Association between sleep during pregnancy and birth outcomes: A prospective cohort study

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Abstract

Objective: A prospective cohort study was conducted to investigate sleep status during the first and second trimester of pregnancy in pregnant women on adverse birth outcome, such as preterm birth (PTB), low birth weight (LBW) and small for gestational age (SGA). **Design:** Prospective cohort study. **Setting:** China. **Population:** Cases were singleton pregnant women aged 18-40 years from the prospective Tongji-Shuangliu Birth Cohort. **Methods:** Multivariable logistic regression models were used to analyze the associationof sleep status during the first and second trimester of pregnancy with adverse birth outcomes and generated the odds ratio (OR) and 95% confidence interval (CI). **Main outcome measures:** Birth outcomes. **Results:** Finally, 5,412 pregnant women were included in the analysis. In the multivariable model, compared with 8-9 hours/night, sleep less than 7 hours/night during second trimester increases the risk of PTB (OR: 1.80, 95% CI: 1.12,2.89), and the risk of PTB was decreased in pregnant women who slept [?]11 hours/night (OR: 0.53, 95% CI: 0.30,0.93). Sleep quality, napping and sleep changes in the first and second trimesters, and sleep duration in the first trimester were not statistically associated with PTB, LBW and SGA. **Conclusions:** Short sleep duration during pregnancy is associated with a higher risk of PTB, while longer sleep duration at night is associated with a lower risk of PTB. Sleep status during pregnancy was not associated with LBW and SGA. In order to reduce risk of adverse birth outcomes, sleep problems in pregnant women should be strengthened during pregnancy care.

Introduction

Adverse birth outcomes are a major public health problem worldwide. Common adverse birth outcomes include preterm birth (PTB), low birth weight (LBW) and small for gestational age (SGA), etc[1-3]. The incidence of PTB, LBW and SGA is estimated to be 10.6 %[1], 14.6%[2] and 9.7%[3] globally. In China, the incidence of PTB, LBW and SGA were reported to be 6.4 %[4], 5.2%[5] and 10.1%[6] respectively. Adverse birth outcomes not only increase perinatalies morbidities and mortality, but also have lasting effects on the growth and development of neonates and even the whole life cycle[7-9].

Pregnant women are more prone to sleep disorders due to the influence of physiological, physical and social factors[10]. Existing research has found that sleep disorders during pregnancy, including insomnia, sleep apnea, and obstructive ventilation disorder, can lead to adverse birth outcomes[11-13]. Similarly, quality and duration of sleep at night were also reported to be associated with adverse outcomes. Studies in other countries have reported that women with PSQI>5 (Pittsburgh sleep quality index, PSQI) and sleep duration during pregnancy had an increased risk of PTB[14-16], LBW and SGA[17-19], while other studies found no association between night sleep quality or duration and adverse outcomes[20-22]. Several studies in China have also reported that poor sleep quality and short sleep duration during pregnancy are associated with an increased risk of PTB, LBW and SGA [23-25]. Other studies, however, have found no link between sleep duration and PTB and LBW [24,26]. Limited studies have also examined the effect of napping duration on adverse birth outcomes. A large cohort study in China found that women who reported napping for >1 hour had a reduced risk of LBW compared to women who did not nap [27]. A small cohort study in Brazil found no relationship[27]. In general, the existing research results are not uniform, which may be related to the differences in regional and research conditions, so more research is necessary.

This study is based on data from the Tongji Shuangliu birth cohort (TSBC), and aims to examine the effects of sleep quality, duration and nap duration during pregnancy on adverse birth outcomes, so as to provide more evidence for current research in this field.

Materials and methods

Study design and population

From 2017 to 2020, the TSBC enrolled women aged 18-40 years with a singleton pregnancy in the Shuangliu Maternal and Child Health Hospital in Chengdu, China. Details of this birth cohort have been reported elsewhere [28]. Briefly, pregnant women who attended antenatal care and had an gestational age [?]15 weeks were invited to participate in our study. Women who met the following criteria were included: 1) women aged 18-40 with a singleton pregnancy; 2) gestational age less than 15 weeks. Participants were excluded if they 1) conceived the fetus using assisted reproductive technology, such as in-vitro fertilization and intrauterine insemination; 2) reported severe chronic disease or infectious disease like cancer, tuberculosis, and HIV infection; 3) refused to sign the written informed consent or was unable to complete the questionnaire.

Of 7281 pregnant women, 21 patients who were diagnosed with hypertension and diabetes before pregnancy or had blood glucose [?] 7.0 mmol/L during early pregnancy and two pregnant women with gestational age [?] 42 were excluded. 374 women were missing birth outcomes, 1696 women were missing interim sleep data, and 1282 women were missing covariate data. Finally, 5412 pregnant women were included in the analysis. A total of 5412 pregnant women were invited to complete a structured questionnaire at [?]15 weeks (first trimester) and 24-28 weeks (second trimester) of pregnancy.

