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Pregnancy Anxiety and Preterm Birth: The Moderating Role of Sleep

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Objective: Preterm birth (PTB) is a prevalent public health concern. Pregnancy anxiety, poor sleep quality, and short sleep duration have been associated with an increased risk of PTB. Theoretically, sleep variables could moderate the strength of the relationship between pregnancy anxiety and PTB; investigating this question was the primary aim of this study. ***Method:*** The sample consisted of 290 pregnant women who were assessed at 2 time points in pregnancy: Time 1 (<22 weeks gestational age [GA]; $M_{GA} = 15.04$, $SD = 3.55$) and Time 2 (32 weeks GA; $M_{GA} = 32.44$, $SD = 0.99$). Pregnancy anxiety was assessed with the Pregnancy-Related Anxiety Scale, sleep quality was assessed by the Pittsburgh Sleep Quality Index, and sleep duration was assessed via actigraphy. Data on gestational age at birth were obtained from the electronic medical record. ***Results:*** After adjustment for relevant covariates, higher levels of pregnancy anxiety were associated with shorter gestational length and an increased risk of PTB. There were no direct associations between sleep quality or sleep duration and gestational length or PTB. Pregnancy anxiety interacted with sleep duration such that pregnancy anxiety was significantly associated with shorter gestational length and PTB only when women had relatively shorter sleep duration (approximately <8.3 hr). ***Conclusions:*** This study reveals new evidence of an interaction between pregnancy anxiety and sleep duration in the prediction of the timing of delivery. The findings point to avenues to better understand and potentially ameliorate risk for PTB.

Keywords: preterm birth, pregnancy anxiety and sleep, APrON Study

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Preterm birth (PTB), defined as birth before 37 weeks, is a prevalent public health problem, with an estimated 15 million babies born preterm annually across the globe (Bartholomew et al., 2008; Hamilton et al., 2015; World Health Organization, 2018). PTB is the underlying cause of over one third of infant deaths (Martin et al., 2010; Mathews & MacDorman, 2011). In the long term, preterm infants are at higher risk for experiencing health and developmental difficulties, including increased likelihood of motor, cognitive, and socioemotional delays in childhood (Cheong et al., 2017; Oudgenoeg-Paz, Mulder, Jongmans, van der Ham, & Van der Stigchel, 2017). Additionally, preterm infants are more likely to need increased medical, income, and educational support

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throughout their lives (Institute of Medicine, 2007; Moster, Lie, & Markestad, 2008).

There is also consensus that each gestational day after 37 weeks is associated with a range of reduced risks, including lower mortality and better respiratory function (Baron, Litman, Ahronovich, & Baker, 2012; Bérard, Le Tiec, & De Vera, 2012; Cheng et al., 2008; Consortium on Safe Labor et al., 2010; Saigal & Doyle, 2008). Thus, induction of birth prior to 39 weeks of gestation is discouraged unless medically necessary (American College of Obstetricians and Gynecologists, 2013; Spong, 2013). The financial and emotional costs of an early birth on children and impacted families make identifying risk and protective factors an urgent priority (Moster et al., 2008; Petrou, Sach, & Davidson, 2001; Saigal et al., 2016).

Pregnancy Anxiety and Gestational Length

Psychological stress experienced during pregnancy has well-documented associations with increased risk of PTB (Dunkel Schetter & Tanner, 2012; Shapiro, Fraser, Frasch, & Séguin, 2013). A specific psychosocial state, pregnancy anxiety, defined as worries or anxieties that are specific to pregnancy, appears to be a unique risk factor for PTB (Bussières et al., 2015). Pregnancy anxiety includes concerns about the health of the developing child, fears about labor and delivery, concerns about changes to appearance, and parenting worries (Dole et al., 2003; Dunkel Schetter, 2009, 2011; Kramer et al., 2009; Lobel et al., 2008; Roesch, Schetter, Woo, & Hobel, 2004; Wadhwa, Sandman, Porto, Dunkel-Schetter, & Garite, 1993). A meta-analysis of prospective studies, including over 5.5 million participants, found that pregnancy anxiety was more predictive of PTB than stressful life events or trait anxiety (Bussières et al., 2015).

