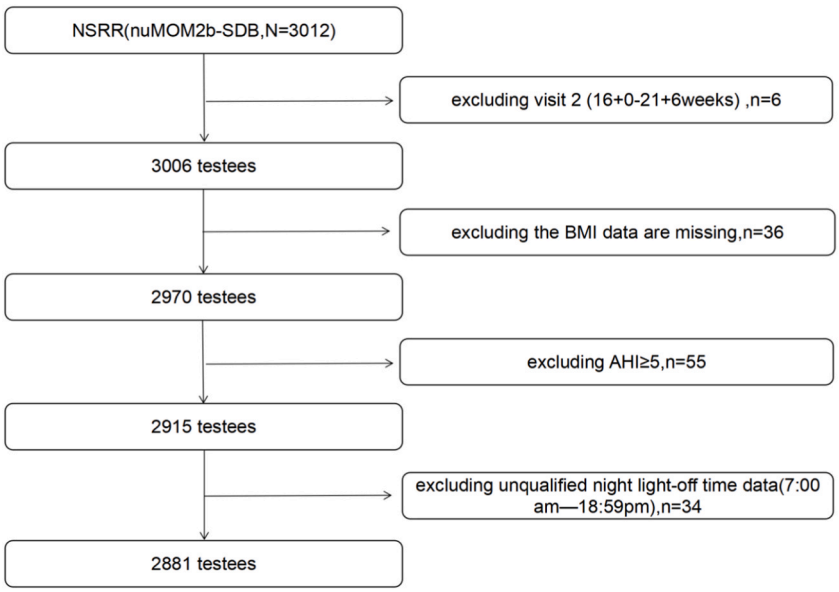

Fig. 1. Flow chart of the study design and the excluded subjects.
Abbreviations: nuMOM2b-SDB, nulliparous pregnancy outcomes study monitoring mothers-to-be and sleep disordered breathing; NSRR, national sleep research resource; AHI, apnea-hypopnea index.

2. Materials and methods

2.1. Data sources

NuMOM2b-SDB is a substudy of Nulliparous Pregnancy Outcomes Study Monitoring Mothers-to-Be (nuMOM2b) trial, which was designed to provide a continuous and objective assessment of sleep-disordered breathing (SDB) during pregnancy [15]. nuMOM2b-SDB included a total of 3702 women from the nuMOM2b parent study and used Embletta-Gold devices to conduct standardized level III home sleep tests during weeks 6°-15^{0} (visit 1) and 22°-31^{0} (visit 3) of gestation. Sleep monitoring devices, as used in this study, do not record sleep directly (i.e. with EEG and electromyography signals). Hence, sleep onset and offset and periods of prolonged wakefulness were determined by certified polysomnologists using information from both participant-completed questionnaires and the collected sleep data. The study was conducted at eight clinical sites and data were managed by a central data coordinating and analysis center (RTI International). Institutional review board approval was obtained at all sites [16].

This study is a secondary analysis of the nuMOM2b-SDB data. Due to partially missing nuMOM2b-SDB data in the NSRR, so the nuMOM2b-SDB data were reorganized before analysis (Fig. 1).

2.2. Variable-definition

In this study, the lights-out times were divided into 12 groups: 19: 00 p.m., 20: 00 p.m., 21: 00 p.m., 22: 00 p.m., 23: 00 p.m., 00: 00 a.m., 1: 00 a.m., 2: 00 a.m., 3: 00 a.m., 4: 00 a.m., 5: 00 a.m., and 6: 00 a.m. This study investigated three parameters of SpO2 measured during sleep: minimum SpO2 (Min-SpO2), average SpO2 (Avg-SpO2), and maximum SpO2 (Max-SpO2). Nocturnal SpO2 fluctuations can reflect an individual's average oxygen consumption and potential hypoxic events [17]. While comparing oxygen consumption at a single point in time offers limited pathological or physiological insight, the present research focused on nocturnal Avg-SpO2 as a more informative measure.

Among the exposure factors, the sleep efficiency was defined as the proportion of sleep duration to total bed time, and sleep maintenance efficiency referred to the proportion of sleep duration in the sleep period. In addition, the database did not contain accurate data for the apnea-hypopnea index (AHI). In this study, the AHI value was calculated by the following formula: AHI = number of respiratory events (apnea + hypopnea)/estimated sleep time (h). An AHI $\geq$5 was the minimum standard for diagnosing SDB [18, 19].

2.3. Variable classification

The data were classified into three categories: sociodemography, the sleep position, and sleep quality (Supplementary table). The sociodemographic data included race/ethnicity, age, and BMI. The age was divided into three subgroups based on the development of the female reproductive system, namely 14–20 years, 20–35 years, and $\geq$35 years [20]. BMI was divided into four subgroups according to international reference standards: $<$18.5 kg/m^2, 18.5–24.9 kg/m^2, 25–29.9 kg/m^2, and $\geq$30 kg/m^2 [21]. The sleep position variables included the duration of supine sleep and non-supine sleep. Sleep quality was determined by the estimated total sleep duration, the sleep efficiency, sleep maintenance efficiency, the number of snores during sleep, and the number of times of awakening. Moreover, the estimated total sleep duration was divided into two groups based on the latest research evidence, namely the $<$ 7h, $\geq$ 7h group [22].