Assessment of sleep duration

(a) During the first trimester and the second trimester, PSQI[29] was used to assess the quality of sleep during the previous week. PSQI >5 was defined as poor sleep quality, and PSQI[?]5 was defined as good sleep quality and was set as the control group. (b) Sleep duration of the past week in the first and second trimester of pregnancy was estimated: “What time did you go to bed at night in the past week?”, “How long does it usually take you to fall asleep each night?”, “What time do you usually get up in the morning?”. The sleep time was defined as the interval between the time to go to bed and the time to get up, which was divided into four grades based on the classification method of previous literature: [?]7 hours of nocturnal sleep is defined as short sleep time, 8-9 hours of nocturnal sleep is defined as adequate sleep time and control group 28, 10 hours of nocturnal sleep is defined as the length of long sleep, [?]11 hours of nocturnal sleep is defined as longer sleep time[24,30]. (c) Nap duration of the past week in the first and second trimester of pregnancy was estimated: ”How many minutes is the usual nap time for nearly a week?”. Nap duration was divided into five levels:0 minutes, 1-30 minutes, 31-60 minutes, 61-90 minutes, 90 minutes[31]. (d) Changes in sleep quality from the first trimester to the second trimester were divided into four mutually exclusive groups according to good/poor sleep quality during the first and second trimesters: always good (Sleep quality were all good in the first and second trimesters and were set as the control group), always poor (Both early and middle trimesters were poor), from good to poor, from poor to good. (e) Changes of sleep duration from the first trimester to the second trimester were divided into four mutually exclusive groups according to the groups of sleep duration during the first and second trimester: always good (Both the first and second trimesters of pregnancy were sufficient and were set as the control group), always poor (The first and second trimesters were short or long), from good to poor (From sufficient to short or long), from poor to good (From short or long to sufficient). (f) Changes in nap duration from the first trimester to the second trimester were divided into four mutually exclusive groups according to nap duration during the first and second trimester: always good (In the first and second trimesters of pregnancy, the napping duration was 1-60 minutes and were set as the control group), always poor (No napping or napping duration [?]90 minutes in the first and second trimesters of pregnancy), from good to poor (From 1-60 minutes to no nap or nap duration [?]90 minutes), from poor to good (From no nap or nap duration [?]90 minutes to 1-60 minutes).

Measurement of birth outcomes

Information on birth outcomes was collected either through medical records. Full term was defined as 37 to 41 weeks[32], and PTB was defined as less than 37 weeks of gestation[14]; LBW is defined as birth weight <2500g, macrosomia defined as birth weight [?]4000g, and normal birth weight (NBW) defined as weight [?]2 500 g to <4 000g [33]; SGA defines newborns whose birth weight is below the 10th percentile of the average weight of children for the same gestational age, and larger than gestational age (LGA) is defined as a newborn whose birth weight is above the 90th percentile of the average weight of children for the same gestational age [34].

Definition of variables

Pregnant women in the first trimester and the second trimester were interviewed by trained investigators to complete structured questionnaires on the maternal sociodemographic characteristics, lifestyle and health status.

Age was treated as three groups: <25, 25-29, [?]30. Employment was categorized as two groups: unemployed and employed. Average family income was categorized as two groups: 49,999 yuan [?] and [?]50,000 yuan. Education was categorized as two groups: senior high school or lower and college or above. Place of residence was categorized as two groups: urban and rural area. Smoking was categorized as three groups: current, former and never. Drinking was categorized as three groups: current, former and never. Parity was categorized as: 0 and [?]1. The Chinese version of the Pregnancy Physical Activity Questionnaire (PPAQ) [35]was used to calculate the past week physical activity energy expenditure (MET-H/week) in the second trimester of pregnancy, which has been validated among pregnant women in China[36]. The physical activity were classified as low, medium and high. Prepregnancy weight was self-reported by the women, and the weight of women in the second trimester was measured by a hospital body fat meter. Weight and standing height were measured with light clothes and no shoes. Prepregnancy BMI (kg/m^2) was calculated using self-reported prepregnancy weight (kg) divided by height squared (m). Prepregnancy BMI was divided into four categories: underweight (<18.5 kg/m^2), normal weight (18.5-23.9 kg/m^2), overweight (24.0-27.9 kg/m^2) and obese ([?]28.0 kg/m^2) [37]. GWG was classified according to prepregnancy BMI and the normal values recommended by the Institute of Medicine (IOM) [38]: Underweight 12.5 to 18.0 kg; Normal 11.5-16.0 kg; 7.0-11.5 kg overweight; Obesity 5.0-9.0 kg. GWG within the recommended range was defined as appropriate, below the recommended range was defined as insufficient, and above the recommended range was defined as excessive. Preeclampsia was divided into two groups: yes and no; HDP was divided into two groups: yes and no; GDM was divided into two groups: yes and no.

Statistical analyses

Baseline characteristics were presented as mean ± standard deviation (SD) or median (interquartile range) for continuous variables, and n (%) for categorical variables. *T* tests, Mann-Whitney *U* tests and $\chi 2$ tests were used to analyze the relationships of basic characteristics between birth outcome categories. Multivariable logistic regression was used to examine the relationship between sleep and birth outcomes. Odds ratios (ORs) and their 95% confidence intervals (95% CIs) were calculated in a stepwise manner. In Model 1: unadjusted. In Model 2: age, employment, education, place of residence, and family income, smoking, drinking, physical activity in the first trimester, physical activity in the second trimester, parity, pre-pregnancy BMI, GWG, sleep quality and changes in sleep quality during pregnancy were adjusted. In Model 3: Based on Model 2, preeclampsia, HDP and GDM were further adjusted. Statistical analyses were conducted by SPSS software version 26 with two-sided Pvalues <0.05 as the level of significance.