Sleep and Gestational Length

Poor sleep in pregnancy is common and has been associated with birth outcomes, including shorter gestational length (Felder, Baer, Rand, Jelliffe-Pawlowski, & Prather, 2017; Micheli et al., 2011; 8; Warland, Dorrian, Morrison, & O'Brien, 2018). The most common method to assess subjective sleep quality is with the Pittsburgh Sleep Quality Index (PSQI), a self-report measure on which higher scores represent worse subjective sleep quality (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Higher PSQI scores have been associated with an increased risk of preterm delivery (Blair, Porter, Leblebicioglu, & Christian, 2015; Okun, Schetter, & Glynn, 2011). In addition to PSQI scores, short sleep duration has been implicated as a risk factor for PTB (Li et al., 2017; Okun et al., 2012; Strange, Parker, Moore, Strickland, & Bliwise, 2009); however, there are varying definitions of what constitutes short sleep. One epidemiological study found that pregnant women who reported an average sleep duration of <5 hr per night were between 1.7 and 2.4 times more likely to deliver preterm compared to women who reported an average of >5 hr of sleep per night (Micheli et al., 2011). In a case-controlled study of Peruvian women, those who reported short sleep duration, defined as ≤ 6 hr per night, in the first 6 months of their pregnancy were significantly more likely to give birth preterm (adjusted odds ratio [OR] = 1.56) than those who reported sleeping 7–8 hr/night (Kajeepeta et al., 2014). Finally, in a large longitudinal study of Chinese women, short sleep duration, defined as <7 hr per night, was associated with an increased risk of PTB ($OR = 4.67$; Li et al., 2017). Mechanisms linking poor sleep quality and shorter sleep duration in pregnancy to gestational length are thought to occur through changes in hypothalamic-pituitary-adrenal (HPA) axis function (i.e., cortisol dysregulation) and inflammatory processes (Bublitz, Bourjeily, D'Angelo, & Stroud, 2018; Okun, Luther, Wisniewski, & Wisner, 2013).

Anxiety and poor sleep are highly comorbid conditions (Lépine, 2002; Mellman, 2006). Sleep quality and duration have each been identified as moderators of associations between psychosocial factors such as high stress and anxiety and cognitive and intermediate health outcomes (i.e., inflammation and HPA axis functioning; Bassett, Lupis, Gianferante, Rohleder, & Wolf, 2015; Chiang et al., 2016; Tomfohr, Edwards, Madsen, & Mills, 2015). Theories have been proposed as to how sleep could function as a moderator in the relationship between psychosocial stressors and physical health outcomes (El-Sheikh, Tu, Saini, Fuller-Rowell, & Buckhalt, 2016). A cumulative or dual-risk perspective proposes that poor sleep may be particularly pernicious in individuals who are already at increased risk for experiencing negative health outcomes due to environmental or psychosocial factors (El-Sheikh et al., 2016; Evans, 2003; Friedman, 2011; Friedman et al., 2005; McEwen & Karatsoreos, 2015; Tu, Erath, & El-Sheikh, 2015). Although several potential moderators of the relationship between pregnancy anxiety and PTB have been examined, to our knowledge, sleep has not been investigated.

Aims of the Current Study

Clear evidence exists for a relationship between both pregnancy anxiety and sleep with gestational length at birth, yet no studies have investigated these variables together to test potential interactions. Our aims were to (a) replicate previous findings showing associations between pregnancy anxiety and sleep using both subjective and objective sleep assessment and the related outcomes of gestational length at birth and PTB and (b) investigate if sleep variables moderated the relationship between pregnancy anxiety and gestational length variables. We hypothesized that both pregnancy anxiety and sleep quality and duration would be associated with gestational length and the clinical category of PTB (less than 37 weeks' gestation). We also hypothesized, based on the cumulative or dual-risk perspective, that sleep would moderate the relationship between pregnancy anxiety and birth outcomes, such that individuals who reported high levels of pregnancy anxiety and high sleep quality or longer sleep duration would show no association, whereas individuals with both high anxiety and worse sleep would have inverse associations with gestational length outcomes.

Method

Participants

Participants (N = 290) were from a substudy of pregnant women who enrolled in an ongoing longitudinal study of mental health and nutrition during pregnancy, known as the Alberta Pregnancy Outcomes and Nutrition (APrON) cohort study (see methodology article for details related to the larger study; Kaplan et al., 2014). Women were recruited in Calgary and Edmonton, Alberta, from 2011 to 2012. Recruitment occurred through collaborations with maternity clinics. All participants provided informed, written consent prior to being included in the study.

For the substudy, women were required to be < 22 weeks gestational age (GA) at the time of the first assessment. Women were excluded if they were younger than 16 years, unable to answer questions in English, or planning on moving away from the geographical region. They were also excluded from the substudy if they self-reported any of the following: (a) steroid medication usage, (b) smoking, (c) consumption of alcohol or "street" drugs, (d) known pregnancy or fetal complications (e.g., preeclampsia, fetal genetic anomalies), (e) illness during data collection (e.g., fever), and (f) multiple pregnancies. These exclusionary criteria were required due to the collection of biomarkers not reported here. Participants received a $10 gift card to a local grocery store after the completion of each assessment.

Women in the sample were an average age of 31 years, and 98% of the sample reported being married or cohabiting. Approximately 11% reported completing a high school education or less, 19% received a trade or technical certificate, 48% reported a university degree, and 22% reported having a graduate school education. More than half of participants (55%) reported an annual household income of $100,000 (Canadian) or more, 24% reported an annual income between $70,000 and $99,999, 12% reported an annual income between $40,000 and $69,999, and 9% of participants reported an annual income of less than $40,000. The sample primarily self-reported that they were White (79.4%); due to the small number of participants in other racial groups, the ethnicity variable was dichotomized as White versus "other." Approximately half of the sample (50%) reported being pregnant with their first child, 37% were pregnant with their second child, and 13% were pregnant for the third or more time (see Table 1).

