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Sleep duration and C-reactive protein: Associations among pregnant and non-pregnant women

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Abstract

Pregnant women experience more sleep disturbances and greater systemic inflammation than non-pregnant women. However, the few studies that have examined the links between sleep and inflammation in pregnant women have been in clinical samples. We examined whether sleep duration is associated with C-reactive protein (CRP) levels, a marker of inflammation, in pregnant and non-pregnant women in a population-based sample of US women. Participants were 2,865 women of reproductive age (aged 20–44 years) in the National Health and Nutrition Examination Survey (NHANES), a nationally representative sample of Americans. Sleeping <5 hours on weeknights or workdays was significantly associated with increased CRP levels among both pregnant and non-pregnant women in unadjusted analyses; however, after adjustment for demographic, and health-related variables (depressive symptoms, self-rated health status, body mass index (BMI), diabetes), sleeping <5 hours was no longer significantly related to CRP levels. Pregnant women had significantly higher CRP levels, after adjusting for sleep duration, demographic, and health-related variables. Our findings suggest that pregnancy is associated with increased peripheral CRP, after adjustment for sleep duration, demographic, and health factors. Further, in both pregnant and non-pregnant U.S. women of reproductive age, short sleep duration is associated with higher CRP levels, but this link is explained by self-rated health, BMI, and diabetes. Further studies are needed to investigate links of other sleep parameters (e.g., sleep fragmentation) with CRP in these populations.

Keywords

pregnancy; sleep; C-reactive protein; epidemiology

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1. Introduction

Pregnant women commonly experience sleep disturbances that persist across trimesters, including insomnia symptoms (e.g., frequent awakenings, poor subjective sleep quality) (Baratte-Beebe and Lee, 1999; Kızıllırmak et al., 2012), sleep-disordered breathing, and restless legs syndrome (Facco et al., 2010; Ohayon et al., 2012). In addition, short sleep, relative to intermediate sleep duration, becomes increasingly common with advancing gestation (Facco et al., 2010; Hutchison et al., 2012; Mindell et al., 2015) and has been linked to multiple adverse pregnancy-related outcomes. Among pregnant women in their third trimester, sleeping less than 6 hours, relative to 6 or more hours, was associated with greater self-reported anxiety (Hall et al., 2009). In addition, compared to pregnant women who slept 8 hours, those who slept <8 hours/night had a greater odds of depressive symptoms across all three trimesters (Yu et al., 2017). Further, when pregnant women who slept 7–9 hours/night in early pregnancy were compared to those sleeping 5 hours/night, the shorter sleepers had an increased risk of preeclampsia (Williams et al., 2010). Short sleep duration is also linked to a greater risk of gestational diabetes (Cai et al., 2016), as well as a higher odds of preterm birth (Micheli et al., 2011)—the leading cause of morbidity and mortality in neonates (Romero et al., 2007).

Inflammation is elevated in pregnancy and, like shorter sleep, is believed to contribute to poor pregnancy-related health outcomes (Christian et al., 2009; Fialova et al., 2006; Okun and Coussons-Read, 2007; Tjoa et al., 2003). Compared to non-pregnant women, pregnant women have elevated inflammatory markers, including advanced oxidation protein products (AOPPs), C-reactive protein (CRP), anticardiolipin antibodies (ACA) of IgG and IgM isotypes, and TNF- α (Fialova et al., 2006; Okun and Coussons-Read, 2007). Inflammation has been identified as a risk factor for depression during pregnancy (Christian et al., 2009), pre-eclampsia (Tjoa et al., 2003), and newborns that are small for gestational age (Tjoa et al., 2003). Further, sleep deprivation and inflammation are highly correlated (Frey et al., 2007; Irwin et al., 2016, 2006; Meier-Ewert et al., 2004; Mullington et al., 2009), and sleep loss has been shown to increase production of monocytes and other inflammatory markers, such as IL-6 and TNF- α , and to increase transcription of IL-6 and TNF- α mRNA (Irwin et al., 2006).