Results

Baseline characteristics

The mean age of all included subjects was 26.6±3.7 years. 223 (4.3%) were PTB; 126 (2.3%) gave birth to LBW infants; The incidence of SGA was 316 (5.8%). Women who delivered PTB infants or LBW infants had higher prevalence of HDP (P <0.05); Compared with full-term women, women who gave PTB have a lower proportion of rural residents (P <0.05); Mothers who gave birth to LBW babies had a higher proportion of non-births than mothers who gave birth to NBW babies (P <0.05); The proportion of mothers who delivered SGA, young in age, annual household income [?]49,999, pre-pregnancy weight, insufficient weight gain during pregnancy and non-birth was higher, and the incidence of gestational diabetes was lower (P <0.05), as detailed in Table 1.

Relationship between nocturnal sleep quality, sleep duration, nap duration and PTB during pregnancy

Binary logistic regression was used to analyze the relationship between sleep quality, sleep duration and nap duration during pregnancy and PTB. After adjusting for confounding factors, the results showed that compared with sleeping 8 to 9 hours/night, sleeping less than 7 hours/night in pregnant women was a risk factor for increased risk of PTB (OR: 1.80, 95%CI: 1.12, 2.89), [?] 11 hours/night remained a protective factor for reduced risk of PTB (OR: 0.53, 95%CI: 0.30, 0.93). Sleep duration in early pregnancy, sleep quality during pregnancy and nap duration were not statistically associated with the risk of PTB (P >0.05), as detailed in Table 2.

Relationship between nocturnal sleep quality, sleep duration, nap duration and LBW and SGA during pregnancy

Binary logistic regression was used to analyze the relationship between sleep quality, sleep duration and nap duration during pregnancy and LBW and SGA. No confounding factor correction was performed in Model 1. The results showed that only pregnant women with nap duration of more than 90 minutes were statistically correlated with SGA. After adjustment for confounder factors, no association was found between night sleep quality, sleep duration, and nap duration during pregnancy and LBW and SGA, as detailed in Table 2-3. At the same time, binary logistic regression was used to analyze the influence of changes in sleep quality, duration and nap duration during pregnancy on adverse birth outcomes, and no statistical significance was found in all model results. See supplemental table 5-7 for details.

Comment

Main findings

Based on the TSBC, this study aimed to examine the relationship between night sleep quality, sleep duration and nap duration and adverse birth outcomes during pregnancy. The results showed that insufficient sleep duration during pregnancy was associated with an increased risk of PTB, but longer sleep duration was associated with a lower risk of PTB, and night sleep quality, duration, and nap duration during pregnancy were not associated with LBW and SGA.

Strengths and limitations

This study was a prospective cohort study with a large sample size. Sleep information was collected before birth outcomes, so the results were credible because of small recall bias. In this study, the PSQI with high reliability and validity was used to assess the effects of sleep at different stages of pregnancy and sleep changes on birth outcomes, adding to the relevant research field. The study has some limitations. First, although this is a prospective cohort study, the sleep information of pregnant women over the past week was obtained from subjective reports, which may have had recall bias. Some studies have shown that pregnant women actually sleep about 30 minutes less than they subjectively report, so sleep duration during pregnancy may be overestimated. However, it was found that subjectively reported sleep data had a more significant effect on adverse birth outcomes than was assessed by objective methods[41]. When conditions permit, future studies can combine subjective reports with sleep assessed by more reliable devices such as polysomnography and wrist motion detectors. Secondly, although we adjusted socio-demographic characteristics, living habits, and health status, other residual confounding may still exist, such as fatigue, restless leg syndrome, sleep apnea, etc., which can be considered for inclusion in future studies. Moreover, the subjects included in this study only included pregnant women who went to Shuangliu Maternal and Child Health Hospital in Chengdu, China, and could not be extended to people in other areas, which could be further discussed by conducting multi-center studies in the future. This study did not collect sleep information during the third trimester of pregnancy, so it could not assess the relationship between sleep during the whole pregnancy and birth outcome. Future studies can add the third trimester to make the study results more comprehensive.

Interpretation, the association between sleep during pregnancy and adverse birth outcomes

This study found that short sleep duration during the second trimester was associated with PTB. Consistent with recent meta-study[39]. Some studies have found the same results in different pregnancies. Micheli et al. assessed sleep in the third trimester (28-32 weeks) of 1091 singleton pregnancies and found that women who slept less than 5 hours had an increased risk of preterm delivery[39]. Similarly, Li et al. assessed sleep duration in 1082 healthy women with single fetal pregnancies at 8-12, 24-28, and 32-36 weeks of gestation and found that participants with short sleep duration ([?]7 h) at 32-36 weeks were more likely to report PTB[23]. However, other studies have reported different results. Previous case-control studies by Guendelman et al. also found no link between short sleep duration and PTB[40]. Two other large-sample prospective cohort studies assessing the relationship between sleep duration and poor birth outcomes in late pregnancy in Chinese women and throughout pregnancy in Japanese women also found no association between short sleep duration and the risk of PTB[20,24]. Different definitions of sleep duration, gestational age of concern, corrected covariates, and sample size may explain this controversial result. The mechanisms underlying the current association between short sleep duration and PTB are not clear, and some mechanisms may explain the association between lack of sleep and PTB. One possibility is the effect of excessive inflammatory reaction. Sleep deprivation will promote the increase of inflammatory cytokines such as interleukin-6 (IL-6) and IL-8, thereby stimulating the production of prostaglandins in pregnancy tissue, leading to cervical maturation and uterine contraction[23,41].