2.4. Statistical analysis

The normality of all variables was first assessed using the Kolmogorov-Smirnov test. The numerical variables conforming to a normal distribution were compared by analysis of variance and were presented as the mean $\pm$ SD. Variables are not conforming to a normal distribution were compared at different levels using the Kruskal-Wallis H test, the variables were presented as the median with the lower and upper quartile (Q1, Q3). The age, BMI, estimated total sleep time, and lights-out time variables were stratified, and the groups were compared with the Chi-square test.

Secondly, the categorical variables were set as dummy variables. Meanwhile, the lights-out time, age, and BMI were converted from categorical variables to continuous variables for data analysis. Linear regression analysis was used to test the quantitative dependence between each variable and SpO2. Single-factor analysis was carried out and the exposure factors showing $p < 0.05$ were included in the multiple linear regression model (ModelsI- III). Finally, the restriction cubic spline (RCS) was performed to determine the relationship between lights-off time and SpO2, and the smooth curve method was employed to explore the relationship between lights-off time and SpO2 based on age, BMI, and race/ethnicity through.

Data analysis software: IBM SPSS Statistics 26. Drawing software: RGui 4.3.1 (ggrcs package version 2.9) and Empower RCH. The significance threshold for all tests was set at two-sided $p < 0.05$.

3. Results

3.1. Descriptive statistics

A total of 2881 subjects subdivided by race/ethnicity were selected for our study. The data demonstrated that the age group of the

subjects was mainly concentrated on 20–35 years old. Normal weight (18.5 ≤ BMI < 24.9) subjects accounted for 50.8 % of the total. More than half of the subjects chose to turn off during the 22:00–23:00 p.m. period, and 63.5 % of gravida had an estimated total sleep time greater than 7 h. Race/ethnicity of gravida were significant difference in age, BMI, estimated total sleep time, lights-out time, total time in supine position, total time in non-supine position, Min-SpO2, Avg-SpO2, and Max-SpO2 (all $p < 0.05$). (Table 1).

3.2. Analysis for SpO2

3.2.1. Univariate analysis for SpO2

As shown in Table 2, race/ethnicity, age, sleep maintenance efficiency, and lights-out time factors could significantly affect nocturnal Min-SpO2, Avg-SpO2, and Max-SpO2 (all $p < 0.05$). Among these factors, age, sleep maintenance efficiency, and lights-out

Table 1
The differences in maternal race/ethnicity characteristics between groups.