Existing studies support strong relationships among pregnancy, sleep, and inflammation. One study found pregnancy to be associated with higher CRP levels (Okun and Coussons-Read, 2007), and found links between sleep and TNF- α but not CRP. In a separate study, Okun et al. found a link between shorter sleep and higher levels of the inflammatory marker IL-6 among pregnant women (Okun et al., 2007). Lastly, Okun et al. observed a stronger link between shorter sleep duration and greater IL-6 levels among pregnant women with depression than among pregnant women without depression (Okun et al., 2013). Importantly, these studies recruited participants through health science centers or obstetrical ultrasound centers, and had relatively small sample sizes. When recruiting from health centers, concerns may arise about the extent to which patients recruited from these centers are representative of the general population of pregnant women, even if they are all community dwelling. In the present study, we examined whether the link between sleep and inflammation differs between pregnant women and non-pregnant women of reproductive

age, in a nationally representative sample, producing results that should generalize to all women of reproductive age in the U.S.

2. Materials and Methods

2.1 Study Population

The National Health and Nutrition Examination Survey (NHANES) is a biennial survey of noninstitutionalized Americans residing in the U.S. conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention. The survey includes an extensive health interview and a physical examination, as well as various laboratory-based tests on biospecimens, including blood. The National Center for Health Statistics Ethics Review Board approved the NHANES study protocols, and written informed consent was obtained from all participants (Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS), 2009a, 2009b, 2007a, 2007b, 2005a, 2005b).

Individuals were included in this analysis if they participated in NHANES during one of 3 rounds of data collection (2005–2010), were women of reproductive age (20–44 years), had a valid measurement of CRP, and had data on self-reported sleep duration and all other variables used in the analysis (see below). These study years were used because they had information on self-reported sleep duration as well as CRP levels. A total of 1,017 women were excluded because of missing covariates, including 213 for whom pregnancy status could not be ascertained. Pregnant women with missing gestational age were also excluded (n=34). Our final sample consisted of 2,865 women of reproductive age, of whom 334 (12%) were pregnant.

2.2 Measurements

2.2.1 Sleep Duration—Participants were asked how much sleep, in hours, they usually get on weekdays or workdays, with 12 or more hours being the maximum value. We created a categorical variable for average reported sleep duration and categorized participants as <5 hours (short sleep); 5–7 hours; or >7 hours.

2.2.2 CRP—CRP, derived from a blood sample in NHANES, is a sensitive marker of systemic inflammation, tissue damage, and infection (Koenig et al., 1999). It has a plasma half-life of 19 hours, meaning it is reasonably representative of current levels of general inflammation in the body (Koenig et al., 1999). It is predictive of future risk of heart attack, stroke, sudden cardiac death, and peripheral arterial disease (Ridker, 2003). In the NHANES, CRP was quantified by latex-enhanced nephelometry. The lowest sensitivity of this assay in NHANES was 0.01 or 0.02 mg/DL, depending on the survey year. Respondents with CRP below this threshold were assigned to 0.01 or 0.02 mg/dL and the highest observed measurement was 13.9 mg/DL.

2.2.3 Pregnancy—We categorized participants as pregnant if they had a positive lab pregnancy test or reported being pregnant at the time of the exam. If neither of these were true, participants were considered non-pregnant.