Studies have reported that longer sleep duration (>9 hours or >10 hours) is significantly associated with impaired glucose tolerance, coronary heart disease, cardiovascular events, stroke, and mortality[30,42]. A study by Yang et al. reported an increased incidence of PTB in pregnant women who slept longer[43]. But, Kajeepeta et al. showed that women who reported long sleep duration and fatigue in the first 6 months of pregnancy had an increased risk of PTB, while women who reported long sleep duration ([?] 9 hours) and no fatigue had no statistically significant risk of PTB, and fatigue may be a new risk factor for PTB[43]. Notably, this study found that longer sleep duration during the second trimester was associated with a lower risk of PTB, and differences in study design and definition of long sleep duration may lead to conflicting findings. We did not find a mechanism to explain the protective effect of longer sleep duration on pregnant women. It may be that longer sleep duration counteracts the effects of fatigue. In conclusion, the results of this study need further verification. In addition, this study did not find an association between sleep duration in early pregnancy and PTB, which is consistent with the results of Li and Nakahara et al[20,23]. Data analysis in this study showed that, compared with the second trimester, women in the first trimester subjectively reported longer sleep duration. The difference in sleep duration between the first trimester and the second trimester may explain the relationship between sleep duration in different stages of pregnancy and PTB, and the lack of sleep information in some subjects may also be one of the reasons.

Analysis of the data in this study found that sleep quality during pregnancy was not associated with PTB. A study by Du et al. in China also reported consistent results[20,23]. Other findings suggest that poor sleep quality during pregnancy may be a risk factor for PTB. A small cohort study in the United States found that PSQI> 5 in early pregnancy was associated with PTB, with a 25% increase in the chance of PTB for every percentage point increase (OR: 1.25, 95% CI: 1.04, 1.50)[44]. However, this study only corrected for obstetric risk, income, and stress. A Chinese cohort with a sample size of 688 Li et al., after adjusting for prepregnancy weight and birth weight, found that women with poor sleep quality in the second and third trimesters had a four-fold (OR: 5.35, 95%CI: 2.10, 13.63) and two-fold (OR: 3.01, 95%CI: 1.26, 7.19) increased risk of PTB, respectively[45]. The results were inconsistent, possibly due to sample size, pregnancy, and adjusted confounding factors.

The study also did not find an association between sleep during pregnancy and LBW and SGA. Consistent with some research findings[14,18,18,26]. However, two large-sample cohort studies in China during the third trimester found that poor sleep quality (PSQI>5) was associated with LBW (OR: 1.50, 95%CI: 1.08, 2.08) [26] and sleep duration [?] 7h was a risk factor for SGA (OR: 2.67, 95%CI: 1.18, 6.54) 23[17]. Another prospective study also reported that women with poor sleep quality or sleep deprivation (<7 hours vs. >9 hours) at 30 weeks gestation had lower baby weight[47]. We speculate that the controversial findings may be related to the study environment, sleep classification, and the focus on differences in sleep gestational age. The relationship between sleep during pregnancy and birth weight of newborn remains to be further verified.

To the best of our knowledge, there have been relatively few studies on nap duration and poor birth outcomes, focusing on birth weight. A Chinese birth cohort study recruiting 10,111 women found that women who reported napping >1 hour had a lower risk of LBW delivery compared to women who reported no napping (OR: 0.61, 95%CI: 0.44, 0.83)[27]. In contrast, the present study found that women who napped for more than 90 minutes had an increased risk of giving birth small for gestational age, but that association disappeared after controlling for potential risk factors. Differences in gestational age and number of outcomes may explain the difference in results. A similar study in Brazil also examined the relationship and found no correlation between nap duration during pregnancy and birth weight, although the sample size was only 176 and the outcome was birth weight z-score[18]. This study found no association between lunchtime sleep during pregnancy and other birth outcomes, and more evidence on the effect of napping on birth outcomes is needed.

Overall, the available research results are inconsistent, but some of the findings suggest that poor sleep leads to the possibility of adverse birth outcome cannot be ignored. Adverse birth outcomes are not only bad for the short-term physical health of newborns harmful effects and increased susceptibility to disease in adulthood. Identification of possible risk factors is helpful for pregnancy preparation, prevention, screening and early intervention during pregnancy, and will have a positive impact on the reduction of the incidence of adverse birth outcomes and good birth and good upbringing.

Conclusions

Overall, this study did not observe the effects of maternal sleep quality, sleep duration and nap duration on LBW and SGA, but found that insufficient sleep duration during pregnancy is an independent risk factor for PTB, and longer sleep duration may be associated with a lower risk of PTB. It is suggested that pregnancy health care providers should strengthen sleep problem care for pregnant women in order to reduce adverse birth outcomes.

