Physical activity and sleep duration during pregnancy have interactive effects on caesarean delivery: a population-based cohort study in Tianjin, China

Yingzi Yang[1†], Weiqin Li[2†], Wen Yang[1], Leishen Wang[2], Jinnan Liu[1], Junhong Leng[3], Wei Li[2], Shuo Wang[2], Jing Li[1], Gang Hu[4], Zhijie Yu[5] and Xilin Yang[1,6,7*]

Abstract

Background: There were inconsistent findings in the literature regarding the associations of physical activity and sleep duration during pregnancy with caesarean delivery for different reasons. It was also unknown whether physical activity and sleep duration during pregnancy had interactive effects on the risks of different types of caesarean delivery. The study aimed to investigate the effects of physical activity, sleep duration and their interactions on the risk of caesarean delivery for medical reasons and non-medical reasons.

Methods: From October 2010 to August 2012, a prospective population-based cohort of 13,015 pregnant women was established in six central urban districts of Tianjin, China. Pregnancy outcomes were retrieved from an electronic database and caesarean delivery was divided into caesarean delivery for medical reasons and caesarean delivery for non-medical reasons. Physical activity and sleep status were collected at 24–28 weeks of gestation using self-reported questionnaires. Logistic regression and additive interaction were used to examine physical activity, sleep duration and their interactive effects on risk of caesarean delivery.

Results: In the cohort, 5692 (43.7%) and 2641 (20.3%) of women had caesarean delivery for medical reasons and non-medical reasons, respectively. Low physical activity increased the risk of caesarean delivery for medical reasons (adjusted OR: 1.13, 95%CI 1.04–1.23) but not caesarean delivery for non-medical reasons. Sleep duration < 7 h/day and poor sleep quality were not associated with caesarean delivery. Sleep duration ≥9 h/day increased the risk of caesarean delivery for medical reasons (1.12, 1.02–1.22) and caesarean delivery for non-medical reasons (1.16, 1.05–1.29). Co-presence of low physical activity and sleep duration ≥9 h/day increased risk of caesarean delivery (1.25, 1.12–1.41), and their additive interaction was statistically significant for caesarean delivery for medical reasons but not for caesarean delivery for non-medical reasons.

(Continued on next page)

* Correspondence: yxl@hotmail.com; yangxilin@tmu.edu.cn
†Yingzi Yang and Weiqin Li contributed equally to this work.
[1]Department of Epidemiology and Biostatistics, School of Public Health, Tianjin Medical University, P.O. Box 154, 22 Qixiangtai Road, Heping District, Tianjin 300070, China
Full list of author information is available at the end of the article

Yang *et al. BMC Pregnancy and Childbirth* (2021) 21:406

Page 2 of 13

(Continued from previous page)

Conclusions: Low physical activity and excessive sleep duration during pregnancy each increased the risk of caesarean delivery, and they had an interactive effect on the risk of caesarean delivery for medical reasons but not on the risk of caesarean delivery for non-medical reasons. Increasing physical activity and maintaining recommended sleep duration during pregnancy may have benefits for perinatal health.

Keywords: Physical activity, Sleep duration, Caesarean delivery, Pregnancy, Chinese

Background

Globally, caesarean delivery (CD) rate had doubled to 21.1% in the past 15 years and increased annually by 4% [1, 2]. China had the highest rate of CD in the world and the rate was also on the rise in the past decades, increased from 46.2% in 2004 to 47.6% in 2011 [3]. The underlying reasons were multifaceted, including policy, clinical decisions, socioeconomic status and psychological state of pregnant women [4, 5]. CD was performed with or without medical indications in clinical practice and had short-term and long-term health consequences such as maternal mortality and neonatal physiology alteration, especially when carried out without medical indications [6]. Thus, curbing the undue increase of CD rate in China has become a critical problem that needs to be solved [7].

Physical activity (PA) was a well-established factor for pregnancy complications. High-level PA was associated with decreased risk of gestational diabetes mellitus (GDM) [8] and low-level PA was associated with increased risk of preterm delivery [9]. Maternal exercise intervention also decreased risk of gestational hypertension and macrosomia [10]. These pregnancy complications could increase the risk of CD, suggesting that PA was likely to associate with CD. A prospective cohort study found that women with low PA levels had higher rates of elective CD and emergency CD [11]. While two meta-analyses of randomized controlled trials failed to generate consistent findings regarding the effects of PA on CD; one found that planned aerobic exercise resulted in a significantly lower incidence of CD [12] while the other found that prenatal exercise had no effects on CD [13]. The effects of PA on CD remained inconclusive.

For adults aged 18–64 years, it's recommended to have 7 to 9 hours' sleep per night by the American National Sleep Foundation [14]. It's established that short and/or long sleep duration was associated with placental abruption [15], GDM [16], preeclampsia and hypertension [17], and these medical conditions increase CD risk. Additionally, several studies found that less than 6 h sleep per day increased CD risk [18, 19] while a small cohort study with 200 subjects found that 8 and more hours of sleep per day was associated with a higher rate of assisted deliveries (CD and instrumental delivery) [20]. Indeed, the association between sleep duration and

CD was less consistent and evidence for excessive sleep duration was insufficient. In addition, Sarah-Jane Paine [21] and Run Li [22] separately reported poor sleep quality increased risk of CD, while an observational study of sleep disturbances failed to find that poor sleep quality was associated with increased risk of CD [23]. Therefore, we also aimed to address the association between sleep quality and CD. In a previous analysis, our group reported that longer sleep duration and low PA increased the risk of GDM [24, 25], which was likely to contribute to a high CD risk. To our knowledge, there were no studies to explore the interactive effects of PA and sleep duration on the risk of CD athough PA was associated with sleep duration [26, 27].

Based on a large population-based prospective cohort of pregnant women in Tianjin, China, the current analyses aimed to explore (1) whether PA and sleep status during pregnancy were associated with CD risk; and (2) whether PA and sleep duration had a synergistic effect on the risk of CD in Chinese pregnant women.
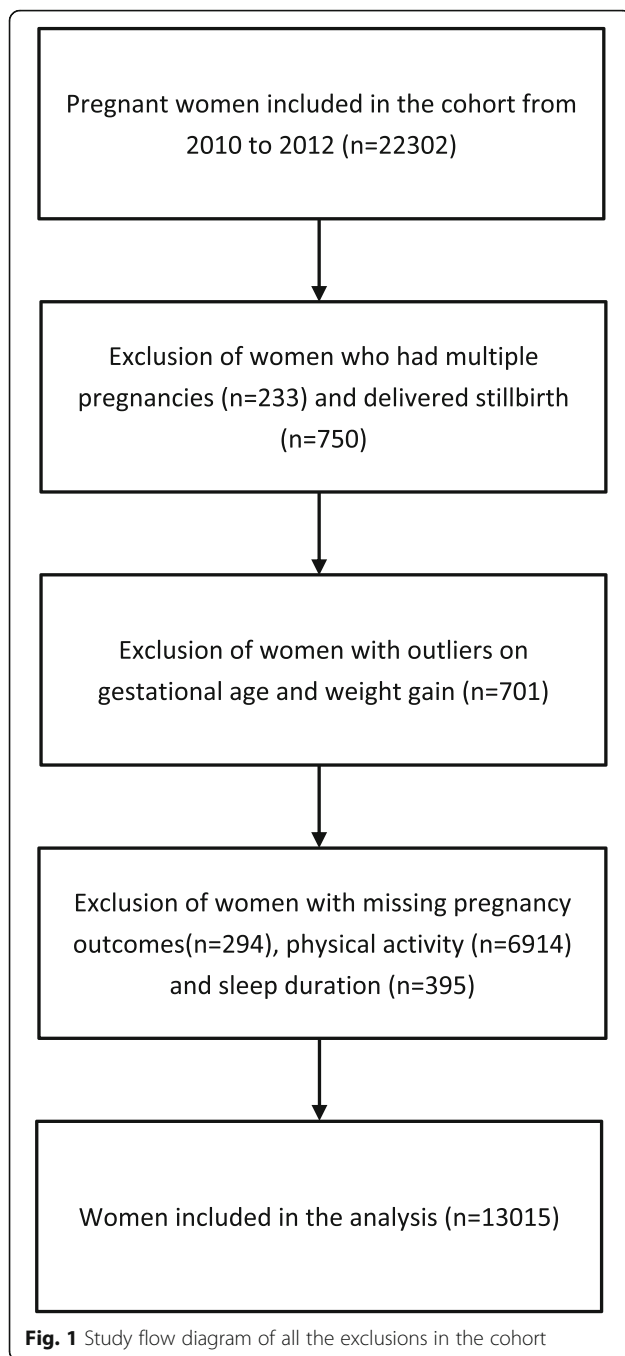
Methods