Characteristics	Total (N = 2881)	Non-Hispanic white (n = 1765)	Non-Hispanic black (n = 340)	Hispanic (n = 531)	Asian (n = 108)	Other (n = 137)	F/χ^2	p
	n (%)/Median (Q1,Q3)	n (%)/Median (Q1,Q3)	n (%)/Median (Q1,Q3)	n (%)/Median (Q1,Q3)	n (%)/Median (Q1,Q3)	n (%)/Median (Q1,Q3)		
Age (years)							219.78	<0.001*
14–20	289 (10.03 %)	90 (0.05 %)	90 (0.26 %)	83 (0.16 %)	4 (0.04 %)	22 (0.16 %)		
20–35	2340 (81.20 %)	1516 (0.86 %)	231 (0.68 %)	415 (0.78 %)	76 (0.70 %)	102 (0.75 %)		
≥35	252 (8.77 %)	159 (0.09 %)	19 (0.06 %)	33 (0.06 %)	28 (0.26 %)	13 (0.09 %)		
BMI(kg/m^2)							117.14	<0.001*
<18.5	68 (2.40 %)	38 (2.20 %)	10 (2.90 %)	9 (1.70 %)	6 (5.60 %)	5 (3.60 %)		
18.5–24.9	1463 (50.80 %)	956 (54.20 %)	121 (35.60 %)	239 (45.0 %)	75 (69.40 %)	72 (52.60 %)		
25–29.9	732 (25.40 %)	457 (25.90 %)	76 (22.40 %)	151 (28.40 %)	18 (16.70 %)	30 (21.90 %)		
≥30	618 (21.5 %)	314 (17.70 %)	133 (39.10 %)	132 (24.90 %)	9 (8.30 %)	30 (21.90 %)		
Supine sleep time (min)	175 (99,258)	184 (107,265)	135 (29,211)	166 (94,248)	257 (141,332)	184 (95,252)	77.61	<0.001*
Non-supine sleep time (min)	252 (168,338)	248 (168,335)	263 (182,36)	260 (175,341)	202.50 (113,283)	258 (154,325)	22.33	<0.001*
Estimation total sleep time(h)							16.62	0.002*
<7	1052 (36.50 %)	617 (35.00 %)	156 (45.90 %)	199 (37.50 %)	34 (31.50 %)	46 (33.60 %)		
≥7	1829 (63.50 %)	1148 (65.00 %)	184 (54.10 %)	332 (62.50 %)	74 (68.50 %)	91 (66.40 %)		
Sleep efficiency (%)	94.95 (90.39,97.58)	95.02 (90.54,97.72)	94.33 (89.34,97.35)	95.27 (90.60,97.54)	95.58 (90.63,97.55)	93.89 (89.85,96.97)	7.18	0.127
Sleep maintenance efficiency (%)	98.61 (96.30,99.85)	98.67 (96.40,100)	98.28 (95.53,99.80)	98.58 (96.47,99.82)	98.62 (96.35,99.80)	98.44 (95.59,100)	6.48	0.166
Number of snoring events	11 (1,93)	11 (1,96)	10 (1,82)	11 (1107)	19 (2137)	9 (1,46)	3.30	0.508
Number of sleep to awake shifts(h)	0.31 (0.15,0.56)	0.30 (0.15,0.55)	0.35 (0.18,0.63)	0.30 (0.16,0.53)	0.30 (0.14,0.47)	0.33 (0.16,0.64)	7.34	0.119
Lights-out time							94.79	<0.001*
19:00pm	15 (0.50 %)	11 (0.60 %)	3 (0.90 %)	1 (0.20 %)	0	0		
20:00pm	97 (3.40 %)	60 (3.40 %)	13 (3.80 %)	16 (3.00 %)	2 (1.90 %)	6 (4.40 %)		
21:00pm	499 (17.30 %)	345 (19.50 %)	51 (10.20 %)	61 (11.50 %)	20 (18.50 %)	22 (16.10 %)		
22:00pm	953 (33.10 %)	628 (35.60 %)	94 (27.60 %)	166 (31.30 %)	27 (25.00 %)	38 (27.70 %)		
23:00pm	764 (26.50 %)	447 (25.30 %)	93 (27.40 %)	146 (27.50 %)	39 (36.10 %)	39 (28.50 %)		
0:00am	349 (12.10 %)	173 (9.80 %)	47 (13.80 %)	88 (16.60 %)	16 (14.80 %)	25 (18.20 %)		
1:00am	128 (4.40 %)	66 (3.70 %)	21 (6.20 %)	33 (6.20 %)	4 (3.70 %)	4 (2.90 %)		
2:00am	49 (1.70 %)	22 (1.20 %)	13 (3.80 %)	0	1 (0.70 %)	49 (1.70 %)		
3:00am	16 (0.60 %)	6 (0.20 %)	4 (1.20 %)	5 (0.90 %)	0	1 (0.70 %)		
4:00am	7 (0.20 %)	3 (0.20 %)	1 (0.30 %)	2 (0.40 %)	0	1 (0.70 %)		
5:00am	2 (0.10 %)	2 (0.10 %)	0	0	0	0		
6:00am	2 (0.10 %)	2 (0.10 %)	0	0	0	0		
Minimum-SpO2 (%)	93 (92,94)	93 (92,94)	93 (92,95)	93 (92,95)	93 (92,95)	93 (92,94)	47.90	<0.001*
Average-SpO2(%)	97 (96,97)	96 (96,97)	97 (97,98)	97 (97,98)	97 (96,98)	97 (96,97)	386.70	<0.001*
Maximum-SpO2 (%)	99 (98,100)	99 (98,99)	100 (99,100)	99 (99,100)	99 (98,100)	99 (99,100)	252.67	<0.001*

Abbreviations: BMI, body mass index; Q_1, low quartile; Q_3, upper quartile; SpO2, oxygen saturation.
% for: Age, BMI, estimation total sleep time, lights-out time. *p*-value was calculated by Chi-square test.
Me(Q1,Q3) for: Supine sleep time, non-supine sleep time, the sleep efficiency, the maintenance efficiency, the number of snoring events, awakening frequency, minimum-SpO2, average-SpO2, maximum-SpO2. *p*-value was calculated by Kruskal-Wallis H test.
Note: *$p < 0.05$.

Table 2
Linear regression relationships between nocturnal oxygen saturation and exposure characteristics.