Table 1
Characteristics of the Sample

Characteristic	*M* (*SD*) or %	Valid *N*
Maternal age	31.42 (3.82)	290
Education (%)		286
High school or less	10.8	
Trade or technical	18.9	
University	49.0	
Postgraduate degree	21.3	
Income (%)		283
Less than $39,999	8.8	
$40,000–$69,999	12.0	
$70,000–$99,999	24.0	
Greater than $100,000	55.1	
Ethnicity (%)	79.4	287
White		
Asian	14.5	
Black	1.4	
Hispanic	3.8	
Other, not specified	.7	
Prepregnancy body mass index	24.94 (5.16)	287
Gestational hypertension (%)	7.6	289
Gestational diabetes (%)	3.8	289
Gestational age weeks	39.17 (1.68)	290
Preterm <37 wks (%)	6.2	290
Sleep duration mean (actigraphy)	501.72 (59.43)	285
Time 1	500.40 (66.12)	275
Time 2	499.59 (70.35)	245
Pregnancy-related anxiety mean	.73 (.40)	289
Time 1	.77 (.45)	288
Time 2	.67 (.40)	254
Pittsburgh Sleep Quality Index Global Score	5.79 (2.50)	288
Time 1	5.45 (2.75)	284
Time 2	6.24 (2.98)	250

Procedure

The study design involved assessments at two time points in pregnancy: Time 1 (<22 weeks GA; M_{GA} = 15.04, *SD* = 3.55) and Time 2 (32 weeks GA; M_{GA} = 32.44, *SD* = 0.99). All participants completed the first assessment; the majority of participants completed both assessments (*N* = 267). Gestational age at each assessment was determined based on last self-reported menstrual period and confirmed by at least one ultrasound—in the case of discrepancy between these two variables, the ultrasound dating was used. Prior to scheduled laboratory visits, questionnaires were mailed to participants, who then returned them at either a subsequent visit or by mail. Questionnaires at each time point assessed a variety of topics that included assessment of subjective sleep quality and pregnancy anxiety. Following questionnaire completion at each assessment, women wore actigraphy watches for two nights and completed sleep diaries. Data regarding birth outcomes were extracted from the medical record. Participants provided informed consent to the procedures prior to data collection. The study procedures were approved by the University of Calgary Conjoint Health Research Ethics Board.

Measures

Birth record. Information about gestational length, gestational diabetes, and gestational hypertension was extracted from provincial birth records. PTB was categorized dichotomously as <37 weeks gestational length versus ≥37 weeks gestational length.

Prepregnancy body mass index. Assessments of body mass index (BMI) prior to pregnancy have been described previously for the study cohort (Begum, Colman, McCargar, Bell,& Alberta Pregnancy Outcomes, 2012; Clayborne, Giesbrecht, Bell, & Tomfohr-Madsen, 2017). Briefly, self-reported prepregnancy weight (kg) and measured height to the nearest 0.1 cm (Charder HM200P Portstad Portable Stadiometer) were collected at the first study visit (<22 weeks' gestation). Prepregnancy BMI was calculated by dividing prepregnancy weight by measured height (m) squared.

Pregnancy anxiety. The Pregnancy-Related Anxiety Scale is a 10-item instrument that examines the extent to which women are worried about their own and baby's health, labor, delivery, and caring for a new baby (Rini, Dunkel-Schetter, Wadhwa, & Sandman, 1999). For instance, specific items on the scale include the following: "I am confident of having a normal childbirth," "I am afraid that I will be harmed during delivery," and "I am concerned (worried) about taking care of a new baby" (Rini et al., 1999). Items were rated on a scale ranging from 1 (*never or not at all*) to 4 (*a lot of the time or very much*), with summative scores ranging from 0 to 30 and higher scores indicating greater anxiety. Consistent with past research that has used this scale, scores were computed by reverse scoring items that were reverse worded and calculating the mean of all item responses; thus, the possible range for mean scores was from 0.0 to 3.0 (Rini, Schetter, Hobel, Glynn, & Sandman, 2006; Thomas et al., 2017). This scale has good internal reliability in the literature (Cronbach's alpha = .78; Rini et al., 1999) and the current study (Time 1: Cronbach's alpha = .76; Time 2: Cronbach's alpha = .74). Pregnancy anxiety scores have been shown to be generally stable over the course of pregnancy (Kane, Dunkel Schetter, Glynn, Hobel, & Sandman, 2014). In the current study, pregnancy anxiety was averaged across both prenatal time points to enhance reliability and validity and represent a mother's cumulative pregnancy-related anxiety.

Pittsburgh Sleep Quality Index. Subjective sleep quality was assessed using the 19-item self-report PSQI. The PSQI measures seven components of sleep: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Component scores range from 0 to 3, with higher scores representing greater sleep difficulties on that specific component. A global PSQI score is calculated by summing each component. Global scores range from 0 to 21, with higher scores indicating lower sleep quality and a more severe sleep disturbance (Buysse et al., 1989). The total PSQI has demonstrated good psychometric properties in pregnancy (Jomeen & Martin, 2007). In the current study, the PSQI had acceptable internal reliability at each time point (Cronbach's alpha between 0.69 and 0.70). Although small increases in PSQI scores have been observed throughout pregnancy, PSQI scores were averaged across both prenatal time points in the current study to create a measure indicative of cumulative sleep quality (Sedov, Cameron, Madigan, & Tomfohr-Madsen, 2018; Tomfohr, Buliga, Letourneau, Campbell, & Giesbrecht, 2015).