2.2.4 Other Measures—Participants reported their race/ethnicity (Non-Hispanic White, Mexican-American, Other-Hispanic, Non-Hispanic Black, Other Race/Multiracial, as categorized in the NHANES data); education (re-coded as less than 9th grade education, 9–11th grade education, high school graduation or GED, some college or Associate (AA) degree, college graduate or above); age (in years); and income-to-poverty ratio (continuous measure of the ratio of a respondent’s self-reported total household income to federal poverty line). Depressive symptoms were measured using the Patient Health Questionnaire (PHQ-9)(Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS), 2005b), a 9-item questionnaire assessing frequency of symptoms over the past two weeks based on the Diagnostic and Statistical Manual of Mental Disorders-IV criteria for major depressive disorder(Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS), 2005b; Kroenke et al., 2001). When calculating PHQ-9 scores, we removed one item that asked, “Over the last 2 weeks, how often have you been bothered by the following problems: trouble falling or staying asleep, or sleeping too much?”. After the removal of the sleep item, PHQ-9 scores ranged from 0 to 24, rather than 0 to 27 in the full version. Diabetes (categorized as no diabetes, diabetes, or borderline diabetes) was assessed by asking the participant about their medical diagnoses. Body mass index (BMI; kg/m²) was calculated based on height and weight measured by study personnel, and was included as a continuous measure. Individuals were asked to rate their general health (excellent, very good, good, fair, or poor). Finally, pregnant women reported their gestational age at study visits (in months), which we converted to trimester.

2.3 Statistical Analysis

To determine whether the association of sleep duration with inflammation was modified by pregnancy status and confirm prior findings concerning main effects of sleep and pregnancy on CRP, we fit five linear regression models. All models included CRP (log-transformed to reduce skewness) as the outcome. In terms of predictors, Model 1 only included sleep duration (<5 hours, 5–7 hours, >7 hours); Model 2 included sleep duration and pregnancy status; Model 3 added demographic variables (age, race/ethnicity, education, income-to-poverty ratio); and Model 4 added relevant health-related covariates (depressive symptoms, self-rated health, BMI, diabetes). Model 5 added an interaction term (sleep duration categories $\times$ pregnancy status). Wald tests were used to examine the significance of coefficients at the $p < 0.05$ level. A significant or near-significant ($p < 0.10$) sleep duration $\times$ pregnancy interaction coefficient would constitute evidence that the association between sleep and inflammation may differ between pregnant and non-pregnant women. Tests of interaction were performed between pregnancy $\times$ < 5 hours of sleep (reference: 5–7 hours of sleep), as well as pregnancy and >7 hours of sleep (reference: 5–7 hours of sleep). After stratifying by pregnancy status, we again fit Models 1 and 4 (without pregnancy status as a covariate). In the stratified analyses for the pregnant women, we further adjusted for gestational age. All analyses used Taylor series linearization to estimate standard errors, to account for complex survey design elements and incorporate survey weights. Thus, estimates are considered representative of the population of women of reproductive age (aged 20–44 years) living in the United States. Analyses were conducted in R 3.4 (Vienna, Austria)(R Core Team, 2015), using the “survey” package (Lumley, 2014, 2004).

3 Results

Participants had a mean age of 32.4 ± 0.21 years. Most participants (65.7%) were Non-Hispanic White, 12.0% were Non-Hispanic Black, 9.7% were Mexican-American, and the remainder were another Hispanic ethnicity, other race, or multiracial. Two thirds (65.7%) of participants had at least some college education (Table 1).

On average, women of reproductive age had a CRP level of 0.18 ± 0.04 mg/dL (natural log -1.7 mg/dL). Overall, 5% of women reported <5 hours of sleep, and 37% reported >7 hours, with the remainder (59%) sleeping 5–7 hours per night. The gestational age of pregnant women ranged from 1–10 months (median 5.5 months).

Compared to participants reporting 5–7 hours of sleep, those reporting <5 hours had higher levels of CRP [model 1 Beta=0.32, 95% CI (0.04, 0.61)] (Table 2). This association remained after adjusting for pregnancy [model 2 Beta=0.34, 95% CI (0.06, 0.62)], but was no longer significant after adjusting for demographic and health-related variables [model 3 Beta=0.20, 95% CI (−0.07, 0.47); model 4 Beta=0.18, 95% CI (−0.05, 0.41)] (Table 2). Pregnancy was associated with higher levels of CRP in all models [model 2 Beta=0.98, 95% CI (0.76, 1.20); model 3 Beta=1.04, 95% CI (0.82, 1.25); model 4 Beta=0.80, 95% CI (0.62, 0.99)] (Table 2, Figure 1). When we included interaction terms (model 5), pregnancy also significantly modified the association between short sleep and inflammation [model 5: sleep <5 hours $\times$ Pregnancy interaction B= −1.05, 95% CI (−1.78, −0.32), $p = 0.009$] (Table 2).