Characteristics		Minimum-SpO2(%)				Average-SpO2(%)				Maximum-SpO2(%)			
		β	95%CI	R^2	*p*	β	95%CI	R^2	*p*	β	95%CI	R^2	*p*
Part One: Demographic information	Maternal race/ethnicity			0.01				0.01				0.09	
	Non-Hispanic white	Ref	Ref	–	–	Ref	Ref	–	–	Ref	Ref	–	–
	Non-Hispanic black	0.55	0.12,0.65	–	0.004*	0.29	0.87,1.11	–	<0.001*	0.26	0.55,0.73	–	<0.001*
	Hispanic	0.92	0.32,0.76	–	<0.001*	0.27	0.68,0.88	–	<0.001*	0.19	0.31,0.46	–	<0.001*
	Asian	0.32	−0.06,0.82	–	0.090	0.11	0.42,0.82	–	<0.001*	0.06	0.09,0.38	–	0.001*
	Other	0.27	−0.11,0.68	–	0.151	0.72	0.20,0.56	–	<0.001*	0.08	0.17,0.43	–	<0.001*
	Age (years)	−0.11	−0.06,-0.03	0.01	<0.001*	−0.12	−0.03,-0.02	0.02	<0.001*	−0.08	−0.02,-0.01	0.01	<0.001*
	BMI(kg/m^2)	−0.32	−0.13,-0.11	0.10	<0.001*	−0.13	−0.03,-0.02	0.02	<0.001*	0.02	0,0.01	0	0.360
Part Two:Sleep position factors	Supine sleep time (min)	−0.04	0,0	0	0.061	−0.07	0,0	0.01	<0.001*	−0.07	0,0	0.01	<0.001*
	Non-supine sleep time (min)	−0.03	0,0	0	0.086	0.05	0,0	0	0.006*	0.12	0,0	0.01	<0.001*
Part Three: Sleep quality factors	Estimation total sleep time(h)			0				0				0	
	<7	Ref	Ref	–	–	Ref	Ref	–	–	Ref	Ref	–	–
	≥7	−0.05	−0.42,-0.08	0	0.004*	−0.02	−0.13,0.04	–	0.283	0.04	0.01,0.12	–	0.033*
	Sleep efficiency (%)	−0.06	−0.03,-0.01	0	0.001*	−0.05	−0.01,0	0	0.013*	−0.03	−0.01,0	0	0.118
	Sleep maintenance efficiency (%)	−0.05	−0.03,0	0	0.012*	−0.05	−0.01,0	0	0.007*	−0.05	−0.01,0	0	0.014*
	Number of snoring events	−0.05	0,0	0	0.004*	−0.05	0,0	0	0.016*	0	0,0	0	0.324
	Number of sleep to awake shifts(h)	0.02	−0.07,0.27	0	0.240	0.01	−0.05,0.12	0	0.446	0.04	0,0.12	0	0.046*
	Lights-out time	−0.06	−0.03,-0.01	0	0.001*	−0.08	−0.02,-0.01	0.01	<0.001*	−0.04	−0.01,0	0	0.023*

Abbreviations: BMI, body mass index; SpO2, oxygen saturation.
Multiple Categorical variable: Including maternal race/ethnicity, estimation total sleep time. These variables were performed in the dummy variable setting, then using linear regression analysis to obtain β, 95 % CI, R^2, *p*-value.
Note: Ref, means reference; - invalid value is indicated. β, it is a standardized coefficient; *$p < 0.05$.

time all exhibited negative correlations with SpO2 (Min-SpO2, Avg-SpO2, Max-SpO2) (age: $\beta = -0.11$, $p < 0.001$, $\beta = -0.12$, $p < 0.001$, $\beta = -0.08$, $p < 0.001$; sleep maintenance efficiency: $\beta = -0.05$, $p = 0.012$, $\beta = -0.05$, $p = 0.007$, $\beta = -0.05$, $p = 0.014$; lights-out time: $\beta = -0.06$, $p = 0.001$, $\beta = -0.08$, $p < 0.001$, $\beta = -0.04$, $p = 0.023$).

3.2.2. Correlation between lights-out time and SpO2

Besides, lights-out time only affected Min-SpO2 in ModelI (Table 3a) ($\beta = -0.04$, $p < 0.001$). Additionally, the number of snoring events and estimated total sleep time (≥7 h) were negatively correlated with Min-SpO2. In ModelI(Table 3b) subject baseline characteristics were adjusted, revealing a significant negative correlation between lights-out time and Avg-SpO2 ($\beta = -0.04$, $p = 0.011$). Based on ModelI, Model II was constructed by further adjusting for the sleeping position. The results still showed a negative correlation ($\beta = -0.05$, $p = 0.011$). Finally, Model III was built based on model II and further adjusted for sleep quality, a negative correlation between the two was still observed ($\beta = -0.05$, $p < 0.010$). All sleep parameters exerted no significant impact on Avg-SpO2. An analysis of Table 3c revealed no significant association between lights-out time and Max-SpO2. However, sleeping posture and sleep maintenance efficiency were identified as factors affecting Max-SpO2 levels.

Moreover, RCS analysis was conducted to quantify the non-linear association between lights-off time and nocturnal Min-SpO2 and Avg-SpO2 levels. Following 22: 00, Min-SpO2 exhibited a modest increase as lights-off time was postponed (Figs. 2–a). Interestingly, Avg-SpO2 demonstrated a progressive decline, reaching a nadir at 22:00, before steadily increasing again to form a U-shaped relationship with lights-off time (Fig. 2–b).

3.2.3. Subgroup analysis for lights-out and SpO2

The association between lights-out time and both minimum and average SpO2 was investigated through subgroup analyses stratified by race/ethnicity, age, and BMI. Fig. 3a-f presents the results after adjusting for all potential confounding variables except those defining the subgroups themselves. Within the 14-20-year-old age group, a gradual increase in Min-SpO2 was observed with later lights-out times. In contrast, the subgroup aged 35 and above displayed significant variations in Min-SpO2 levels, with an overall stepwise decline evident across the range of lights-out times (Fig. 3b).