Actigraphy. Actigraphy was used to assess objective sleep in the current study. An actigraph continuously measures the frequency and degree of wrist movement; these data are stored in 1-min epochs. Four of five actigraphy indices (i.e., number of awakenings, wake time after sleep onset, total sleep time, and sleep efficiency percentage) have been shown to correlate well with polysomnography, the gold-standard assessment of sleep (Lichstein et al., 2006). The Micro Motionlogger Sleep Watch® actigraphy monitor (Ambulatory Monitoring, Inc., Ardsley, NY) used in the current study has well-documented reliability and validity (Rupp & Balkin, 2011). In the current study, participants wore the actigraph on their nondominant wrist for 2 consecutive days in both early and late pregnancy for a total of 4 days. Participants were asked to wear the device continuously from 9 p.m. on Day 1 until 9 p.m. on Day 3, resulting in two consecutive 24-hr periods.

Actigraphy data were analyzed in 1-min epochs with Action-W Version 2.7.1 software. The Cole-Kripke sleep-scoring algorithm was used to determine sleep from wake times for data collected in the zero-crossing mode setting, a setting that sums the signal frequency crossing the zero voltage over the epoch (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). This algorithm calculates a continuous average of activity prior to and following each minute to determine whether that time point should be coded as sleep or wake. Self-report diary data were used to define the "in-bed" period. In cases where actigraphy identified sleep outside this period, we took two steps to ensure accurate sleep scoring. First, if the actigraph was returned immediately after use, we contacted the participant to clarify in-bed and out-of-bed times. Second, we adjusted the in-bed period to include all objectively scored nighttime sleep.

Statistical Analyses

Statistical analyses were performed using SPSS statistical software package (IBM SPSS Statistics, Version 23). Participant data were included if there was information available about birth outcomes, sleep, and pregnancy anxiety from at least one of the two assessment points. Missing data patterns were explored by creating a "Missingness" indicator variable, such that data were coded 0 if there was sleep or pregnancy anxiety data available for analysis at one time point and 1 if it was missing entirely. A series of one-way analysis of variance or logistic regression analyses were fitted with the "Missingness" indicator as the predictor and baseline demographic, sleep, and outcome variables as the outcomes. In total, only seven participants were missing both data points for self-reported sleep, anxiety, or actigraphy data: 1.7% for actigraph, 0.3% for pregnancy anxiety, and 0.7% for PSQI. Participants who were missing sleep or anxiety data at both time points did not differ from those with complete data on any sleep or anxiety variables, infant GA, PTB, maternal age, maternal education, maternal ethnicity, prepregnancy BMI, gestational hypertension, or gestational diabetes diagnosis ($ps > .118$). Participants with missing data reported lower household income ($p = .024$). We also investigated if there were differences in Time 1 and Time 2 PSQI global scores, pregnancy anxiety, or sleep duration (actigraphy) between women who had complete data on these variables versus only one assessment point. We found no differences between the groups on any of the above variables at either assessment point ($ps > .19$).

Unadjusted bivariate associations between average pregnancy anxiety and sleep during pregnancy and birth outcomes were evaluated using Pearson correlations. Next, hierarchical linear regression models were conducted with pregnancy anxiety predicting infant gestational length at birth correcting for a number of covariates with known associations to PTB (i.e., maternal age, education, ethnicity, gestational hypertension, gestational diabetes, household income, parity, and prepregnancy BMI; Institute of Medicine, 1985). Moderation was investigated using the macro PROCESS (Hayes, 2013). The Johnson–Neyman technique and tests of regions of significance simple slopes were examined to determine the points at which sleep variables had a significant conditional effect of pregnancy anxiety in the prediction of gestational length or PTB (Hayes & Matthes, 2009).

Results

Characteristics of the Sample

Actigraphy data showed that the sample slept an average of approximately 8.3 hr per night over the two assessment points (see Table 1). Racial groups (White vs. other) did not differ on the variables of maternal age, prepregnancy BMI, maternal education, parity, gestational hypertension, or PTB. The "other" group was more likely to have a diagnosis of gestational diabetes ($OR = 3.41$, $p = .49$), deliver at an earlier gestational age ($M = 39.30$ weeks [$SD = 1.54$] vs. $M = 38.69$ weeks [$SD = 2.10$], $p = .013$), and report being in a lower income bracket (χ^2 = 30.63, p < .001, Nagelkerke = 4.9%) than the White group.

Hierarchical Regression Analyses

Relationships between pregnancy anxiety, sleep, and birth outcomes. Results of regression analyses are presented in Table 2. After adjusting for covariates (maternal age, education, ethnicity, gestational hypertension, gestational diabetes, household income, parity, and prepregnancy BMI), higher pregnancy anxiety was associated with shorter gestational length and a higher risk of PTB. After controlling for covariates, neither PSQI scores nor sleep duration were directly associated with either birth outcome.