Authors' contributions

CL, HC, RW, XF and XS designed the study. CL, HC performed the statistical analysis and wrote the manuscript. CL, HC, SY, CZ, WH, YL, QL, ZS, ,RW, XF and XS contributed to the interpretation of the results and revision of the manuscript. CL, HC contributed equally to this work. All authors judged and reviewed the manuscript and approve the final version, and have obtained permission from RW, XF and XS corresponding authors before submission.

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Conflict of interest statement

The authors declare that they have no competing interests.

Ethic approval

The cohort was approved by the Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology (approval number: S225) . All participants provided written informed consent at recruitment.

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Table 1 Demographic and clinical characteristics of the study population

Characteristic	Total	PTB No (n=5188)	PTB Yes (n=224)	LBW No (n=5059)	LBW Yes (n=126)	SGA No (n=4395)	SG Ye (n=
Age[c]	26.6±3.7	26.6±3.7	27.0±3.6	26.6±3.7	26.0±3.5	26.5±3.7	25.
<25	2523 (31.2)	1623 (31.3)	65 (29.0)	1574 (31.1)	44 (34.9)	1377 (31.3)	12 (38
25~29	1688 (46.6)	2420 (46.6)	103 (46.0)	2355 (46.6)	61 (48.4)	2068 (47.1)	14 (45
[?]30	1201 (22.2)	1145 (22.1)	56 (25.0)	1130 (22.3)	21 (16.7)	950 (21.6)	48 (15

Residence[a]									
Rural	1143 (21.1)	4104 (79.1)	165 (73.7)		3985 (78.8)	101 (80.2)		3457 (78.7)	25 (8
Education									
Senior high school or lower	3075 (56.8)	2954 (56.9)	121 (54.0)		2877 (56.9)	72 (57.1)		2502 (56.9)	17 (5
Employment									
Unemployed	3114 (57.5)	2985 (57.5)	129 (57.6)		2911 (57.5)	69 (54.8)		2533 (57.6)	16 (5
Average family income (RMB per year)[c]									
[?]49,999	2285 (42.2)	2180 (42.0)	105 (46.9)		2130 (42.1)	60 (47.6)		1857 (42.3)	15 (4
Pre-pregnancy BMI (kg/m^2)[c]									
Underweight	973 (18.0)	925 (17.8)	48 (21.4)		924 (18. 3)	33 (26.2)		824 (18.7)	89 (2
Normal	3680 (68.0)	3541 (68. 3)	139 (62.1)		3457 (68.3)	76 (60.3)		2997 (68.2)	19 (6
Overweight	599 (11.1)	567 (10.9)	32 (14.3)		533 (10.5)	15 (11.9)		451 (10.3)	26 (8.
Obese	160 (3.0)	155 (3.0)	5 (2.2)		145 (2.9)	2 (1.6)		123 (2.8)	4 (
GWG[c]									
Appropriate	499 (9.2)	474 (9.1)	25 (11.2)		436 (8.6)	10 (7.9)		369 (8.4)	14 (4.
Insufficient	4816 (89.0)	4625 (89.1)	191 (85.3)		4542 (89.8)	114 (90.5)		3958 (90.1)	29 (9
Excessive	97 (1.8)	89 (1.7)	8 (3.6)		81 (1.6)	2 (1.6)		68 (1.5)	3 (
Smoking									
Never	5049 (93.3)	4842 (93.3)	207 (92.4)		4720 (93.3)	121 (96.0)		4097 (93.2)	29 (9
Former	267 (4.9)	252 (4.9)	15 (6.7)		248 (4.9)	4 (3.2)		218 (5.0)	18 (5.
Current	96 (1.8)	94 (1.8)	2 (0.9)		91 (1.8)	1 (0.8)		80 (1.8)	5 (
Drinking									
Never	4294 (79.3)	4120 (79.4)	174 (77.7)		4017 (79.4)	104 (82.5)		3486 (79.3)	25 (7
Former /Current	1118 (20.7)	1068 (20.6)	50 (22.3)		1042 (20.6)	22 (17.5)		909 (20.7)	64 (2

Parity[bc]									
[?]1	2344 (43.3)	2258 (43.5)	85 (37.9)		2203 (43.5)	40 (31.7)		1888 (43.0)	85 (26
HDP[ab]									
Yes	101 (1.9)	91 (1.8)	10 (4.5)		88 (1.7)	6 (4.8)		79 (1.8)	7 (
Pre-eclampsia									
Yes	40 (0.7)	37 (0.7)	3 (1.3)		37 (0.7)	2 (1.6)		30 (0.7)	3 (
GDM[c]									
Yes	369 (6.8)	347 (6.7)	22 (9.8)		340 (6.7)	7 (5.6)		292 (6.6)	7 (
Physical activity during pregnancy									
Low	1804 (33.3)	1733 (33.4)	71 (31.7)		1687 (33.3)	43 (34.1)		1470 (33.4)	118 (37
Medium	1805 (33.4)	1721 (33.2)	84 (37.5)		1679 (33.2)	47 (37.3)		1455 (33.1)	101 (32
High	1803 (33.3)	1734 (33.4)	69 (30.8)		1693 (33.5)	36 (28.6)		147 (33.4)	97 (30

Abbreviations: BMI=body mass index; GDM=gestational diabetes mellitus; GWG=gestational weight gain; HDP=hypertensive disorders in pregnancy.