Study population and settings

Using an established three-tiered screening and management system for GDM in 1999 in six central urban districts of Tianjin, China [28], our group set up a large population-based cohort of pregnant women and their offspring from October 2010 to August 2012 [29]. A total of 22,302 pregnant women made their first antenatal care visit to primary care hospitals close to their residence during the study period. Among them, we sequentially excluded 233 women with multiple pregnancies, 750 women who delivered stillbirth, 294 women with missing pregnancy outcomes, 701 women with outliers on gestational age and weight gain, 7309 women with missing PA (*n* = 6914) and sleep duration (*n* = 395). Eventually, 13,015 subjects were included in the analyses (Fig. 1).

Clinical measurements and data collection of potential confounders

Clinical and biochemical data were collected longitudinally from their first antenatal care visit to delivery by a series of questionnaires or retrieved from the database of the Maternal and Child Health Information System [30]. Information on height, weight, body mass index (BMI), gestational age,

Pregnant women included in the cohort from 2010 to 2012 (n=22302)

Exclusion of women who had multiple pregnancies (n=233) and delivered stillbirth (n=750)

Exclusion of women with outliers on gestational age and weight gain (n=701)

Exclusion of women with missing pregnancy outcomes(n=294), physical activity (n=6914) and sleep duration (n=395)

Women included in the analysis (n=13015)

Fig. 1 Study flow diagram of all the exclusions in the cohort

systolic/diastolic blood pressure (SBP/DBP), weight at registration and glucose challenge test (GCT), maternal age, nationality, parity, family history of diabetes in first degree relatives, smoking and drinking habits were measured or collected by care providers. Weight gain was computed as the difference in weight between at the first antenatal care visit and at GCT time. GDM was identified using a two-step procedure: a 50-g 1-h GCT followed by a 75-g 2-h oral glucose tolerance test if the GCT was 7.8 mmol/L and more [31]. The International Association of Diabetes and

Pregnancy Study Group (IADPSG) criteria were used to diagnose GDM [32].

Assessment of physical activity and sleep status

PA was collected at the GCT time by a self-reported questionnaire. The questionnaire was used in a study [33] and also used in one of previous analyses of the cohort [25]. The detailed description of the methods and validation information were available elsewhere [34]. To collect data on PA accurately and comprehensively, we further collected information about housework PA. Briefly, occupational, commuting, leisure-time and housework physical activities were documented. Occupational PA was divided into three categories: low (unemployment or work always sitting indoor, e.g. desk work of a secretary), moderate (work with standing, walking or lifting, e.g. waiter), and high (work with heavy manual labor, e.g. industrial workers or athletes). Commuting PA was classified into two categories: low (barely outgoing, using motorized transportation or < 30 min/day walking or cycling) and moderate-to-high (≥30 min/day walking or cycling). Leisure-time PA was divided into two categories: no leisure-time PA or exercise less than 150 min per week (< 150 min/week) and exercise more than 150 min per week (≥150 min/week). Housework PA was divided into ≤1 h/day and > 1 h/day. To gain a representative indicator of PA, we regrouped PA into two categories based on the four types of activities above: low (low occupational and commuting PA, leisure-time PA < 150 min/week and housework PA ≤1 h/day), and moderate-to-high (any of the four categories: moderate and high levels of occupational PA, moderate-to-high commuting PA, leisure-time PA ≥150 min/week and housework PA > 1 h/day).

Sleep items were collected in the same questionnaire at the GCT time. For use in busy clinical settings in this study, we adapted and further modified two questions from a well-validated scale (The Pittsburg Sleep Quality Index, PSQI) for measurement of self-reported sleep duration and quality of sleep [35]. The questions to collect sleep status were 'How many hours did you sleep every day during pregnancy including both day and night time?' and 'How did you feel about your sleep quality during pregnancy: good, moderate or poor?'. To be consistent with the classification of sleep duration in our previous investigation [24], we defined sleep duration into three categories: < 7 h/day, ≥7- < 9 h/day and ≥ 9 h/day. Sleep quality was classified into three categories: good, moderate and poor.

Definition of caesarean delivery

CD status and related information were retrieved from the electronic database of the Maternal and Children's Health Information System. CD was divided into two types, CD for medical reasons and CD for non-medical reasons. Medical indications of CD included fetal distress, cephalopelvic disproportion, scar uterus, abnormal

fetal position (breech, transverse, etc.), placenta previa, umbilical cord prolapse, placental abruption, gestational severe complications (GDM, gestational hypertensive or other internal diseases), macrosomia, uterine malformation, uterine inertia, hysteromyoma, pathological pelvis, prolonged labor and cervical lesions. Non-medical indications included social factors, family factors and personal factors. CD without any reasons provided was also classified as the CD for non-medical reasons.

Statistical analyses

R software (R version 4.0.0) was used to perform statistical analyses unless specified. A *P*-value of less than 0.05 for the two-tailed test was considered to be statistically significant. Normal distribution of continuous variables was test with Q-Q plots. Continuous variables were presented as mean ± SD or median (25th percentile, 75th percentile). Analysis of variance (ANOVA) (if the normal distribution and Levene test were not rejected) or the Kruskal-Wallis test where appropriate was used for comparisons of continuous variables among vaginal delivery, CD for medical reasons and CD for non-medical reasons. Bonferroni test or Kruskal-Wallis H test where appropriate was used to perform multiple comparisons. Categorical variables were presented as number (percentages). Chi-squared test or Fisher's exact test where appropriate was used to compare categorical variables among the three groups.

Binary logistic regression was used to obtain the odds ratio (OR) and 95% confidence interval (CI). At first, we obtained ORs and 95% CIs of PA and sleep status for CD in univariable analyses (model 1). Then, we adjusted for potential confounding factors (model 2), including maternal age (continuous), BMI (continuous), weight gain from registration to GCT (continuous), gestational age at delivery (continuous), habitual smokers before and during pregnancy, alcohol drinkers before and during pregnancy, family history of diabetes, parity, ethnicity, SBP (continuous), birth weight (continuous) and neonatal height (continuous). Those confounding factors were selected for being statistically siginifanct different between the CD group and the non-CD group or considering having clinical significance for CD by researchers. Because PA and sleep status were risk factors of GDM, we further adjusted for GDM status to check whether GDM played an intermediate role in the associations of PA and sleep status with CD (model 3).

Subgroup analyses were carried out to examine the consistency in the effects of low PA on CD among different sleep duration groups, and the effects of excessive sleep duration on CD among different PA groups. Short sleep duration was not further analyzed because it was not significant in univariate and multivariate analyses. Synergistic effects between PA and sleep duration on CD risk were checked using additive interaction. Three indicators were used to evaluate additive interaction: relative excess risk due to

interaction (RERI), attributable proportion due to interaction (AP) or synergy index (S). Relative excess risk due to interaction > 0, attributable proportion due to interaction > 0 or synergy index > 1 was regarded as significant additive interaction [36].