The smooth curve fitting graph of the relationship between lights-out time and Avg-SpO2 for different racial/ethnic variables revealed that the lowest point of the Avg-SpO2 in the non-Hispanic white group, Hispanic group, and other groups was found at 23:00, and the Avg-SpO2 levels then gradually increased (Fig. 3d). Similarly, the Avg-SpO2 of pregnant women over 35 years old also gradually decreased as the lights-out time was delayed (Fig. 3e). The trend of Avg-SpO2 in the normal BMI group (18.5 ≤ BMI <24.9) was extremely unstable. In contrast, the Avg-SpO2 trend in the overweight group (25 ≤ BMI <29.9) dropped slightly from 19:00 to 22:00, and then gradually increased, with the curve approaching a U-shape (Fig. 3f).

Table 3a
Relationship between lights-out time and minimum value of oxygen saturation in different models.

Characteristics		Model I				Model II			
		β	95%CI	*p*	VIF	β	95%CI	*p*	VIF
Part One: Demographic information	Maternal race/ethnicity								
	Non-Hispanic white	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
	Non-Hispanic black	0.10	0.42,0.94	<0.001*	1.17	0.09	0.40,0.92	<0.001*	1.17
	Hispanic	0.11	0.40,0.83	<0.001*	1.12	0.11	0.41,0.83	<0.001*	1.12
	Asian	0.01	−0.26,0.58	0.449	1.05	0.01	−0.26,0.57	0.461	1.05
	Other	0.02	−0.11,0.63	0.171	1.03	0.02	−0.12,0.62	0.187	1.03
	Age (years)	−0.06	−0.04,-0.01	0.001*	1.14	−0.06	−0.04,-0.01	0.003*	1.15
	BMI(kg/m^2)	−0.34	−0.14,-0.12	<0.001*	1.05	−0.34	−0.14,-0.12	<0.001*	1.06
	Lights-out time	−0.04	−0.02,0	0.012*	1.03	−0.03	−0.02,0	0.089	1.09
Part Three: Sleep quality factors	Estimation total sleep time (h)								
	<7	–	–	–	–	Ref	Ref	Ref	Ref
	≥7	–	–	–	–	−0.05	−0.39,-0.06	0.008*	1.09
	Sleep efficiency (%)	–	–	–	–	−0.05	−0.03,0	0.103	2.67
	Sleep maintenance efficiency (%)	–	–	–	–	0.01	−0.02,0.02	0.798	2.64
	Number of snoring events	–	–	–	–	−0.03	0,0	0.050*	1.01
	R^2		0.13				0.14		
	F		62.13				41.23		
	p-value		<0.001*				<0.001*		

Abbreviations: BMI, body mass index.
Model construction information: Multiple linear regression was performed after categorical variable was set to a dummy variable. Adjusting age, BMI, maternal race/ethnicity variables in ModelI. Model II adjusted the estimation total sleep time, the sleep efficiency, the sleep maintenance efficiency, number of snoring events variables on the basis of modelI.
Note: represents that this variable was not included in the model; Ref, means reference; β, it is a standardized coefficient; *$p < 0.05$.

Table 3b
Relationship between lights-out time and average value of oxygen saturation in different models.

Characteristics		Model I				Model II				Model III			
		β	95%CI	*p*	VIF	β	95%CI	*p*	VIF	β	95%CI	*p*	VIF
Part One: Demographic information	Maternal race/ethnicity												
	Non-Hispanic white	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
	Non-Hispanic black	0.31	0.96,1.21	<0.001*	1.17	0.31	0.94,1.19	<0.001*	1.18	0.31	0.94,1.19	<0.001*	1.18
	Hispanic	0.28	0.71,0.91	<0.001*	1.12	0.28	0.70,0.91	<0.001*	1.12	0.28	0.70,0.90	<0.001*	1.12
	Asian	0.09	0.34,0.75	<0.001*	1.05	0.10	0.37,0.77	<0.001*	1.05	0.10	0.36,0.77	<0.001*	1.05
	Other	0.71	0.19,0.55	<0.001*	1.03	0.07	0.20,0.55	<0.001*	1.03	0.07	0.19,0.54	<0.001*	1.03
	Age (years)	−0.01	−0.01,0.01	0.473	1.14	−0.01	−0.01,0.01	0.559	1.14	−0.01	−0.01,0.01	0.661	1.15
	BMI(kg/m^2)	−0.19	−0.04,-0.03	<0.001*	1.05	−0.19	−0.04,-0.03	<0.001*	1.07	0.19	−0.04,-0.03	<0.001*	1.07
	Lights-out time	−0.04	−0.01,0	0.011*	1.03	−0.05	−0.01,0	0.011*	1.09	−0.05	−0.01,0	0.010*	1.09
Part Two:Sleep position factors	Supine sleep time (min)	–	–	–	–	−0.03	0,0	0.131	1.69	−0.03	0,0	0.231	1.77
	Non-supine sleep time (min)	–	–	–	–	0.03	0,0	0.127	1.72	0.04	0,0	0.068	1.75
Part Three: Sleep quality factors	Sleep efficiency (%)	–	–	–	–	–	–	–	–	−0.01	−0.01,0.01	0.847	2.68
	Sleep maintenance efficiency (%)	–	–	–	–	–	–	–	–	−0.03	−0.01,0	0.295	2.64
	Number of snoring events	–	–	–	–	–	–	–	–	−0.03	0,0	0.052	1.01
R^2			0.16				0.17				0.17		
F			79.43				63.37				48.26		
p-value			<0.001*				<0.001*				<0.001*		