Data are mean ± SD or n (%) or median (P25, P75). Percentages may not sum up to 100% because of rounding.

227 women were excluded from the LBW analysis due to delivery Macrosomia. 126 women were excluded from the Macrosomia analysis due to delivery LBW.

695 women were excluded from the SGA analysis due to delivery LGA.

[a]Statistically significant differences between preterm delivery groups ($p < 0.05$). [b]Statistically significant differences between LBW groups ($p < 0.05$).

[c]Statistically significant differences between SGA groups ($p < 0.05$).

Table 2 Relationship between nocturnal sleep duration and PTB

Sleep variable		Total				PTB	PTB		
			Model 1 OR (95% CI)	Model 1		Model 2 OR (95% CI)	Model 2		Model 3 OR (95% CI)
<15 weeks Sleep quality[a]	<15 weeks Sleep quality[a]								

PSQI[?]5	PSQI[?]5	4572 (84.5)	1	1	1
PSQI>5	PSQI>5	840 (15.5)	1.56 (0.81,1.64)	1.16 (0.81,1.66)	1.15 (0.80,1.64)
Sleep duration (h)[b]	Sleep duration (h)[b]				
[?]7	[?]7	4572 (84.5)	1.15 (0.57,2.30)	1.10 (0.55,2.23)	1.09 (0.54,2.20)
8-9	8-9	840 (15.5)	1	1	1
10	10	4572 (84.5)	1.02 (0.75,1.39)	1.03 (0.75,1.41)	1.03 (0.75,1.41)
[?]11	[?]11	840 (15.5)	0.97 (0.68,1.41)	0.99 (0.68,1.45)	1.01 (0.69,1.57)
Napping (h)[c]	Napping (h)[c]				
0	0	4572 (84.5)	0.56 (0.18,1.78)	0.53 (0.17,1.70)	0.55 (0.17,1.75)
1-30	1-30	840 (15.5)	1	1	1
31-60	31-60	4572 (84.5)	1.11 (0.60,2.06)	1.12 (0.60,2.10)	1.09 (0.58,2.05)
61-90	61-90	840 (15.5)	0.93 (0.29,2.96)	0.88 (0.27,2.82)	0.60 (0.19,1.91)
90	90	4572 (84.5)	0.67 (0.21,2.12)	0.60 (0.19,1.91)	0.59 (0.18,1.90)
24-28 weeks Sleep quality[a]	24-28 weeks Sleep quality[a]				
PSQI[?]5	PSQI[?]5	4572 (84.5)	1	1	1
PSQI>5	PSQI>5	840 (15.5)	1.10 (0.79,1.54)	1.12 (0.80,1.57)	1.11 (0.79,1.56)
Sleep duration (h)[b]	Sleep duration (h)[b]				
[?]7	[?]7	4572 (84.5)	1.78 (1.13,2.79)	1.79 (1.11,2.87)	1.80 (1.12,2.89)
8-9	8-9	840 (15.5)	1	1	1
10	10	4572 (84.5)	0.98 (0.71,1.35)	0.98 (0.70,1.36)	0.96 (0.69,1.33)
[?]11	[?]11	840 (15.5)	0.53 (0.30,0.92)	0.52 (0.30,0.92)	0.53 (0.30,0.93)
Napping (h)[c]	Napping (h)[c]				

0	0	4572 (84.5)	1.05 (0.72,1.54)	1.07 (0.73,1.57)	1.09 (0.74,1.60)
1-30	1-30	840 (15.5)	1	1	1
31-60	31-60	4572 (84.5)	0.87 (0.60,1.26)	0.89 (0.61,1.29)	0.89 (0.62,1.30)
61-90	61-90	840 (15.5)	1.25 (0.78,1.98)	1.28 (0.80,2.05)	1.29 (0.80,2.07)
90	90	4572 (84.5)	0.77 (0.46,1.28)	0.79 (0.47,1.34)	0.81 (0.48,1.36)

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

[a]Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during regnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for sleep quality basis of a Model 2. Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