To further check different effects of PA, sleep status and their interactive effects on CD for medical reasons and non-medical reasons, we further performed multinomial logistic regression with two response levels, CD for medical reasons and CD for non-medical reasons using the Statistical Analysis System (SAS) release 9.3 (SAS Institute Inc., Cary, NC, USA).

Additional analyses were perfomed to check potential bias in the main analyses. First, we compared the clinical and biochemical characteristics of women excluded and those included in the analyses. Second, we re-included 979 women who had multiple pregnancies or delivered stillbirth to check the impacts of exclusion of those women on the main findings. Third, we analyzed the effect of PA classes, i.e., occupational, commuting, leisure-time and housework physical activities, on the risk of CD for medical reasons and CD for non-medical reasons to further explore the specific effect of PA classes.

Results

Characteristics of the study population

The mean age of 13,015 pregnant women was 28.5 (standard deviation, SD: 2.9) years, with 96.3% of them being primipara. The mean gestation age at registration was 10 (SD: 2.3) weeks. The mean pre-pregnancy BMI was 22.3 (SD: 3.4) kg/m^2 and they delivered an infant at a means of 39.1 (SD: 1.5) weeks of gestation. A total of 8333 women (64.0%) had CD. The CD rates for medical reasons and non-medical reasons were 43.7 and 20.3%, respectively. The main medical indications of CD were cephalopelvic disproportion (32.8%), fetal distress (18.7%), others (18.0%), social factors (5.8%), and breech presentation (5.0%). Women with CD for medical reasons or non-medical reasons were older, had higher pre-pregnancy BMI, SBP and DBP, and more likely to smoke and have a family history of diabetes than women without CD. Infants born by CD had higher weight and height. Women with CD were more likely to have low PA and excessive sleep duration. Individually, women with CD for medical reasons or non-medical reasons had lower levels of occupational PA, commuting PA, leisure-time PA, housework PA, and longer sleep duration, while sleep quality were similar among the three groups (Table 1).

Physical activity and sleep status for caesarean delivery risk

Using moderate-to-high PA as the reference, the unadjusted OR and adjusted OR of low PA for CD were 1.10 (95%CI: 1.03–1.19) and 1.12 (95%CI: 1.03–1.21),

Table 1 Clinical and biochemical characteristics of subjects by three different delivery types

Variables	Vaginal delivery	CD for medical reasons	CD for non-medical reasons	P-value
n	4682	5692	2641	
Variables at registration for pregnancy				
Age, year	$28.07 \pm 2.60^{\dagger,\ddagger}$	$28.72 \pm 3.04^{\dagger}$	$28.66 \pm 3.11^{\ddagger}$	< 0.001[*]
Pre-pregnancy BMI, kg/m^2	$21.56 \pm 2.97^{\dagger,\ddagger}$	$22.81 \pm 3.54^{\dagger}$	$22.62 \pm 3.48^{\ddagger}$	< 0.001[*]
Han-nationality	4481 (95.7%)	5404 (94.9%)	2516 (95.3%)	0.186[**]
Weight, kg	$57.82 \pm 8.68^{\dagger,\ddagger}$	$60.67 \pm 10.20^{\dagger,\S}$	$60.09 \pm 10.04^{\ddagger,\S}$	< 0.001[*]
Height, cm	$163.68 \pm 4.55^{\dagger,\ddagger}$	$162.99 \pm 4.82^{\dagger}$	$162.88 \pm 4.74^{\ddagger}$	< 0.001[*]
Systolic blood pressure, mmHg	$104.80 \pm 10.38^{\dagger,\ddagger}$	$106.24 \pm 10.82^{\dagger}$	$106.22 \pm 11.10^{\ddagger}$	< 0.001[*]
Diastolic blood pressure, mmHg	$67.73 \pm 7.50^{\dagger,\ddagger}$	$68.95 \pm 7.83^{\dagger}$	$69.00 \pm 8.05^{\ddagger}$	< 0.001[*]
Parity ≥1	138 (2.9%)	249 (4.4%)	97 (3.7%)	0.001[**]
Family history of diabetes in first degree relatives	364 (8.3%)	538 (10.0%)	223(9.1%)	0.014[**]
Gestational age at registration, weeks	$10.45 \pm 2.40^{\dagger}$	$10.32 \pm 2.31^{\dagger}$	10.39 ± 2.27	0.008[*]
History of caesarean delivery ≥1	5 (0.1%)	193 (3.4%)	64 (2.4%)	< 0.001[**]
Variables at Glucose challenge test				
Smoke before or during pregnancy	119 (2.5%)	326 (5.7%)	162 (6.1%)	< 0.001[**]
Drink before or during pregnancy	1462 (31.2%)	1818 (31.9%)	846 (32.0%)	0.680[**]
Gestational diabetes mellitus	261 (5.9%)	453(8.4%)	183 (7.4%)	< 0.001[**]
Glucose challenge test, mmol/L	$6.49 \pm 1.50^{\dagger,\ddagger}$	$6.72 \pm 1.60^{\dagger}$	$6.71 \pm 1.56^{\ddagger}$	< 0.001[*]
Weight gain from registration to GCT, kg	$7.41 \pm 3.02^{\dagger,\ddagger}$	$7.81 \pm 3.58^{\dagger}$	$7.72 \pm 3.18^{\ddagger}$	< 0.001[*]
Occupational physical activity				0.347[**]
Low	4022 (86.0%)	4946 (86.9%)	2289 (86.7%)	
Moderate-to-high	656 (14.0%)	743 (13.1%)	351 (13.3%)	
Commuting physical activity(min/day) [a]				0.003[**]
low	4374 (93.6%)	5386 (94.7%)	2513 (95.4%)	
Moderate-to-high	301 (6.4%)	302 (5.3%)	122(4.6%)	
Leisure-time physical activity(min/week)				0.123[**]
0	2477(53.1%)	3074(54.3%)	1474 (56.0%)	
0–150	1391 (29.8%)	1657 (29.2%)	716 (27.2%)	
≥ 150	797 (17.1%)	935 (16.5%)	441 (16.8%)	
Housework physical activity(h/day)				0.007[**]
≤ 1	3544 (77.6%)	4432 (79.9%)	2008 (77.6%)	
> 1	1022 (22.4%)	1114 (20.1%)	579(22.4%)	
Physical activity during pregnancy [b]				
Low	2454 (52.4%)	3147(55.3%)	1427 (54.0%)	0.014[**]
Moderate-to-high	2228 (47.6%)	2545 (44.7%)	1214 (46.0%)	
Sleep duration during pregnancy(h/day)				0.025[**]
< 7	88 (1.9%)	98 (1.7%)	65(2.5%)	
≥ 7 to < 9	2067 (44.1%)	2410 (42.3%)	1091 (41.3%)	
≥ 9	2527 (54.0%)	3184 (55.9%)	1485 (56.2%)	
Sleep quality during pregnancy				0.872[**]
Good	1762 (37.7%)	2161 (38.1%)	990 (37.6%)	
Moderate	2792 (59.8%)	3390 (59.8%)	1583 (60.1%)	
Poor	114 (2.4%)	122(2.2%)	63 (2.4%)	

Yang *et al. BMC Pregnancy and Childbirth*   (2021) 21:406

Page 6 of 13

Table 1 Clinical and biochemical characteristics of subjects by three different delivery types *(Continued)*