We then stratified by pregnancy status and re-ran analyses for Models 1 and 4. Although sleeping <5 hours (relative to 5–7 hours) was significantly associated with higher CRP among both pregnant and non-pregnant women in unadjusted models [pregnant women: B= 0.79 95% CI (0.16, 1.43); non-pregnant women: B=0.33 95% CI (0.05, 0.62)] (Table 3), after adjustment for all covariates in Model 4, these associations were attenuated and non-significant [pregnant women: B= −0.34 95% CI (−0.182, 0.14); non-pregnant women: B=0.21 95% CI (−0.03, 0.44)] (Table 3). In adjusted stratified models, BMI and poorer health were associated with significantly higher CRP (Table 3).

Finally, we conducted a sensitivity analysis among pregnant women in which we further adjusted for gestational age in trimester. While it is known that inflammation changes across pregnancy, in this sample, the association between CRP and pregnancy did not differ by gestational age, and including trimester in our models did not change the association between sleep and CRP (data not shown).

4 Discussion

In this study, we found that pregnancy was significantly associated with elevated CRP levels in a nationally representative sample of U.S. women, and this association persisted after adjustment for a range of potential confounders. Reports of fewer than five hours of sleep were also associated with higher CRP levels in analyses adjusted for pregnancy, but this association was no longer significant after further adjustment for demographic and health-related variables. Individuals with poorer self-rated health or higher BMI were also more

likely to have shorter sleep and higher CRP, suggesting that general health and BMI confounded or perhaps drove or mediated the association between sleep and CRP levels.

We also found some evidence that pregnancy modified the association between sleep and inflammation, with stronger links between short sleep and CRP among pregnant women than among non-pregnant women in unadjusted, stratified analyses. However, there was no statistically significant association between sleep and inflammation in either pregnant or non-pregnant women after adjusting for sociodemographic and health-related variables. The significant interaction term likely reflected different, albeit non-significant, effect estimates of sleep on CRP between pregnant and non-pregnant women. Our adjusted models suggest that in both groups, the relationship between short sleep and CRP levels is accounted for by health factors.

This study builds on prior research examining the link between sleep and markers of inflammation during pregnancy (Okun et al., 2013, 2007; Okun and Coussons-Read, 2007). Our findings are consistent with work by Okun et al., who found that CRP levels were higher in pregnant women compared to non-pregnant women (Okun and Coussons-Read, 2007). In the present study, in which we additionally adjusted for BMI, self-reported health, and diabetes, which were not controlled for in this earlier study, we similarly found no association between short sleep and CRP among pregnant women. A 2009 study by Okun and Coussons-Read (Okun et al., 2009) found a significant association between poor sleep quality and greater sleep discontinuity with CRP levels, but this association was not adjusted for self-reported health, BMI, or diabetes. Our unadjusted results supported an association between short sleep and increased peripheral CRP, but this significant association became null after adjustment for demographic and health variables.

There are at least two ways in which health-related variables (i.e., self-rated health, BMI, diabetes) may have accounted for the association between short sleep and CRP. First, these health factors could be common causes of both shorter sleep and elevated CRP levels, making them confounders of our relationship of interest. Medical conditions, including obesity and diabetes, are known to negatively affect sleep (Luyster and Dunbar-Jacob, 2011; Miller and Cappuccio, 2007; Taub and Redeker, 2008) and increase inflammation (Bastard et al., 2006; Tchernof, 2002) (Dandona et al., 2004; Jagannathan-Bogdan et al., 2011), and depression is associated with poor sleep and elevated inflammatory biomarkers.