Table 3 Relationship between nocturnal sleep duration and LBW

Sleep variable		Total	Model 1 OR (95% CI)	Model 1	LBW. Model 2 OR (95% CI)	LBW. Model 2	Model 3 OR (95%
<15 weeks	<15 weeks						
Sleep quality[a]	Sleep quality[a]						
PSQI[?]5	PSQI[?]5	4572 (84.5)	1		1		1
PSQI>5	PSQI>5	840 (15.5)	1.23 (0.78,1.94)		1.25 (0.79,1.98)		1.24 (0.7
Sleep duration (h)[b]	Sleep duration (h)[b]						
7	[?]7	4572 (84.5)	1.01 (0.36,2.83)		1.10 (0.55,2.23)		1.02 (0.3
8-9	8-9	840 (15.5)	1		1		1
10	10	4572 (84.5)	1.10 (0.72,1.68)		1.03 (0.75,1.41)		1.04 (0.6
11	[?]11	840 (15.5)	1.40 (0.89,219)		0.99 (0.68,1.45)		1.31 (0.8
Napping (h)[c]	Napping (h)[c]						
0	0	4572 (84.5)	0.56 (0.18,1.78)		0.53 (0.17,1.70)		0.55 (0.1
1-30	1-30	840 (15.5)	1		1		1
31-60	31-60	4572 (84.5)	1.11 (0.60,2.06)		1.12 (0.60,2.10)		1.09 (0.5
61-90	61-90	840 (15.5)	0.93 (0.29,2.96)		0.88 (0.27,2.82)		0.60 (0.1
90	90	4572 (84.5)	0.67 (0.21,2.12)		0.60 (0.19,1.91)		0.59 (0.1
24-28 weeks	24-28 weeks						
Sleep quality[a]	Sleep quality[a]						
PSQI[?]5	PSQI[?]5	4572 (84.5)	1		1		1
PSQI>5	PSQI>5	840 (15.5)	1.08 (0.69,1.68)		1.12 (0.72,1.75)		1.11 (0.7
Sleep duration (h)[b]	Sleep duration (h)[b]						
7	[?]7	4572 (84.5)	1.76 (0.94,3.30)		1.84 (0.96,3.54)		1.86 (0.9
8-9	8-9	840 (15.5)	1		1		1
10	10	4572 (84.5)	1.48 (1.00,2.21)		1.42 (0.95,2.13)		1.39 (0.9
11	[?]11	840 (15.5)	0.62 (0.30,1.30)		0.58 (0.27,1.22)		0.58 (0.2
Napping (h)[c]	Napping (h)[c]						
0	0	4572 (84.5)	1.05 (0.72,1.54)		1.13 (0.67,1.89)		1.15 (0.6

1-30	1-30	840 (15.5)	1	1	1
31-60	31-60	4572 (84.5)	0.87 (0.60,1.26)	0.78 (0.46,1.30)	0.78 (0.4
61-90	61-90	840 (15.5)	1.25 (0.78,1.98)	1.22 (0.64,2.31)	1.23 (0.6
90	90	4572 (84.5)	0.77 (0.46,1.28)	1.37 (0.75,2.48)	1.41 (0.7

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

227 women were excluded from the LBW analysis due to delivery Macrosomia.

[a] Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during regnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for sleep quality basis of a Model 2. Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

Table 4 Relationship between nocturnal sleep duration and SGA

Sleep variable		Total	Model 1 OR (95% CI)	Model 1	SGA Model 2 OR (95% CI)	SGA Model 2	Model 3 OR (95
<15 weeks	<15 weeks						
Sleep quality[a]	Sleep quality[a]						
PSQI[?]5	PSQI[?]5	4572 (84.5)	1		1		1
PSQI>5	PSQI>5	840 (15.5)	0.80 (0.57,1.12)		0.77 (0.55,1.09)		0.77 (0.5
Sleep duration (h)[b]	Sleep duration (h)[b]						
7	[?]7	4572 (84.5)	0.88 (0.44,1.75)		0.96 (0.48,1.94)		0.96 (0.4
8-9	8-9	840 (15.5)	1		1		1
10	10	4572 (84.5)	1.18 (0.90,1.54)		1.08 (0.83,1.42)		1.08 (0.8
11	[?]11	840 (15.5)	1.30 (0.96,1.75)		1.15 (0.84,1.57)		1.13 (0.8
Napping (h)[c]	Napping (h)[c]						
0	0	4572 (84.5)	0.56 (0.18,1.78)		0.90 (0.39,2.09)		0.90 (0.3
1-30	1-30	840 (15.5)	1		1		1
31-60	31-60	4572 (84.5)	0.67 (0.35,1.28)		0.74 (0.39,1.43)		0.74 (0.3
61-90	61-90	840 (15.5)	1.35 (0.58,3.15)		1.48 (0.63,3.48)		1.45 (0.6
90	90	4572 (84.5)	1.18 (0.51,2.44)		1.13 (0.51,2.48)		1.09 (0.5
24-28 weeks	24-28 weeks						
Sleep quality[a]	Sleep quality[a]						
PSQI[?]5	PSQI[?]5	4572 (84.5)	1		1		1
PSQI>5	PSQI>5	840 (15.5)	0.89 (0.66,1.20)		0.89 (0.65,1.21)		0.89 (0.6
Sleep duration (h)[b]	Sleep duration (h)[b]						
7	[?]7	4572 (84.5)	1.76 (0.94,3.30)		1.16 (0.70,1.93)		1.17 (0.7
8-9	8-9	840 (15.5)	1		1		1
10	10	4572 (84.5)	1.48 (1.00,2.21)		1.30 (0.99,1.70)		1.29 (0.9
11	[?]11	840 (15.5)	0.62 (0.30,1.30)		1.24 (0.86,1.78)		1.22 (0.8
Napping (h)[c]	Napping (h)[c]						
0	0	4572 (84.5)	1.15 (0.83,1.60)		1.15 (0.82,1.61)		1.15 (0.8
1-30	1-30	840 (15.5)	1		1		1
31-60	31-60	4572 (84.5)	0.94 (0.68,1.30)		0.93 (0.67,1.29)		0.93 (0.6
61-90	61-90	840 (15.5)	1.13 (0.73,1.74)		1.10 (0.71,1.71)		1.10 (0.7
90	90	4572 (84.5)	1.48 (1.01,2.16)		1.37 (0.93,2.03)		1.38 (0.9

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

695women were excluded from the SGA analysis due to delivery LGA.