Variables	Vaginal delivery	CD for medical reasons	CD for non-medical reasons	*P*-value
Variables at delivery				
Gestational age at delivery, weeks	39.09 ± 1.60[†]	39.06 ± 1.40[†,§]	39.13 ± 1.52[§]	< 0.001[*]
Birth weight, kg	3.28 ± 0.42[†,‡]	3.46 ± 0.49[†,§]	3.40 ± 0.45[‡,§]	< 0.001[*]
Neonatal height, cm	50.03 ± 1.67[†,‡]	50.21 ± 1.63[†]	50.22 ± 1.60[‡]	< 0.001[*]

Abbreviations: BMI body mass index; *GCT* glucose challenge test; *CD* caesarean delivery
[*]Derived from analyses of variance (ANOVA) or the Kruskal-Wallis test;
[**]Derived from Chi-square Test or Fisher's exact test
For analyses of continuous variables, Bonferroni test or Kruskal-Wallis H test was used to perform multiple comparisons with identical †, ‡, or § indicating statistically significant differences between two means
[a] Low was defined was defined barely outgoing, using motorized transportation or < 30 min/day walking or cycling to and from work
[b] Low was defined when subjects simultaneously reported the light level of occupational physical activity, low commuting physical activity, < 150 min/week of leisure-time physical activity, and ≤ 1 h/day housework physical activity; and others were defined as 'moderate-to-high'

respectively. Compared to sleep duration from ≥7 to < 9 h/day, sleep duration < 7 h/day was not associated with CD risk while sleep duration ≥9 h/day was significantly associated with increased risks of CD (unadjusted OR: 1.09, 95%CI: 1.01–1.17 & adjusted OR: 1.13, 95%CI: 1.04–1.22). Using good sleep quality as the reference, moderate and poor sleep quality were not associated with CD risk. Further adjustment for GDM status did not significantly attenuate the effect size of PA and sleep duration for CD (Table 2).

Additive interaction between physical activity and sleep duration for caesarean delivery

Compared to moderate-to-high PA, low PA was not associated with CD risk among women with sleep duration < 9 h/day. However, the unadjusted and adjusted ORs of low PA were significant among women with sleep duration ≥9 h/day (unadjusted OR:

1.16, 95%CI: 1.06–1.28 & adjusted OR: 1.20, 95%CI: 1.08–1.34).

Among women with low PA, the unadjusted and adjusted ORs of sleep duration ≥9 h/day for CD were 1.15 (95%CI:1.04–1.27) and 1.21 (95%CI:1.09–1.35), respectively. Among women with moderate-to-high PA, sleep duration ≥9 h/day was not associated with the risk of CD.

Using the moderate-to-high PA and sleep duration < 9 h/day as the reference, presence of low PA alone and sleep time ≥ 9 h/day alone were not associated with increased risk of CD. However, co-presence of low PA and sleep duration ≥9 h/day significantly increased the risk of CD (adjusted OR: 1.25, 95%CI: 1.12–1.41) with significant additive interaction (Relative excess risk due to interaction: 0.17, 95%CI: 0.01–0.34; Attributable proportion due to interaction: 0.14, 95%CI: 0.01–0.27). The additive interaction between low PA and sleep duration

Table 2 ORs of physical activity and sleep status during pregnancy for caesarean delivery

Variables	n (%)	OR (95% CI)		
		Model 1	Model 2	Model 3
Physical activity				
Low	4574 (35.1%)	1.10 (1.03–1.19)	1.12 (1.03–1.21)	1.12 (1.04–1.22)
Moderate-to-high	3759 (28.9%)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Sleep duration (h/day)				
< 7	163 (1.3%)	1.09 (0.84–1.43)	1.05 (0.79–1.41)	1.04 (0.78–1.39)
≥ 7 to < 9	3501 (26.9%)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
≥ 9	4669 (35.9%)	1.09 (1.01–1.17)	1.13 (1.04–1.22)	1.13 (1.04–1.22)
Sleep quality				
Good	3151 (24.2%)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Moderate	4973 (38.2%)	1.00 (0.92–1.07)	0.99 (0.91–1.07)	1.00 (0.92–1.09)
Poor	185 (1.4%)	0.91 (0.71–1.16)	0.88 (0.68–1.14)	0.91 (0.70–1.19)

Abbreviations: n% number of cases (% of number at risk); *OR* odds ratio; *CI* confidence interval
Model 1: Univariable analyses
Model 2: Multivariable analyses, adjusted for age, body mass index, weight gain from registration to glucose challenge test, gestational age at delivery, habitual smokers before and during pregnancy, alcohol drinkers before and during pregnancy, family history of diabetes in first-degree relatives, parity≥1, Han nationality, systolic blood pressure at registration for pregnancy, birth weight, neonatal height
Model 3: Further adjusted for gestational diabetes, in addition to the variables listed in model 2

Yang *et al. BMC Pregnancy and Childbirth*   (2021) 21:406

Page 7 of 13

≥9 h/day for CD persisted after adjustment for GDM (Table 3).

Physical activity and sleep status for risk of caesarean delivery for medical reasons and non-medical reasons

Low PA was associated with increased risk of CD for medical reasons (adjusted OR:1.13, 95%CI: 1.04–1.23) but not associated with CD for non-medical reasons. Sleep duration ≥9 h/day was associated with increased risk of both CD for medical reasons (adjusted OR: 1.12, 95%CI: 1.02–1.22) and CD for non-medical reasons (adjusted OR:1.16, 95%CI: 1.05–1.29). However, sleep duration < 7 h/day and sleep quality were not associated with increased risk of either CD for medical reasons or CD for non-medical reasons (Table 4).

Additive interaction between physical activity and sleep duration for risk of caesarean delivery for medical reasons and non-medical reasons

Co-presence of low PA and sleep duration ≥9 h/day was associated with elevated risk of CD for medical reasons (adjusted OR: 1.35, 95%CI: 1.17–1.55) with significant additive interaction (Relative excess risk due to interaction: 0.26, 95%CI: 0.06–0.45; Attributable proportion due to interaction: 0.19, 95%CI: 0.05–0.33). However, their additive interaction for CD for non-medical reasons was not significant (Table 5).

Sensitivity analyses

There were statistical differences in some of the variables between the included women and those excluded from the analyses, including age, BMI, weight, SBP, parity, alcohol drinking habit, GDM, weight gain from registration to GCT, sleep duration, gestational age at delivery, birth weight and fetal height (eTable 1). Re-inclusion of the 979 women who had multiple pregnancies or delivered stillbirth did not substantially change the effect sizes of PA and sleep duration for CD (eTable 2). Using moderate-to-high commuting PA as the reference, low commuting PA was associated with CD for non-medical reasons but not with CD for medical reasons. On the contrary, ≤1 h/day housework was associated with increased risk of CD for medical reasons but not CD for non-medical reasons. On the other hand, occupational PA and leisure-time PA were not associated with altered risk of CD for medical reasons and CD

Table 3 Subgroup and additive interaction analyses of physical activity and sleep duration for CD

Variables	OR (95% CI)		
	Model 1	**Model 2**	**Model 3**
Subgroup analyses			
Among sleep time < 9 h/day			
Low V.S Moderate-to-high PA	1.04 (0.94–1.16)	1.04 (0.92–1.17)	1.03 (0.91–1.16)
Among sleep time ≥ 9 h/day			
Low V.S Moderate-to-high PA	1.16 (1.06–1.28)	1.20 (1.08–1.34)	1.22 (1.09–1.36)
Among low PA			
≥9 h/day V.S < 9 h/day sleep time	1.15 (1.04–1.27)	1.21 (1.09–1.35)	1.22 (1.10–1.37)
Among moderate-to-high PA			
≥9 h/day V.S < 9 h/day sleep time	1.03 (0.92–1.14)	1.03 (0.92–1.16)	1.02 (0.90–1.15)
Additive interaction models			
Moderate-to-high PA and sleep time < 9 h/day	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Low PA and sleep time < 9 h/day	1.04 (0.94–1.16)	1.04 (0.92–1.16)	1.03 (0.91–1.16)
Moderate-to-high PA and sleep time ≥ 9/day	1.03 (0.92–1.14)	1.04 (0.93–1.17)	1.03 (0.92–1.16)
Low PA and sleep time ≥ 9 h/day	1.20 (1.08–1.33)	1.25 (1.12–1.41)	1.25 (1.12–1.41)
Additive interaction indications			
RERI	0.13 (−0.02–0.28)	0.17 (0.01–0.34)	0.20 (0.03–0.36)
AP	0.11 (− 0.02–0.23)	0.14 (0.01–0.27)	0.16 (0.02–0.29)
S	2.85 (0.24–33.50)	3.20 (0.30–34.42)	4.40 (0.15–130.67)