Sleep as a moderator of the relationship between pregnancy-related anxiety and birth outcomes. Next, regression analyses were conducted to assess whether associations between pregnancy anxiety and birth outcomes were dependent on sleep quality (PSQI global scores) or sleep duration. Interactions between pregnancy anxiety and subjective sleep quality were not significant in the prediction of gestational length (β = −.006, *SE* = .097, *p* = .95, 95% CI [−0.197, 0.185]) or PTB (β = −.092, *SE* = .30, *p* = .76, 95% CI [−0.678, 0.494]). There were significant interactions between pregnancy anxiety and objectively assessed sleep duration during pregnancy in the prediction of both gestational length (β = .012, *SE* = .005, *p* = .011, 95% CI [0.003, 0.022]) and PTB (β = −.033, *SE* = .016, *p* = .039, 95% CI [−0.064, −0.002]).[1] See Figures 1a and 2a.

To interpret the interactions, a series of Johnson–Neyman regions of significance tests were conducted. Results showed that the point of transition between a statistically significant and nonsignificant effect of sleep duration was 517.3 min (63.10% of the sample was below) for the outcome of GA and 497.34 min (48.34% of the sample was below) for the outcome of PTB. This means that the effect of pregnancy anxiety on birth outcomes was significant when participants slept less than about 8.3 hr per night (497–517 min). See Figures 1b and 2b.

Exploratory analysis. As all studies to date investigating relationships between sleep duration and PTB have relied on self-report measures, we also investigated whether self-reported sleep duration from the PSQI moderated the relationship between pregnancy anxiety and birth outcomes. Mean sleep duration scores between self-report and actigraphy were correlated, *r* = .37, *p* < .01; however, we did not observe moderation when self-reported sleep duration scores were entered in the prediction of gestational length (β = .398, *SE* = .0230, *p* = .084, 95% CI [−0.054, 0.850]) or PTB (β = −.807, *SE* = .586, *p* = .169, 95% CI [−1.954, −0.341]).

We also examined if pregnancy anxiety was associated with gestational length variables through indirect effects on sleep (i.e., mediational pathways). To test, we investigated if pregnancy anxiety at the first assessment point was associated with either sleep duration and PSQI at the second assessment point. There was no association between pregnancy anxiety and sleep duration (a path), which is a requirement to test mediation; however, there was an association between pregnancy anxiety at the first assessment point and PSQI scores at the second point. There was not a significant indirect pathway between pregnancy anxiety at the first assessment point and PSQI scores at the second assessment point and the outcomes of GA (β = −.047, *SE* = 0.05, 95% CI [−0.176, 0.045]) or PTB (β = −.0354, *SE* = 0.429, 95% CI [−0.447, 1.192]).

Finally, we investigated associations between other actigraphy-derived sleep variables, gestational length at birth and PTB. We found no direct significant associations or interactions with pregnancy anxiety and other actigraphy variables. Results are presented in online supplemental table S1.

Discussion

Results from this study replicated previous findings showing that higher pregnancy anxiety was associated with shorter gestational length at birth and PTB in both adjusted and unadjusted models (Dole et al., 2003; Kramer et al., 2009; Lobel et al., 2008; Roesch et al., 2004; Wadhwa et al., 1993). In contrast to prior research, we did not observe direct associations between subjective or objective sleep variables and gestational length variables (Okun et al., 2011); however, a significant interaction was observed between pregnancy anxiety and objectively assessed sleep duration, such that the relationship between pregnancy anxiety and birth outcomes was present only in the context of shorter sleep duration. Results from this study support a cumulative risk perspective of how sleep may moderate the relationship between pregnancy anxiety and birth timing (El-Sheikh et al., 2016). These findings are important because pregnancy anxiety combined with sleep deprivation may represent a dual-risk profile for PTB risk—questions that should be explored in further research.

Stress and anxiety experienced during pregnancy are thought to influence birth outcomes through numerous direct and indirect mechanisms, one of which is through changes to the HPA axis (Dunkel Schetter, 2011; Wadhwa, Entringer, Buss, & Lu, 2011). Cortisol is the primary hormone released by the HPA axis in response to stress and is required for various aspects of normal fetal development and maturation (Howerton & Bale, 2012; Jensen Peña, Monk, & Champagne, 2012). Although cortisol is growth promoting in lower concentrations, at higher concentrations of maternal or fetal cortisol, fetal growth is inhibited and gestation shortened (Drake, Tang, & Nyirenda, 2007; Gitau, Cameron, Fisk, & Glover, 1998; Hobel, Dunkel-Schetter, Roesch, Castro, &