[a] Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during pregnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for sleep quality basis of [a] Model 2. Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

Table 5 Relationship between sleep changes during pregnancy and PTB

Sleep variable		Total	Model 1 OR (95% CI
Changes in sleep quality during pregnancy [a]	Changes in sleep quality during pregnancy [a]		
Always good	Always good	3888 (71.8)	1
Always poor	Always poor	326 (6.0)	1.09 (0.62,1.9
From good to poor	From good to poor	684 (12.6)	1.15 (0.78,1.7
From poor to good	From poor to good	514 (9.5)	1.24 (0.80,1.9
Changes in sleep duration during pregnancy [b]	Changes in sleep duration during pregnancy [b]		
Always good	Always good	1745 (32.2)	1
Always poor	Always poor	1436 (26.5)	0.97 (0.67,1.3
From good to poor	From good to poor	856 (15.8)	1.13 (0.75,1.6
From poor to good	From poor to good	1375 (25.4)	1.15 (0.81,1.6
Changes in napping during pregnancy [c]	Changes in napping during pregnancy [c]		
Always good	Always good	2867 (53.0)	1
Always poor	Always poor	153 (2.8)	0.64 (0.23,1.7
From good to poor	From good to poor	2237 (41.3)	1.12 (0.85,1.4
From poor to good	From poor to good	155 (2.9)	0.80 (0.32,1.9

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

[a] Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during regnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for changes in sleep quality during pregnancy basis of [a] Model 2. Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

Table 6 Relationship between sleep changes during pregnancy and LBW

Sleep variable		Total	Model 1 OR (95% CI
Changes in sleep quality during pregnancy [a]	Changes in sleep quality during pregnancy [a]		
Always good	Always good	3726 (71.9)	1
Always poor	Always poor	314 (6.1)	1.48 (0.78,2.8
From good to poor	From good to poor	658 (12.7)	0.89 (0.50,1.4
From poor to good	From poor to good	487 (9.4)	1.03 (0.56,1.9

Changes in sleep duration during pregnancy [b]	Changes in sleep duration during pregnancy [b]		
Always good	Always good	1676 (32.3)	1
Always poor	Always poor	314 (26.5)	1.46 (0.91,2.
From good to poor	From good to poor	818 (15.8)	1.49 (0.86,2.
From poor to good	From poor to good	1316 (25.4)	1.32 (0.81,2.
Changes in napping during pregnancy [c]	Changes in napping during pregnancy [c]		
Always good	Always good	2759 (53.2)	1
Always poor	Always poor	147 (2.7)	0.67 (0.25,1.
From good to poor	From good to poor	2136 (41.2)	1.14 (0.87,1.
From poor to good	From poor to good	148 (2.9)	0.81 (0.83,2.

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

227 women were excluded from the LBW analysis due to delivery Macrosomia.

[a] Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during regnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for changes in sleep quality during pregnancy basis of [a] Model 2. Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

Table 7 Relationship between sleep changes during pregnancy and SGA

Sleep variable		Total	Model 1 OR (95% CI
Changes in sleep quality during pregnancy [a]	Changes in sleep quality during pregnancy [a]		
Always good	Always good	3380 (71.7)	1
Always poor	Always poor	286 (6.1)	0.83 (0.50,1.
From good to poor	From good to poor	597 (12.7)	0.87 (0.61,1.
From poor to good	From poor to good	448 (9.5)	0.75 (0.49,1.
Changes in sleep duration during pregnancy [b]	Changes in sleep duration during pregnancy [b]		
Always good	Always good	1494 (31.7)	1
Always poor	Always poor	1268 (26.9)	1.45 (1.08,1.
From good to poor	From good to poor	734 (15.6)	1.20 (0.84,1.
From poor to good	From poor to good	1215 (25.8)	1.11 (0.81,1.
Changes in napping during pregnancy [c]	Changes in napping during pregnancy [c]		
Always good	Always good	2502 (53.1)	1
Always poor	Always poor	136 (2.9)	1.50 (0.60,2.
From good to poor	From good to poor	1942 (41.2)	1.25 (0.99,1.
From poor to good	From poor to good	131 (2.8)	0.87 (0.40,1.

Abbreviations: CI=confidence interval; OR=odds ratio. Data are n (%) or OR (95% CI).

695women were excluded from the SGA analysis due to delivery LGA.

[a] Model 1: unadjusted. Model 2: Adjusted for age, employment, education, residence, and family income, smoking, drinking, Physical activity during pregnancy, Parity, Pre-pregnancy BMI, GWG. Model 3: HDP, GDM and preeclampsia were added on the basis of Model 2.

[b] Model 1: unadjusted. Model 2:Adjusted for changes in sleep quality during pregnancy basis of [a] Model 2.

Model 3:HDP, GDM and preeclampsia were added on the basis of Model 2.

[C] Adjusted for the same factors as b.

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