Abbreviations: CD caesarean delivery; *PA* physical activity; *RERE* relative excess risk due to interaction; *AP* attributable proportion due to interaction and *S* synergy index. RERI> 0, AP > 0, or S > 1 suggest significant additive interaction; *OR* odds ratio; *CI* confidence interval
Model 1: Univariable analyses
Model 2: Multivariable analyses, adjusted for age, body mass index, weight gain from registration to glucose challenge test, gestational age at delivery, habitual smokers before and during pregnancy, alcohol drinkers before and during pregnancy, family history of diabetes in first-degree relatives, parity≥1, Han nationality, systolic blood pressure at registration for pregnancy, birth weight, neonatal height
Model 3: Further adjusted for gestational diabetes, in addition to the variables listed in model 2

Table 4 ORs of Physical activity and sleep status for CD for medical reasons and non-medical reasons

Variables		OR (95% confidence interval)	
		CD for medical reasons	CD for non-medical ressons rereasons
Model 1	Physical activity		
	Low V.S Moderate-to-high	1.12 (1.04–1.21)	1.07 (0.97–1.17)
	Sleep duration (h/day)		
	< 7	0.96 (0.71–1.28)	1.40 (1.01–1.95)
	≥7 to < 9	1.00 (Reference)	1.00 (Reference)
	≥9	1.08 (0.99–1.17)	1.11 (1.01–1.23)
	Sleep quality		
	Good	1.00 (Reference)	1.00 (Reference)
	Moderate	0.99 (0.91–1.07)	1.01 (0.91–1.11)
	Poor	0.87 (0.67–1.14)	0.98 (0.72–1.35)
Model 2	Physical activity		
	Low V.S Moderate-to-high	1.13 (1.04–1.23)	1.10 (0.99–1.22)
	Sleep duration (h/day)		
	< 7	0.90 (0.65–1.24)	1.37 (0.96–1.94)
	≥7 to < 9	1.00 (Reference)	1.00 (Reference)
	≥9	1.12 (1.02–1.22)	1.16 (1.05–1.29)
	Sleep quality		
	Good	1.00 (Reference)	1.00 (Reference)
	Moderate	0.98 (0.90–1.07)	0.99 (0.89–1.11)
	Poor	0.85 (0.64–1.13)	0.93 (0.66–1.31)
Model 3	Physical activity		
	Low V.S Moderate-to-high	1.13(1.04–1.24)	1.11 (0.99–1.23)
	Sleep duration (h/day)		
	< 7	0.88 (0.64–1.22)	1.37 (0.96–1.95)
	≥7 to < 9	1.00 (Reference)	1.00 (Reference)
	≥9	1.12 (1.02–1.22)	1.16 (1.04–1.29)
	Sleep quality		
	Good	1.00 (Reference)	1.00 (Reference)
	Moderate	0.99 (0.91–1.09)	1.01 (0.91–1.13)
	Poor	0.88 (0.66–1.18)	0.98 (0.69–1.38)

Abbreviations: CD caesarean delivery; *OR* odds ratio
Model 1: Univariable analyses
Model 2: Multivariable analyses, adjusted for age, body mass index, weight gain from registration to glucose challenge test, gestational age at delivery, habitual smokers before and during pregnancy, alcohol drinkers before and during pregnancy, family history of diabetes in first-degree relatives, parity≥1, Han nationality, systolic blood pressure at registration for pregnancy, birth weight, neonatal height
Model 3: Further adjusted for gestational diabetes, in addition to the variables listed in model 2

for non-medical reasons (eTable 3). More detailed information is available in these tables (see eTables 1, 2, 3).

Discussion

Our study revealed that (1) low PA and excessive sleep duration during pregnancy were two risk factors for CD; (2) there was a significant synergistic effect of low PA and excessive sleep duration on the risk of CD for medical reasons and overall CD; (3) low PA increased risk of CD for medical reasons while excessive sleep duration

increased the risk of both CD for medical reasons and non-medical reasons.

Implications

Some studies investigated the association between PA and CD but their findings were inconsistent. A prospective longitudinal study with 94 Caucasian pregnant women failed to observe any differences in PA levels during the early second trimester of pregnancy between women with vaginal delivery and those with CD [37]. A

Table 5 Additive interaction of physical activity and sleep duration on CD for medical and non-medical reasons

Variables		OR (95% CI)	
		CD for medical reasons	CD for non-medical reasons
Model 1	Additive interaction		
	Moderate-to-high PA and sleep time < 9 h/day	1.00(Reference)	1.00(Reference)
	Low PA and sleep time < 9 h/day	1.07(0.96–1.19)	1.07(0.93–1.22)
	Moderate-to-high PA and sleep time ≥ 9/day	1.00(0.89–1.12)	1.08(0.94–1.25)
	Low PA and sleep time ≥ 9/day	1.27(1.12–1.44)	1.24(1.05–1.45)
	Additive interaction indications		
	RERI	0.20(0.03–0.37)	0.09(−0.13–0.31)
	AP	0.16(0.03–0.29)	0.07(−0.10–0.25)
	S	3.98(0.26–61.04)	1.60(0.37–6.99)
Model 2	Additive interaction		
	Moderate-to-high PA and sleep time < 9 h/day	1.00(Reference)	1.00(Reference)
	Low PA and sleep time < 9 h/day	1.06(0.95–1.20)	1.09(0.95–1.26)
	Moderate-to-high PA and sleep time ≥ 9/day	1.02(0.90–1.15)	1.11(0.95–1.29)
	Low PA and sleep time ≥ 9/day	1.34(1.16–1.54)	1.36(1.14–1.61)
	Additive interaction indications		
	RERI	0.26(0.06–0.45)	0.15(−0.09–0.40)
	AP	0.19(0.05–0.33)	0.11(−0.06–0.29)
	S	4.13(0.35–48.48)	1.75(0.54–5.67)
Model 3	Additive interaction		
	Moderate-to-high PA and sleep time < 9 h/day	1.00(Reference)	1.00(Reference)
	Low PA and sleep time < 9 h/day	1.07(0.95–1.20)	1.07(0.93–1.24)
	Moderate-to-high PA and sleep time ≥ 9/day	1.01(0.89–1.15)	1.08(0.92–1.26)
	Low PA and sleep time ≥ 9/day	1.34(1.16–1.54)	1.36(1.14–1.62)
	Additive interaction indications		
	RERI	0.26(0.06–0.45)	0.21(−0.04–0.45)
	AP	0.19(0.05–0.33)	0.15(−0.02–0.33)
	S	4.21(0.32–56.28)	2.36(0.47–11.79)

Abbreviations: CD caesarean delivery; *RERE* relative excess risk due to interaction; *AP* attributable proportion due to interaction and S, synergy index. RERI> 0, AP > 0, or S > 1 suggest significant additive interaction; *OR* odds ratio; *CI* confidence interval
Model 1: Univariable analyses
Model 2: Multivariable analyses, adjusted for age, body mass index, weight gain from registration to glucose challenge test, gestational age at delivery, habitual smokers before and during pregnancy, alcohol drinkers before and during pregnancy, family history of diabetes in first-degree relatives, parity ≥1, Han nationality, systolic blood pressure at registration for pregnancy, birth weight, neonatal height
Model 3: Further adjusted for gestational diabetes, in addition to the variables listed in model 2

secondary analysis of a cluster-randomized trial in Germany (*n* = 1994) showed that lack of PA before or during 12th week of gestation increased risk of CD [38]. A large population-based cohort study with 39,187 Norway nulliparous singleton women found that exercise during pregnancy was associated with a reduced risk of acute CD and high exercise frequency in the 30th week of pregnancy was associated with the greatest risk reduction for elective CD [39]. The differences in period, intensity and types of PA in these studies might be the main reason for these inconsistent findings. In this regard, our study found that low PA increased the risk of CD for medical reasons and overall CD but not CD for non-medical reasons in Chinese pregnant women.