Alternatively, these health-related variables may drive or mediate the association between sleep duration and CRP. Indeed, shorter sleep is linked to an increased likelihood of higher BMI and obesity (Patel and Hu, 2008; Taheri et al., 2004), diabetes (Spiegel et al., 2005; Yaggi et al., 2006), and poor health consequences more broadly (Alvarez and Ayas, 2004). If short sleep promoted the development of health conditions, and health conditions, in turn, promoted inflammation, then the link between sleep duration and CRP might be mediated by poor health consequences of short sleep. On the other hand, it is also plausible that poor health negatively affected sleep, and that sleep mediates a link between poor health and inflammation. Regardless of whether confounding or mediation accounts for the link between short sleep and CRP, our results suggest that self-rated health, BMI, and diabetes are attractive targets for reduction of systemic inflammation in both pregnant and non-pregnant women.

The present study has a number of strengths. To our knowledge, it is the first to use data from a large, nationally representative survey to assess the relationship between sleep duration and inflammation in pregnant women. We were able to control for many covariates, including BMI, which prior studies did not control for (Okun et al., 2007; Okun and Coussons-Read, 2007). A limitation of this study is that we were only able to examine one sleep parameter – duration – for interaction with pregnancy on CRP levels, because this is the only measure of sleep that was included in the NHANES in year 2005 through 2010—the years that included CRP and pregnancy. Additionally, we relied on a single retrospective question regarding sleep duration. Future work should be done using prospective, objective measures of sleep, such as polysomnography or actigraphy (de Souza et al., 2003). Moreover, we were unable to account for weekend/non-work day sleep duration in our analysis. It is possible that weekday sleep measures are not generalizable to weekend measures and our findings may have differed if data on weekend sleep were available. Lastly, because these data are cross-sectional, we were unable to evaluate the directionality of these relationships. This makes the interpretation of our findings challenging, because the relationships between health status, sleep and inflammation levels may be bidirectional. In spite of this, it is important to note that health factors accounted for the association between shorter sleep and higher CRP levels among both pregnant and non-pregnant women in our study. This work emphasizes the importance of chronic disease management in both pregnant and non-pregnant women, given that poorer self-rated health, greater BMI, and having diabetes were significantly associated with greater CRP levels.

4.1 Conclusions

Sleep and inflammation are critical aspects of health, and both have been associated with increased risk of poor health outcomes. Our results suggest that pregnant women are at greater risk of short sleep duration and greater inflammation compared to their non-pregnant counterparts. After adjusting for a wide array of covariates, we found that the association between short sleep and higher CRP levels was accounted for by other health-related variables. Larger, prospective studies with a broad range of inflammatory cytokines and objective measures of sleep and wake are needed to elucidate links of sleep and inflammation in pregnant and non-pregnant women.

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Figure 1.
Inflammation in Women of Reproductive Age.

Figure 2.
Association of Sleep Duration and Inflammation Modification by Pregnancy Status

Table 1.

Weighted participant characteristics. (N=2865)