Abbreviations: BMI, body mass index.
Model construction information: Multiple linear regression was performed after categorical variable was set to a dummy variable. Adjusting age, BMI, maternal race/ethnicity variables in ModelI. Model II adjusted the supine sleep time, non-supine sleep time variables on the basis of modelI. Model III adjusted the sleep efficiency, sleep maintenance efficiency, number of snoring events variables on the basis of Model II.
Note: represents that this variable was not included in the model; Ref, means reference; β, it is a standardized coefficient; *$p < 0.05$.

Table 3c
Relationship between lights-out time and maximum value of oxygen saturation in different models.

Characteristics		Model I				Model II				Model III			
		β	95%CI	*p*	VIF	β	95%CI	*p*	VIF	β	95%CI	*p*	VIF
Part One: Demographic information	Maternal race/ethnicity												
	Non-Hispanic white	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
	Non-Hispanic black	0.26	0.55,0.73	<0.001*	1.12	0.26	0.55,0.73	<0.001*	1.14	0.26	0.54,0.72	<0.001*	1.14
	Hispanic	0.19	0.31,0.46	<0.001*	1.11	0.18	0.30,0.45	<0.001*	1.11	0.18	0.30,0.45	<0.001*	1.11
	Asian	0.06	0.09,0.38	0.002*	1.04	0.06	0.11,0.40	0.001*	1.05	0.06	0.10,0.39	0.001*	1.05
	Other	0.08	0.17,0.43	<0.001*	1.03	0.08	0.17,0.43	<0.001*	1.03	0.08	0.16,0.42	<0.001*	1.03
	Age (years)	0	−0.01,0.01	0.853	1.13	0.01	−0.01,0.01	0.791	1.13	0.01	0,0.01	0.702	1.14
	Lights-out time	−0.01	0,0	0.541	1.03	−0.03	−0.01,0	0.085	1.09	−0.03	−0.01,0	0.071	1.09
Part Two:Sleep position factors	Supine sleep time (min)	–	–	–	–	0.05	0,0	0.039*	1.71	0.06	0,0	0.018*	1.76
	Non-supine sleep time (min)	–	–	–	–	0.14	0,0	<0.001*	1.68	0.15	0,0	<0.001*	1.76
Part Three: Sleep quality factors	Sleep efficiency (%)	–	–	–	–	–	–	–	–	0.12	0,0.01	0.679	2.68
	Sleep maintenance efficiency (%)	–	–	–	–	–	–	–	–	−0.06	−0.01,0	0.042*	2.64
	Number of snoring events	–	–	–	–	–	–	–	–	−0.02	0,0	0.392	1.01
R^2		0.09				0.10				0.10			
F		45.20				39.53				29.58			
p-value		<0.001*				<0.001*				<0.001*			

Model construction information: Multiple linear regression was performed after categorical variable was set to a dummy variable. Adjusting age, maternal race/ethnicity variables in ModelI. Model II adjusted the supine sleep time, non-supine sleep time variables on the basis of modelI. Model III adjusted the sleep efficiency, sleep maintenance efficiency, number of snoring events variables on the basis of Model II.

Note: represents that this variable was not included in the model; Ref, means reference; β, it is a standardized coefficient; $*p < 0.05$.