Previous studies also reported inconsistent findings regarding the association of sleep quality and sleep duration with CD. A prospective observational study (*n* = 131) found that poor sleep quality and < 6 h of sleep per day were significantly associated with risk of CD [40]. A meta-analysis of sleep disturbances during pregnancy reported that poor sleep quality and long sleep duration significantly increased risk of CD, while short sleep duration was not associated with CD [41]. A cohort study (*n* = 200) revealed that

assisted deliveries, defined as a composite endpoint of CD and instrumental delivery, were more frequent among women with > 8 h/night sleep while CD alone was more frequent among women with < 6.5 h/night sleep [20]. In our study, poor sleep quality and short sleep duration were not significant for CD, possibly due to their low prevalence in our cohort (i.e., 2.3 and 1.9%, respectively). However, our study did find that sleep duration ≥9 h/day increased risk of CD for medical reasons and non-medical reasons. In addition, given to inconsistency in the definition of long sleep duration in previous studies [42], we also performed the same analyses using ≥10 h of sleep per day as excessive sleep duration and found that sleep duration ≥10 h/day had similar effects on CD after adjusting for confounding factors (OR:1.18, 95%CI:1.08–1.29). Excessive sleep duration increased risk of a number of pregnancy complications such as GDM [34], preeclampsia and hypertension [17], late stillbirth [43], and preterm birth [44]. Therefore, avoiding excessive sleep duration might be an important antenatal practice not only to lower the risk of CD but also to reduce other pregnancy complications such as GDM [23].

To our knowledge, there were no studies, to date, reporting interactive effects of PA and sleep duration during pregnancy on the risk of CD. Our study revealed a significant additive interactive effect of low PA and sleep duration ≥9 h/day towards increasing the risk of CD. The additive interaction effect was only significant for CD for medical reasons but not CD for non-medical reasons. Although PA and sleep duration might affect maternal blood glucose metabolism during pregnancy, we did not observe that PA, sleep duration and their interactive effects were mediated via their impacts on GDM. Produced in adipose tissue and placental trophoblasts [45], leptin might be a signaling molecule for placental development and embryonal growth during pregnancy [46]. In early pregnancy, women with physical inactivity or excessive sleep duration were found to have elevated plasma leptin [47, 48]. A prospective longitudinal study found that pregnancies with adverse outcomes had higher a leptin concentration than uncomplicated pregnancies in the first trimester [49]. Therefore, it remained to be tested whether copresence of physical inactivity and excessive sleep duration during pregnancy was related to aberrant placental development, which leaded to high CD risk.

China had the highest CD rate in the world, reaching an overall hospital-based rate of 41.1% in 2016, and the high CD rate was deemed associated with a high medical expense and overuse of medical recourses in China [5]. The CD rate in our cohort was as high as 64%. In this connection, a study in Guangzhou, China, showed that a two-stage intervention program with population health education, skills training for healthcare professionals, equipment and technical support for local healthcare facilities was able to substantially reduce the CD rate, i.e., from 42.4% in 2008 to 35.0% in 2016 [50]. Our study suggested that either to increase PA or/and to maintain recommended sleep duration may reduce about 19% risk of CD for medical reasons due to co-exposure to lack of PA and excessive sleep duration. Such intervention might also have other health benefits such as reduced risk of GDM in the mother and decreased risk of childhood obesity and asthma in the offspring [6]. Indeed, integrated organizational and clinical interventions including health education to pregnant women and professionals are needed to reduce the high CD rate in China, especially in the large cities. PA and sleep should be considered to be included in the intervention package in future intervention studies.

Strenth and limitations

The major strength of the prospective population-based cohort study was the large sample size, which provided sufficient statistical power to estimate PA, sleep duration and especially for their interactive effect on the risk of CD. Furthermore, our study retrieved the details of the pregnancy outcomes including the indications of CD from the electronic health system, which provided the possibility to explore the specific effect of PA and sleep status on different types of CD. Additionally, many clinical and biochemical risk factors were available to the analyses so that we could adjust for their potential confounding effects.

Our study had several limitations. First, a high proportion of women (34.1%) were not included in the analyses due to missing of key variables such as PA and sleep duration, so the selection bias was not avoidable. However, we had carefully adjusted for potential confounders including but not limited to those who were different between women used in the analyses and those women excluded from the analyses, which may have partially removed their confounding effects if any. Second, body weight at delivery was not systematically documented and not available to the analyses and we could only adjust for weight gain from first care visit to GCT time for the confounding effect of weight gain. The confounding effect of weight gain was only partial removed and the residual confounding could not be completely removed. Also, we cannot exclude the possibility that there were other unmeasured factors that had introduced bias. Third, PA and sleep duration were self-reported and the potential self-reporting bias could not be excluded. Fourth, the majority of the women in the analyses were primipara and had singleton live birth and therefore, our findings could not be extrapolated to multiparous and

multiple pregnancy population of women. Fifth, the CD rate of 64% in the central urban areas of Tianjin reported in this study was consistent with the CD rate in the population in 2000 [51] but higher than the overall rate in Chinese supercities, i.e., around 50% and much higher than that in the rural areas [52]. Further validation studies are warranted in other populations, especially in the rural populations.

Conclusions

The study revealed that low PA and excessive sleep duration during pregnancy increased risk of CD in a synergistic manner, and the significant additive interaction was due to their interactive effect on the risk of CD for medical reasons. Our results highlighted the significance of increasing PA and maintaining recommended sleep duration during pregnancy for perinatal health. Randomized controlled trials were warranted to confirm the effects of promoting PA and maintaining recommended duration of sleep during pregnancy on the rate of CD in Chinese population of pregnant women.

Abbreviations
CD: Caesarean delivery; PA: Physical activity; BMI: Body mass index; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; GDM: Gestational diabetes mellitus; GCT: Glucose challenge test; SD: Standard deviation; OR: Odds ratio; CI: Confidence interval

Supplementary Information
The online version contains supplementary material available at https://doi.org/10.1186/s12884-021-03788-4.

> **Additional file 1** Supplemental tables of sensitivity analyses. Illustrates the details of sensitivity analyses, including **eTable S1**, **eTable S2** and **eTable S3**.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee for Clinical Research of Tianjin Women and Children's Health Centre (TWCHC) on 1 December 2009 (Approval number: 2009–02) and conducted in accordance with Helsiki Declaration. Written informed consent was obtained from all the subjects before data collection and the private information in the study was well protected.

Consent for publication
All the authors agreed to publish the current article.

Competing interests
All the authors did not have conflict of interest.