Characteristic	Total Sample (n= 2865)	Pregnant (n = 334)	Not Pregnant (n= 2531)	<i>p</i> -value*
	Mean or Percent	Mean or Percent	Mean or Percent	
Sleep Duration (Hours)	7.0	7.3	6.9	0.0001
Sleep Duration (5–7 hours)	59%	48%	59%	<0.05
Sleep Duration (<5 hours)	5%	2%	5%	
Sleep Duration (>7 hours)	37%	50%	36%	
Pregnant (yes)	5%	100%	0%	NA
CRP, mg/dL (log)	−1.7	−0.8	−1.8	<0.0001
Age (years)	32.4	28.3	32.7	<0.0001
Race				<0.001
<i>Non-Hispanic White</i>	66%	55%	66%	
<i>Mexican-American</i>	10%	19%	9%	
<i>Other Hispanic</i>	6%	5%	6%	
<i>Non-Hispanic Black</i>	12%	10%	12%	
<i>Other Race/Multiracial</i>	7%	11%	7%	
Education				<0.05
<i>Less than 9th grade</i>	4%	4%	3%	
<i>9–11th grade</i>	11%	16%	11%	
<i>High school grad/GED</i>	19%	17%	20%	
<i>Some college/AA degree</i>	36%	31%	36%	
<i>College grad or above</i>	30%	32%	30%	
Income to Poverty Ratio	2.8	2.8	2.8	<0.05
Depressive Symptoms Score (range 0–26)	2.8	2.5	2.9	0.26
Self-report health status				<0.001
<i>Excellent/Very Good</i>	49%	61%	49%	
<i>Good</i>	39%	31%	39%	
<i>Fair/Poor</i>	12%	8%	12%	
BMI (kg/m ²)	28.1	29.8	28.1	<0.01
Diabetes				0.13
<i>No</i>	97%	96%	97%	
<i>Yes</i>	3%	1%	3%	
<i>Borderline</i>	1%	2%	1%	

Table 1 describes the participant characteristics for the whole sample and pregnant and non-pregnant women separately

* *p*-value from t-test for continuous variables or chi-square test for categorical variables.

Table 2.

Association between sleep duration and log-CRP (mg/dL), by pregnancy status

	Beta (95% Confidence Interval)				
	Model 1	Model 2	Model 3	Model 4	Model 5
Sleep duration (ref: 5–7 hours)					
<5 hours	0.32 (0.04, 0.61)	0.34 (0.06, 0.62)	0.20 (–0.07, 0.47)	0.18 (–0.05, 0.41)	0.21 (–0.03, 0.44)
>7 hours	0.03 (–0.1, 0.17)	0.01 (–0.13, 0.15)	0.03 (–0.11, 0.17)	0.09 (–0.03, 0.2)	0.1 (–0.03, 0.22)
Pregnant		0.98 (0.76, 1.20)	1.04 (0.82, 1.25)	0.8 (0.62, 0.99)	0.9 (0.62, 1.17)
Sleep <5 hours × Pregnancy					–1.05 (–1.78, –0.32)
Sleep >7 hours × Pregnancy					–0.15 (–0.49, 0.19)
Age (years)			0.01 (0, 0.02)	0 (–0.01, 0.01)	0 (–0.01, 0.01)
Race (ref: Non-Hispanic White)					
Mexican-American			0.22 (0.02, 0.42)	0.13 (–0.03, 0.3)	0.14 (–0.02, 0.3)
Other Hispanic			–0.03 (–0.29, 0.22)	–0.06 (–0.25, 0.14)	–0.06 (–0.25, 0.14)
Non-Hispanic black			0.27 (0.09, 0.45)	–0.09 (–0.23, 0.06)	–0.08 (–0.23, 0.06)
Other/Multiracial			–0.43 (–0.63, –0.23)	–0.26 (–0.41, –0.11)	–0.26 (–0.41, –0.11)
Education (ref: less than 9 th grade)					
9–11 grade			0.16 (–0.08, 0.4)	0.06 (–0.12, 0.24)	0.07 (–0.12, 0.25)
High school grad/GED			0.07 (–0.18, 0.32)	0.04 (–0.16, 0.23)	0.04 (–0.16, 0.24)
Some college/AA degree			–0.01 (–0.22, 0.21)	–0.03 (–0.22, 0.16)	–0.03 (–0.22, 0.17)
College grad or above			–0.18 (–0.46, 0.1)	0.04 (–0.17, 0.24)	0.04 (–0.17, 0.24)
Income to poverty ratio			–0.06 (–0.12, 0)	–0.02 (–0.06, 0.03)	–0.01 (–0.06, 0.03)
Depressive Symptoms Score (1 unit, 0–24)				–0.004 (–0.02, 0.01)	0 (–0.02, 0.01)
Self-rated health status (ref: excellent)					
Good					
Fair/Poor				0.15 (0.04, 0.27)	0.16 (0.04, 0.27)
BMI				0.16 (0.03, 0.29)	0.16 (0.03, 0.3)
Diabetes (ref: no)				0.1 (0.1, 0.11)	0.1 (0.1, 0.11)
Yes					
Borderline				0.2 (–0.15, 0.55)	0.19 (–0.16, 0.54)
				–0.25 (–0.83, 0.33)	–0.26 (–0.83, 0.31)