[1] We investigated if there were differences in prediction of gestational length outcomes when using data from only the first or second assessment point. Using paired-samples *t* tests, we first tested if variables changed significantly over time and found that pregnancy anxiety decreased over time (0.76–0.66, *t* = 4.07, *p* < .001), PSQI scores increased (5.44–6.24, *t* = −4.19, *p* < .001), and minutes of sleep remained unchanged (497.4–498.5, *t* = –0.22, *p* = .82). See Table 1. Similar to results above, we found that pregnancy anxiety was associated with gestational length at both the first (β = –.557, *SE* = .233, *p* = .018) and second (β = –.826, *SE* = .229, *p* < .0001) assessment points. At the first assessment, pregnancy anxiety was not associated with PTB (*OR* = 3.523, *p* = .066), but it was at the second assessment (*OR* = 7.63, *p* = .002). There were no significant associations between PSQI or sleep duration and birth outcomes at either assessment point (*ps* > .19). There were no significant interactions between pregnancy anxiety and PSQI global scores at the first or second assessment points in the prediction of GA or PTB (*ps* > .17). Pregnancy anxiety did interact with sleep duration in the prediction of GA at the first assessment (β = –.009, *SE* = .004, *p* = .019) but not the second (β = –.006, *SE* = .004, *p* = .129), nor were there any significant interactions in the prediction of PTB at the first (β = –.018, *SE* = .011, *p* = .095) or second assessment (β = –.020, *SE* = .022, *p* = .367). Thus, the combination of scores produces clearer results, likely due to lower reliability or power of the tests when not averaged.

Table 2
Linear and Logistic Regression Analyses Showing Pregnancy-Related Anxiety, PSQI Global Score, and Sleep Duration Predicting Preterm Birth and Gestational Length

Predictor	Outcome	*n*	β	*SE*	*p*	ΔR^2	*OR*
Pregnancy-related anxiety	Preterm birth	275	2.15	.79	.007	—	8.54
	Gestational length	275	−.82	.26	.002	.03	—
PSQI Global Score	Preterm birth	274	.03	.12	.817	—	1.03
	Gestational length	274	−.04	.04	.296	<.01	—
Actigraphy sleep duration (minutes)	Preterm birth	272	−.004	.005	.442	—	1.00
	Gestational length	272	<.01	.002	.873	<.01	—

Note. Models are adjusted for maternal age, education, household income, ethnicity, prepregnancy body mass index, parity, gestational hypertension, and gestational diabetes. PSQI = Pittsburgh Sleep Quality Index; *OR* = odds ratio.

Arora, 1999; Howerton & Bale, 2012; Korebrits et al., 1998; McLean et al., 1995; O'Donnell et al., 2012; Wadhwa et al., 2004; Wadhwa, Porto, Garite, Chicz-DeMet, & Sandman, 1998). One study of anxiety and salivary cortisol assessed at multiple times across the day throughout gestation found that higher average levels of anxiety predicted steeper increases in prenatal cortisol trajectories (Kane et al., 2014). Findings from a similar study indicate that compared to controls who delivered at term, the pregnant woman who delivered preterm had higher concentrations of cortisol and a cortisol precursor (i.e., corticotropin-releasing hormone [CRH]) across three gestational time points (Hobel, Arora, & Korst, 1999). Further, higher levels of self-reported stress at 18 to 20 weeks' gestation were associated with CRH concentrations 10 or more weeks later (at 28 to 30 weeks' gestation), suggesting that maternal stress and CRH may be markers for preterm delivery (Hobel et al., 1999).

Disturbed sleep has also been associated with cortisol dysregulation in pregnancy (Miller, 2004; Teran-Perez et al., 2012). For instance, short sleep duration has been associated with dysregulated diurnal cortisol patterns, including a steeper increase in cortisol awakening response and higher levels of late-day cortisol (Abell, Shipley, Ferrie, Kivimäki, & Kumari, 2016). Thus, it follows that longer sleep could act as a buffer against adverse effects of anxiety on the HPA axis and subsequent negative birth outcomes; however, little is known regarding the effects of sleep as a moderator of this relationship, and it is rarely considered in conceptual models of the relationship between stress and PTB (Wadhwa et al., 2011). Given the substantial evidence for a cumulative or dual-risk perspective showing the moderating role of sleep duration on stress and other intermediate health outcomes, more research is needed to support a potential buffering effect of longer sleep duration on pregnancy anxiety and birth outcomes (Alvarez & Ayas, 2004; Rueggeberg, Wrosch, & Miller, 2012).

A strength of our study was reliance on actigraphy-assessed sleep duration compared to self-reported ratings. Actigraphy-assessed and self-reported sleep duration were only moderately correlated in the current study, a discrepancy that has been shown in other pregnant populations (Herring et al., 2013). Additionally, we observed associations between self-reported symptoms of anxiety and subjective sleep, but no association was observed between anxiety and sleep duration as assessed via actigraphy (Volkovich, Liat Tikotzky, & Manber, 2016). These findings suggest a discrepancy between objective and subjective sleep in pregnancy and their relationship with mental health variables. This discrepancy may be an important consideration as objective sleep likely provides a more accurate estimate of sleep duration. Additionally, self-reported sleep measures such as the PSQI may be assessing a negative cognitive style rather than unique sleep-related disturbance (Grandner, Kripke, Yoon, & Youngstedt, 2006). The clinical limitations of needing actigraphy to assess sleep duration in preg-