Author details
[1]Department of Epidemiology and Biostatistics, School of Public Health, Tianjin Medical University, P.O. Box 154, 22 Qixiangtai Road, Heping District, Tianjin 300070, China. [2]Project Office, Tianjin Women and Children's Health Center, Tianjin, China. [3]Department of Child Health, Tianjin Women and Children's Health Center, Tianjin, China. [4]Chronic Disease Epidemiology Laboratory, Pennington Biomedical Research Center, Baton Rouge, Louisiana, USA. [5]Population Cancer Research Program and Department of Pediatrics, Dalhousie University, Halifax, Canada. [6]Tianjin Key Laboratory of Environment, Nutrition and Public Health, Tianjin, China. [7]Tianjin Center for International Collaborative Research on Environment, Nutrition and Public Health, Tianjin, China.

References
1. Stemming the global caesarean section epidemic. Lancet. 2018;392(10155): 1279.
2. Boerma T, Ronsmans C, Melesse DY, Barros AJD, Barros FC, Juan L, et al. Global epidemiology of use of and disparities in caesarean sections. Lancet. 2018;392(10155):1341–8. https://doi.org/10.1016/S0140-6736(18)31928-7.
3. Vogel JP, Betrán AP, Vindevoghel N, Souza JP, Torloni MR, Zhang J, et al. Use of the Robson classification to assess caesarean section trends in 21 countries: a secondary analysis of two WHO multicountry surveys. Lancet Glob Health. 2015;3(5):e260–e70. https://doi.org/10.1016/S2214-109X(1 5)70094-X.
4. Rejno G, Lundholm C, Oberg S, Lichtenstein P, Larsson H, D'Onofrio B, et al. Maternal anxiety, depression and asthma and adverse pregnancy outcomes - a population based study. Sci Rep. 2019;9(1):13101. https://doi.org/10.103 8/s41598-019-49508-z.
5. Liang J, Mu Y, Li X, Tang W, Wang Y, Liu Z, et al. Relaxation of the one child policy and trends in caesarean section rates and birth outcomes in China between 2012 and 2016: observational study of nearly seven million health facility births. BMJ. 2018;360:k817.
6. Sandall J, Tribe RM, Avery L, Mola G, Visser GHA, Homer CSE, et al. Short-term and long-term effects of caesarean section on the health of women and children. Lancet. 2018;392(10155):1349–57. https://doi.org/10.1016/S014 0-6736(18)31930-5.
7. Long Q, Kingdon C, Yang F, Renecle MD, Jahanfar S, Bohren MA, et al. Prevalence of and reasons for women's, family members', and health professionals' preferences for cesarean section in China: a mixed-methods systematic review. PLoS Med. 2018;15(10):e1002672. https://doi.org/10.1371/journal.pmed.1002672.
8. Aune D, Sen A, Henriksen T, Saugstad OD, Tonstad S. Physical activity and the risk of gestational diabetes mellitus: a systematic review and dose-response meta-analysis of epidemiological studies. Eur J Epidemiol. 2016; 31(10):967–97. https://doi.org/10.1007/s10654-016-0176-0.
9. Takami M, Tsuchida A, Takamori A, Aoki S, Ito M, Kigawa M, et al. Effects of physical activity during pregnancy on preterm delivery and mode of delivery: the Japan environment and Children's study, birth cohort study. PLoS One. 2018;13(10):e0206160. https://doi.org/10.1371/journal.pone.0206160.

10. Barakat R, Pelaez M, Cordero Y, Perales M, Lopez C, Coteron J, et al. Exercise during pregnancy protects against hypertension and macrosomia: randomized clinical trial. Am J Obstet Gynecol. 2016;214(5):649.e1–8.

11. Morgan KL, Rahman MA, Hill RA, Zhou SM, Bijlsma G, Khanom A, et al. Physical activity and excess weight in pregnancy have independent and unique effects on delivery and perinatal outcomes. PLoS One. 2014;9(4): e94532. https://doi.org/10.1371/journal.pone.0094532.

12. Di Mascio D, Magro-Malosso ER, Saccone G, Marhefka GD, Berghella V. Exercise during pregnancy in normal-weight women and risk of preterm birth: a systematic review and meta-analysis of randomized controlled trials. Am J Obstet Gynecol. 2016;215(5):561–71. https://doi.org/10.1016/j.ajog.2016.06.014.

13. Davenport MH, Ruchat SM, Sobierajski F, Poitras VJ, Gray CE, Yoo C, et al. Impact of prenatal exercise on maternal harms, labour and delivery outcomes: a systematic review and meta-analysis. Br J Sports Med. 2019; 53(2):99–107. https://doi.org/10.1136/bjsports-2018-099821.

14. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. Sleep Health. 2015;1(1):40–3. https://doi.org/10.1016/j.sleh.2014.12.010.

15. Qiu C, Sanchez SE, Gelaye B, Enquobahrie DA, Ananth CV, Williams MA. Maternal sleep duration and complaints of vital exhaustion during pregnancy is associated with placental abruption. J Matern Fetal Neonatal Med. 2015;28(3):350–5. https://doi.org/10.3109/14767058.2014.916682.

16. Xu YH, Shi L, Bao YP, Chen SJ, Shi J, Zhang RL, et al. Association between sleep duration during pregnancy and gestational diabetes mellitus: a meta-analysis. Sleep Med. 2018;52:67–74. https://doi.org/10.1016/j.sleep.2018.07.021.

17. Williams MA, Miller RS, Qiu C, Cripe SM, Gelaye B, Enquobahrie D. Associations of early pregnancy sleep duration with trimester-specific blood pressures and hypertensive disorders in pregnancy. Sleep. 2010;33(10):1363–71. https://doi.org/10.1093/sleep/33.10.1363.

18. Teong ACA, Diong AX, Omar SZ, Tan PC. The impact of self-reported sleep on caesarean delivery in women undergoing induction of labour: a prospective study. Sci Rep. 2017;7(1):12339. https://doi.org/10.1038/s41598-017-12410-7.

19. Chang JJ, Pien GW, Duntley SP, Macones GA. Sleep deprivation during pregnancy and maternal and fetal outcomes: is there a relationship? Sleep Med Rev. 2010;14(2):107–14. https://doi.org/10.1016/j.smrv.2009.05.001.

20. Plancoulaine S, Flori S, Bat-Pitault F, Patural H, Lin JS, Franco P. Sleep trajectories among pregnant women and the impact on outcomes: a population-based cohort study. Matern Child Health J. 2017;21(5):1139–46. https://doi.org/10.1007/s10995-016-2212-9.

21. Paine SJ, Signal TL, Sweeney B, Priston M, Muller D, Smith A, et al. Maternal sleep disturbances in late pregnancy and the association with emergency caesarean section: a prospective cohort study. Sleep Health. 2020;6(1):65–70. https://doi.org/10.1016/j.sleh.2019.11.004.

22. Li R, Zhang J, Zhou R, Liu J, Dai Z, Liu D, et al. Sleep disturbances during pregnancy are associated with cesarean delivery and preterm birth. J Matern Fetal Neonatal Med. 2017;30(6):733–8. https://doi.org/10.1080/14767058.2016.1183637.

23. Sharma SK, Nehra A, Sinha S, Soneja M, Sunesh K, Sreenivas V, et al. Sleep disorders in pregnancy and their association with pregnancy outcomes: a prospective observational study. Sleep Breath. 2016;20(1):87-93. https://doi.org/10.1007/s11325-015-1188-9.

24. Wang H, Leng J, Li W, Wang L, Zhang C, Li W, et al. Sleep duration and quality, and risk of gestational diabetes mellitus in pregnant Chinese women. Diabet Med. 2017;34(1):44–50. https://doi.org/10.1111/dme.13155.

25. Leng J, Liu G, Zhang C, Xin S, Chen F, Li B, et al. Physical activity, sedentary behaviors and risk of gestational diabetes mellitus: a population-based cross-sectional study in Tianjin, China. Eur J Endocrinol. 2016;174(6):763–73. https://doi.org/10.1530/EJE-15-1103.