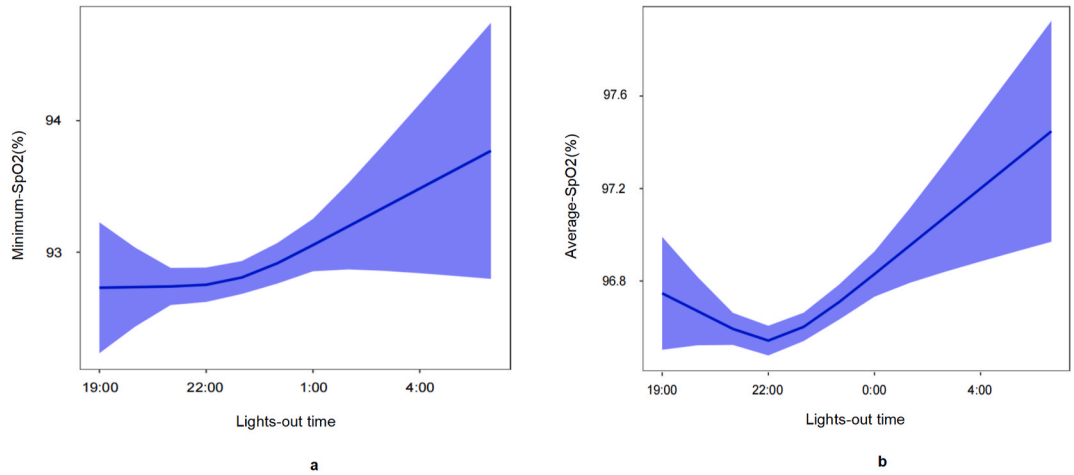

Fig. 2. (a–b). Restricted cubic spline plot of the relationship between lights-out time and oxygen saturation. (a) The relationship between the minimum value of SpO2 and the lights-out time; (b) The relationship between the average value of SpO2 and the lights-out time.
Abbreviations: SpO2, oxygen saturation.

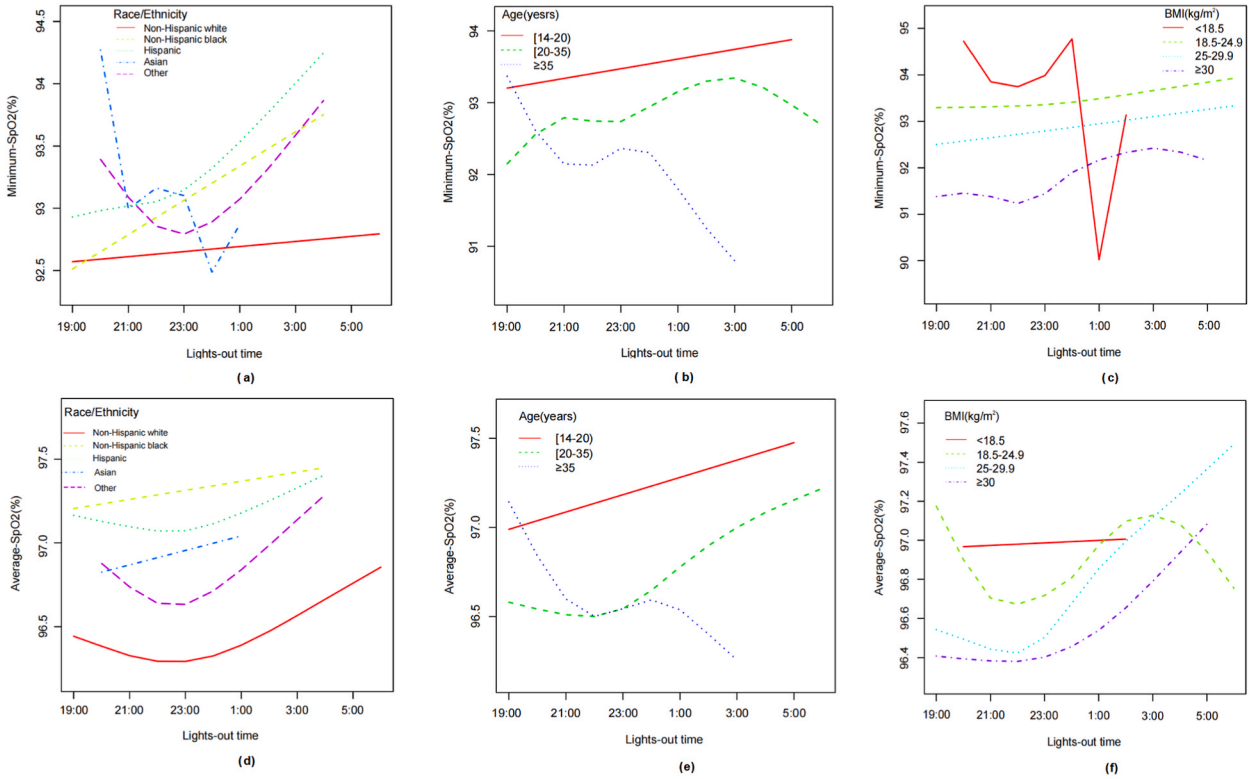

Fig. 3. (a–f). Relationship between lights-out time and oxygen saturation in different subgroup variables. (a–c) Smooth curve fitting of the relationship between lights-out time and minimum-SpO2 in different race/ethnic, age, BMI groups; (d–f) Smooth curve fitting of the relationship between lights-out time and average-SpO2 in different race/ethnic, age, BMI groups.
Abbreviations: BMI, body mass index; SpO2, oxygen saturation.

4. Discussion

This investigation provides hitherto undocumented evidence of the potential association between lights-out time and nocturnal blood SpO2 during the critical first trimester of pregnancy. Our analysis indicated a significant association between SpO2 and lights-out time, showing a U-shaped pattern with an inflection point at 22:00.