Model 5 examines the interaction between pregnancy status and sleep duration on log-CRP. Significant beta estimates ($p < 0.05$) are **bolded**.

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Table 3.Models 1^{*} and 4^{**}: Pregnancy-stratified associations of sleep duration with log-CRP (mg/dL)

Beta (95% Confidence Intervals)				
	Model 1 Pregnant	Model 1 Not Pregnant	Model 4 Pregnant	Model 4 Not Pregnant
Sleep duration (ref: 5–7 hours)			---	---
<5 hours	0.79 (0.16, 1.43)	0.33 (0.05, 0.62)	−0.34 (−0.82, 0.14)	0.21 (−0.03, 0.44)
>7 hours	−0.14 (−0.45, 0.18)	0.02 (−0.13, 0.17)	−0.17 (−0.41, 0.07)	0.1 (−0.02, 0.22)
Age (years)	---	---	−0.02 (−0.04, 0.01)	0 (−0.01, 0.01)
Race (ref: Non-Hispanic White)				
Mexican-American	---	---	0.25 (−0.03, 0.52)	0.12 (−0.06, 0.3)
Hispanic	---	---	0.17 (−0.37, 0.7)	−0.08 (−0.29, 0.12)
Non-Hispanic Black	---	---	0.04 (−0.2, 0.29)	−0.09 (−0.25, 0.06)
Other Race/Multiracial	---	---	0.42 (−0.39, 1.23)	−0.32 (−0.47, −0.17)
Education (ref: less than 9 th grade)				
9–11 th grade	---	---	−0.02 (−0.36, 0.33)	0.07 (−0.12, 0.27)
High school grad/GED	---	---	0.31 (−0.03, 0.65)	0.03 (−0.19, 0.24)
Some college/AA degree	---	---	−0.2 (−0.58, 0.18)	−0.01 (−0.22, 0.19)
College graduate+	---	---	−0.14 (−0.67, 0.39)	0.04 (−0.18, 0.26)
Income to poverty ratio	---	---	0.04 (−0.05, 0.13)	−0.02 (−0.07, 0.03)
Depressive Symptoms Score (1 unit, 0–24)	---	---	−0.01 (−0.05, 0.04)	0 (−0.02, 0.01)
Self-reported health status (ref: excellent)				
Good	---	---	0.36 (0.04, 0.67)	0.14 (0.02, 0.27)
Fair/Poor	---	---	−0.09 (−0.5, 0.32)	0.17 (0.04, 0.31)
BMI	---	---	0.08 (0.06, 0.09)	0.1 (0.1, 0.11)
Diabetes (ref: no)				
Yes	---	---	−0.62 (−1.13, −0.12)	0.21 (−0.15, 0.56)
Borderline	---	---	0.09 (−0.48, 0.65)	−0.28 (−0.96, 0.39)

Table 3 summarizes the linear regressions Model 1 and Model 4 between sleep and log-CRP, stratified by pregnancy status. Model 4 controls for age, race, education, income to poverty ratio, depressive symptoms, self-reported health, BMI, and diabetes.

* Based on Model 4: log CRP ~ sleep duration

** Based on Model 4: log CRP ~ sleep duration + age + race + education + income to poverty ratio + depressive symptoms + self-reported health status + BMI + diabetes

Significant beta estimates (p < 0.05) are **bolded**.