26. Hawkins M, Marcus B, Pekow P, Rosal MC, Tucker KL, Spencer RMC, et al. Physical activity and sleep quality and duration during pregnancy among Hispanic women: Estudio PARTO. Behav Sleep Med. 2019;17(6):804–17. https://doi.org/10.1080/15402002.2018.1518225.

27. Chennaoui M, Arnal PJ, Sauvet F, Leger D. Sleep and exercise: a reciprocal issue? Sleep Med Rev. 2015;20:59–72. https://doi.org/10.1016/j.smrv.2014.06.008.

28. Yang X, Hsu-Hage B, Zhang H, Yu L, Dong L, Li J, et al. Gestational diabetes mellitus in women of single gravidity in Tianjin City, China. Diabetes Care. 2002;25(5):847–51. https://doi.org/10.2337/diacare.25.5.847.

29. Yang W, Liu J, Li J, Liu J, Liu H, Wang Y, et al. Interactive effects of prepregnancy overweight and gestational diabetes on macrosomia and large for gestational age: a population-based prospective cohort in Tianjin, China. Diabetes Res Clin Pract. 2019;154:82–9. https://doi.org/10.1016/j.diabres.2019.06.014.

30. Zhang C, Li Y, Wang L, Sun S, Liu G, Leng J, et al. Blood group AB is protective factor for gestational diabetes mellitus: a prospective population-based study in Tianjin, China. Diabetes/Metabolism Res Rev. 2015;31(6):627–37. https://doi.org/10.1002/dmrr.2650.

31. Leng J, Shao P, Zhang C, Tian H, Zhang F, Zhang S, et al. Prevalence of gestational diabetes mellitus and its risk factors in Chinese pregnant women: a prospective population-based study in Tianjin, China. PLoS One. 2015;10(3):e0121029. https://doi.org/10.1371/journal.pone.0121029.

32. Metzger BE, Gabbe SG, Persson B, Buchanan TA, Catalano PA, Damm P, et al. International association of diabetes and pregnancy study groups recommendations on the diagnosis and classification of hyperglycemia in pregnancy. Diabetes Care. 2010;33(3):676–82.

33. Hu G, Lindström J, Valle TT, Eriksson JG, Jousilahti P, Silventoinen K, et al. Physical activity, body mass index, and risk of type 2 diabetes in patients with normal or impaired glucose regulation. Arch Intern Med. 2004;164(8):892–6. https://doi.org/10.1001/archinte.164.8.892.

34. Sallis JF, Haskell WL, Wood PD, Fortmann SP, Rogers T, Blair SN, et al. Physical activity assessment methodology in the Five-City project. Am J Epidemiol. 1985;121(1):91–106. https://doi.org/10.1093/oxfordjournals.aje.a113987.

35. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2):193–213. https://doi.org/10.1016/0165-1781(89)90047-4.

36. Andersson T, Alfredsson L, Källberg H, Zdravkovic S, Ahlbom A. Calculating measures of biological interaction. Eur J Epidemiol. 2005;20(7):575–9. https://doi.org/10.1007/s10654-005-7835-x.

37. Baena-Garcia L, Ocon-Hernandez O, Acosta-Manzano P, Coll-Risco I, Borges-Cosic M, Romero-Gallardo L, et al. Association of sedentary time and physical activity during pregnancy with maternal and neonatal birth outcomes. The GESTAFIT project. Scand J Med Sci Sports. 2019;29(3):407–14. https://doi.org/10.1111/sms.13337.

38. Hoffmann J, Gunther J, Geyer K, Stecher L, Kunath J, Meyer D, et al. Associations between Prenatal Physical Activity and Neonatal and Obstetric Outcomes-A Secondary Analysis of the Cluster-Randomized GeliS Trial. J Clin Med. 2019;8:10.

39. Owe KM, Nystad W, Stigum H, Vangen S, Bo K. Exercise during pregnancy and risk of cesarean delivery in nulliparous women: a large population-based cohort study. Am J Obstet Gynecol. 2016;215(6):791 e1–e13.

40. Lee KA, Gay CL. Sleep in late pregnancy predicts length of labor and type of delivery. Am J Obstet Gynecol. 2004;191(6):2041–6. https://doi.org/10.1016/j.ajog.2004.05.086.

41. Lu Q, Zhang X, Wang Y, Li J, Xu Y, Song X, et al. Sleep disturbances during pregnancy and adverse maternal and fetal outcomes: a systematic review and meta-analysis. Sleep Med Rev. 2021;58:101436. https://doi.org/10.1016/j.smrv.2021.101436.

42. Won CH. Sleeping for two: the great paradox of sleep in pregnancy. J Clin Sleep Med. 2015;11(6):593–4. https://doi.org/10.5664/jcsm.4760.

43. Cronin RS, Wilson J, Gordon A, Li M, Culling VM, Raynes-Greenow CH, et al. Associations between symptoms of sleep-disordered breathing and maternal sleep patterns with late stillbirth: findings from an individual participant data meta-analysis. PLoS One. 2020;15(3):e0230861. https://doi.org/10.1371/journal.pone.0230861.

44. Wang L, Jin F. Association between maternal sleep duration and quality, and the risk of preterm birth: a systematic review and meta-analysis of observational studies. BMC Pregnancy Childbirth. 2020;20(1):125. https://doi.org/10.1186/s12884-020-2814-5.

45. Masuzaki H, Ogawa Y, Sagawa N, Hosoda K, Matsumoto T, Mise H, et al. Nonadipose tissue production of leptin: leptin as a novel placenta-derived hormone in humans. Nat Med. 1997;3(9):1029–33. https://doi.org/10.1038/nm0997-1029.

46. Toth B, Fischl A, Scholz C, Kuhn C, Friese K, Karamouti M, et al. Insulin and leptin receptors as possible new candidates for endocrine control in normal and disturbed human pregnancy. Mol Hum Reprod. 2009;15(4):231–9. https://doi.org/10.1093/molehr/gap014.

47. Ning Y, Williams MA, Butler CL, Muy-Rivera M, Frederick IO, Sorensen TK. Maternal recreational physical activity is associated with plasma leptin concentrations in early pregnancy. Hum Reprod. 2005;20(2):382–9. https://doi.org/10.1093/humrep/deh615.

48. Qiu C, Frederick IO, Sorensen TK, Enquobahrie DA, Williams MA. Sleep duration and plasma leptin concentrations in early pregnancy among lean and overweight/obese women: a cross sectional study. BMC Res Notes. 2014;7(1):20. https://doi.org/10.1186/1756-0500-7-20.

49. Leijnse JEW, de Heus R, de Jager W, Rodenburg W, Peeters LLH, Franx A, et al. First trimester placental vascularization and angiogenetic factors are associated with adverse pregnancy outcome. Pregnancy Hypertens. 2018;13: 87–94. https://doi.org/10.1016/j.preghy.2018.04.008.

50. Xia X, Zhou Z, Shen S, Lu J, Zhang L, Huang P, et al. Effect of a two-stage intervention package on the cesarean section rate in Guangzhou, China: a before-and-after study. PLoS Med. 2019;16(7):e1002846. https://doi.org/10.1371/journal.pmed.1002846.

51. Yang X, Hsu-Hage B, Zhang H, Zhang C, Zhang Y, Zhang C. Women with impaired glucose tolerance during pregnancy have significantly poor pregnancy outcomes. Diabetes Care. 2002;25(9):1619–24. https://doi.org/10.2337/diacare.25.9.1619.

52. Li HT, Luo S, Trasande L, Hellerstein S, Kang C, Li JX, et al. Geographic variations and temporal trends in cesarean delivery rates in China, 2008-2014. JAMA. 2017;317(1):69–76. https://doi.org/10.1001/jama.2016.18663.

Publisher's Note