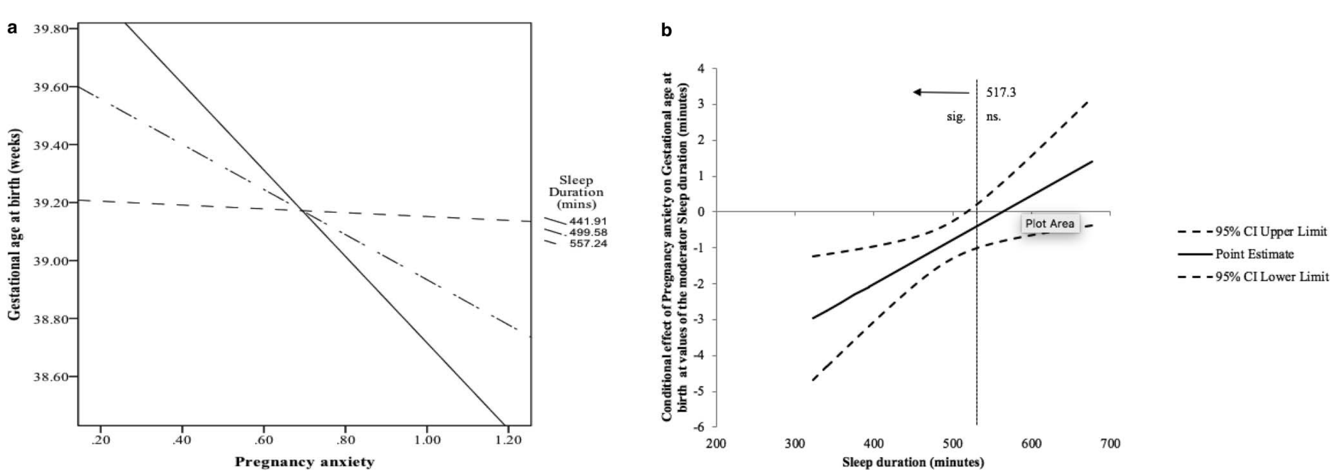

Figure 1. Standardized (a) conditional moderation effect of sleep duration (minutes) on the relationship between pregnancy anxiety and gestational length at birth and Johnson–Neyman confidence limits (b).

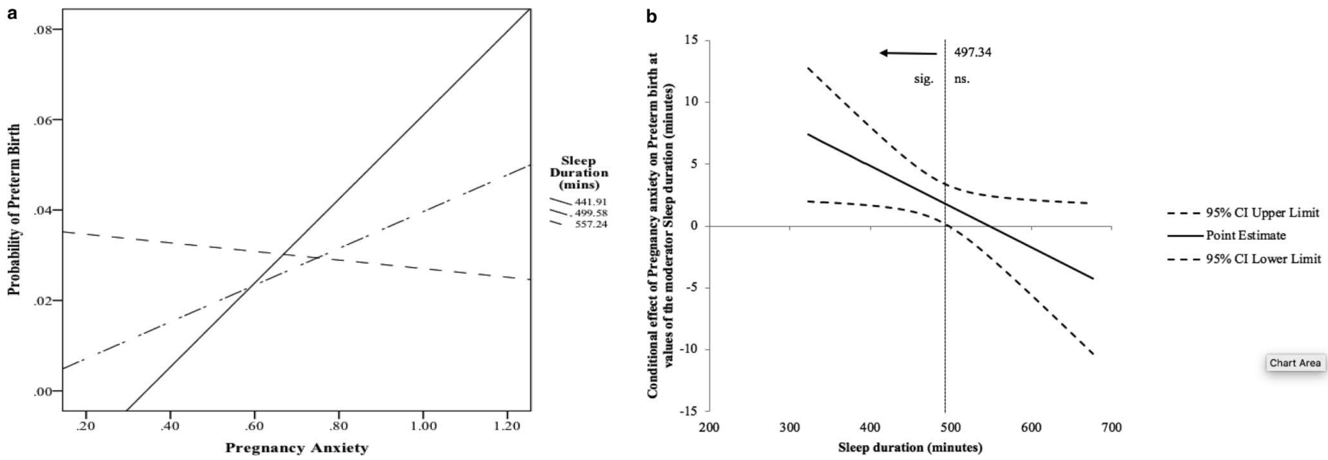

Figure 2. Standardized (a) conditional moderation effect of sleep duration (minutes) on the relationship between pregnancy anxiety and preterm birth and Johnson–Neyman confidence limits (b).

nancy (compared to self-report) are important to acknowledge, and although there has been increased availability of wearable technologies that assess sleep parameters, they tend to inaccurately assess total sleep time, especially in individuals with insomnia (Kang et al., 2017; Kolla, Mansukhani, & Mansukhani, 2016).