In modern life, the blue light emitted by LED lighting or other artificial lights in the environment can impact the secretion of melatonin [23]. A study confirmed that after prolonged exposure to blue light, neurons in the suprachiasmatic nucleus (SCN) inhibit neurons in the paraventricular hypothalamic nucleus that stimulates the pineal gland to release melatonin, meaning that melatonin production is inhibited by blue light [24]. Melatonin is a neurohormone secreted by the pineal gland and is known to regulate a wide range of circadian functions, including sleep [25]. Under normal conditions, melatonin is secreted at night, peaks in the early morning, and falls to a minimum before dawn. Research shows that there is a direct relationship between melatonin secretion disorders and sleep quality. Once the melatonin secretion period is missed, the depth and stability of sleep will be affected [26].This may lead to rapid eye movement sleep (paradoxical sleep), which induces dreams and muscle twitching symptoms, increased cerebral blood flow [27], and may reduce SpO2.

The SpO2 levels lightly increased after 22 o'clock. In cases with later lights-out, lower energy and oxygen consumption are observed relative to the exercise state due to the reduced frequency of nighttime activities, and the body remains in a resting state. This result in a slight increase in SpO2. However, long-term light exposure not only activates the adrenal glands and induces a surge in glucocorticoid levels through the SCN of the sympathetic nervous system but also inhibits melatonin secretion and causes insomnia [28,29]. Under such conditions, the cerebral cortex of the gravida is in a state of excitement, and the vagus nerve is stimulated to varying degrees, which reduces the nocturnal spontaneous activities mediated by the parasympathetic nerve [30]. These changes cause a decrease in the heart rate and blood pressure, thereby reducing the total oxygen consumption of the human body [31,32]. Consequently, SpO2 also shows a slight increase.

This study investigated the association between lights-out time and both Min-SpO2 and Avg-SpO2, stratified by maternal age. The findings suggest that later bedtimes in mothers of advanced maternal age were linked to lower Min-SpO2 and Avg-SpO2. Existing research has indicated a higher prevalence of sleep disorders and a greater risk of sustained decreases in SpO2 among older gravidas compared to younger ones [33]. Nighttime exposure to bright light might further exacerbate this effect. Therefore, early lights-out and adequate sleep are recommended for pregnant women, particularly those of advanced maternal age.

In addition, our analysis revealed that both Avg-SpO2 and Min-SpO2 levels were lower in pregnant women within the overweight and obese groups compared to those in the normal weight group. This observation aligns with existing research demonstrating that organs in overweight individuals exhibit elevated oxygen consumption and diminished oxygen-carrying capacity, even during nocturnal rest periods [34]. Interestingly, post-3:00 a.m. Avg-SpO2 levels in the overweight and obese groups were marginally higher than those observed in the normal weight group. However, due to the limitations imposed by the relatively small sample size, further investigation is warranted to definitively confirm these findings.

Nevertheless, the limitations of this study should be acknowledged. Firstly, a portion of the lights-out time data was derived from self-report questionnaires and recall bias cannot be completely eliminated. However, the data were determined by multiple polysomnologists based on participant information combined with collected data such as the heart rate, the breathing pattern, movement, and artifacts, which strengthens the credibility of our findings. Secondly, the self-report questionnaire lacked information about light intensity and light source type. Consequently, the impact of different light intensities and sources on the SpO2 levels of pregnant women in the first trimester could not be evaluated. Yet, given current societal habits, where exposure to blue light is common before turning off the lights [35], the results of this study remain reliable. Lastly, the interpretation of the research results was limited by incomplete subject information in the nuMOM2b-SDB database in NSRR, such as sleep quality (stage),psychology, social factors, educational status, etc. Our future research will focus on elucidating this area.

5. Conclusion

An analysis of early pregnancy data revealed a U-shaped association between lights-out time and nocturnal Avg-SpO2 within the established physiological range. This relationship exhibited an inflection point at approximately 22:00. Notably, advanced maternal age who reported later lights-out times demonstrated lower Min-SpO2 levels. These findings suggest that, for pregnant women, maintaining a consistent sleep schedule characterized by appropriate pre-sleep light exposure duration and a state of relative restfulness may not only be beneficial but potentially crucial for ensuring SpO2 stability. Conversely, deviations from these practices could potentially lead to pathological alterations in SpO2 levels.

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Ethics declarations

This study was reviewed and approved by the Columbia University Human Subjects Institutional Review Board and the City University of New York CUNY HRPP/IRB, with the approval numbers IRB-AAAR9413 and 2019–0855, respectively.

Data availability statement

The dataset supporting the findings of this study originates from the National Sleep Research Resource (NSRR) (https://sleepdata.org/). Access to NSRR data requires a formal application process. Due to data use agreements with NSRR, the authors are not

authorized to share the dataset directly.

CRediT authorship contribution statement

Hongxu Chen: Writing – original draft, Visualization, Methodology, Conceptualization. **Danyang Zhao:** Writing – review & editing, Data curation. **Zixuan Guo:** Writing – review & editing, Data curation. **Duo Ma:** Resources. **Yan Wu:** Supervision, Resources. **Guangxue Chen:** Funding acquisition. **Yanlong Liu:** Writing – review & editing, Funding acquisition. **Tiantian Kong:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Fan Wang:** Writing – review & editing, Supervision, Resources, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29494.

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