The null findings regarding sleep variables and birth outcomes may be explained several ways. First, sleep quality and short sleep duration have varying definitions in the literature. For instance, one study found an association between sleep quality in the second and third trimesters and PTB, but sleep quality was assessed using only a single self-report question about frequency of sleep difficulties (Li et al., 2017). Other studies have reported relationships between short sleep duration and gestational length, with short sleep duration ranging from less than 5 to 7 hr per night (Facco, Kramer, Ho, Zee, & Grobman, 2010; Mindell, Cook, & Nikolovski, 2015; Qiu, Gelaye, Fida, & Williams, 2012). Although we tested if shorter self-reported sleep duration was associated with gestational length, our ability to detect a relationship may have been underpowered due to restricted range in our sample. For example, the majority of our sample was sleeping well within the recommended range of 7–9 hr/night recommended for adults (Watson et al., 2015). Only 30% of the sample reported sleeping less than 7 hr per night, 8.3% reported sleeping less than 6 hr, and less than 1% reported sleep less than 5 hr per night; however, when we tested if sleep duration of fewer than 7 hr per night was associated with gestational length or PTB, we still found no association (ps $>$ .76). Additionally, although the average PSQI score in our sample ($M = 5.79$) was within the range reported as average in a recent meta-analysis on the topic (95% CI [5.30, 6.85]; Sedov et al., 2018), it was lower than that reported in other populations in which associations have been observed between the PSQI and birth outcomes (Blair et al., 2015; Okun et al., 2011). Potentially, the relatively low observed PSQI score in the sample restricted our ability to detect associations with birth timing.

In exploratory analyses, we observed that few of the interactions replicated when investigated at only one assessment point (vs. an average of both). This could point to the fact that a cumulative measure of sleep duration and anxiety across pregnancy is more predictive of birth outcomes than assessment at any one time point. Another possibility is that, because we used only 2 days of actigraphy assessment, the study did not capture a reliable assessment of sleep characteristics when investigated at only one assessment point. Some studies have reported that a minimum of 7 (or greater) days of monitoring is necessary to obtain reliable sleep estimates, and the minimum number recommended for monitoring is three 24-hr periods (Littner et al., 2003; Van Someren, 2007). Finally, future studies may yield more insight into questions of timing effects by assessing the exposures more frequently and in narrower windows during gestation.

An additional consideration is that the participants in the current study may not be comparable to participants in previous studies in terms of relevant characteristics. For example, a study of African American and European American women reported that only in the African American sample was an elevated PSQI score associated with an increased risk of PTB, a finding that the authors suggested may be due to the fact that the African American population experienced greater sensitivity to the adverse physiological response to sleep disturbance (Blair et al., 2015). Thus, in our primarily White, high socioeconomic status sample, these findings may not replicate. Finally, some studies have not observed associations between self-reported sleep duration and PTB, potentially a result of a limited range of sleep duration (Guendelman et al., 2013). The variation in findings across studies may be in part a factor of additional third variables that need to be explored, such as exposure to multiple stressors in pregnancy or other risk factors for PTB such as low social support (Hetherington et al., 2015).

Results of this study should be interpreted in light of several limitations. First, the sample was primarily White, was generally highly educated, and reported high annual household income; it is unclear if these findings will extend into lower socioeconomic status or other racial groups. Overall, the rate of PTB in participants was lower than national or provincial averages, suggesting that this cohort may be at lower risk (Statistics Canada, 2017). We had relatively few cases of PTB in the sample, which may have limited our ability to detect associations between previously observed sleep variables and PTB; we also did not include a measure of prior PTB or delivery problems. On average, the participants reported good sleep quality, and very few women were classified as experiencing short sleep duration; the limitation in sleep range may have restricted our ability to detect associations, and the generalizability of our findings to other populations with more severe sleep problems is unclear. Additionally, we collected only 2 days of actigraphy data at each time point. The recommendations from the American Academy of Sleep Medicine are for a minimum of three consecutive 24-hr periods (Littner et al., 2003; Van Someren, 2007); future research investigating this topic should include longer periods of actigraphy monitoring. Further, the current study collected information on nighttime sleep exclusively; as such, the results do not take into account a potential influence of daytime napping. As there are no clinical cutoff scores available for pregnancy anxiety, we are unable to speak to the prevalence of clinically significant pregnancy anxiety in the sample. As such, the lack of a dichotomous variable for pregnancy anxiety may affect the ability to determine whether the current sample was comparable to typical populations. We also did not include a measure of more generalized or trait anxiety, and the extent to which pregnancy anxiety confers a specific and unique separate from general anxiety should be investigated further. Finally, we did not adjust for all medical problems in pregnancy, and although our findings persisted after inclusion of gestational diabetes and gestational hypertension in our models, other relevant variables (i.e., previous miscarriage) should be included in future studies.

Despite these limitations, our results indicate that sleep duration during pregnancy is one variable that may buffer the effects of pregnancy anxiety on PTB. Exploration of the potential to increase sleep duration and decrease anxiety during pregnancy through evidence-based behavioral interventions, such as cognitive–behavioral therapy, is one potential avenue of further study that may influence gestational length. Future research should also investigate mechanisms to explain the relationship between sleep and/or anxiety on PTB, as mechanisms may be a critical target for intervention and prevention strategies.

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