Multidimensional sleep health during pregnancy- The influences of prenatal depression and experiences of racial discrimination

by

Wei-Hsin (Teresa) Hsiao

BS, Taipei Medical University, 2016

MS, Tulane University, 2018

Submitted to the Graduate Faculty of the

School of Public Health in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2022

UNIVERSITY OF PITTSBURGH

SCHOOL OF PUBLIC HEALTH

This dissertation was presented

by

Wei-Hsin Hsiao

It was defended on

May 23, 2022

and approved by

Marquis Hawkins, Assistant Professor, Department of Epidemiology

Michele D Levine, Associate Professor, Department of Psychiatry

Meredith L Wallace, Associate Professor, Department of Psychiatry

Dara D Mendez, Assistant Professor, Department of Epidemiology

Multidimensional sleep health during pregnancy-
The influences of prenatal depression and experiences of racial discrimination

Wei-Hsin Hsiao, PhD

University of Pittsburgh, 2022

Poor sleep health in pregnancy is associated with pregnancy complications including gestational diabetes and hypertension. Studies have predominantly assessed sleep health in pregnancy by its quality and duration. More recent studies have defined sleep health to be multidimensional. It is important to characterize multidimensional sleep health and identify risk factors to improve sleep health in pregnancy.

The first goal of this dissertation was to characterize sleep health in pregnancy through individual dimensions and composite sleep health score. The second and third goals were to identify risk factors related to poor sleep health during pregnancy, including prenatal depression and the experiences of racial discrimination. We used data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMom2b). Sleep was characterized through satisfaction, duration, daytime sleepiness, continuity, timing, and bedtime, waketime, and midpoint sleep regularity. To describe multidimensional sleep health, we created the composite sleep health score by summing z scores centering from the specified cutoffs for each dimension. Prenatal depression was assessed using the Edinburgh Postnatal Depression Scale (EPDS). We identified cross-sectional and longitudinal associations between prenatal depression and sleep health in early and mid-pregnancy. The experiences of racial discrimination were measured using the Experiences of Discrimination (EOD) scale. We identified the associations between the experiences of racial discrimination and sleep health in early and mid-pregnancy.

Our findings suggested that the multidimensional sleep health was consistent from early to mid-pregnancy with changes in specific dimensions. There were declines in satisfaction, duration, and continuity while timing was consistent, and regularity improved from early to mid-pregnancy. There were cross-sectional and longitudinal associations between prenatal depression and satisfaction, duration, sleepiness, continuity, timing, and composite sleep health score. We also found associations between the experiences of racial discrimination and satisfaction, sleepiness, and composite sleep health score during pregnancy.

The completion of the dissertation informs multidimensional sleep characteristics in pregnancy. The findings also support the consideration of maternal mental health and racial discrimination as potential risk factors to improve sleep health during pregnancy under individual dimensions and multidimensional sleep health, which may further reduce adverse maternal health outcomes attributed to poor sleep health during pregnancy.

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Overview

Poor sleep health in pregnancy is associated with pregnancy complications including gestational diabetes and hypertension. Sleep health during pregnancy has been described predominantly with sleep quality and duration. More recent studies have defined sleep health to be multidimensional. It is important to characterize multidimensional sleep health and identify risk factors to improve sleep health in pregnancy.

The first goal of this dissertation was to characterize sleep health in pregnancy through individual dimensions and multidimensional sleep health. The second and third goals were to identify risk factors related to poor sleep health during pregnancy, including prenatal depression and the experiences of racial discrimination. We used data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMom2b). Sleep was characterized through satisfaction, duration, sleepiness, continuity, timing, and bedtime, waketime, and midpoint sleep regularity. We created the composite sleep health score to represent multidimensional sleep health by summing z scores centering from the specified cutoffs for each dimension. Prenatal depression was assessed using the Edinburgh Postnatal Depression Scale (EPDS). We identified cross-sectional and longitudinal associations between prenatal depression and sleep health in early and mid-pregnancy. The experiences of racial discrimination were measured using the Experiences of Discrimination (EOD) scale. We identified the associations between the experiences of racial discrimination and sleep health in early and mid-pregnancy.

Our findings suggested that the multidimensional sleep health was consistent during pregnancy with changes in specific dimensions. There were declines in satisfaction, duration, and continuity while timing was consistent, and regularity improved from early to mid-pregnancy. Pregnant people with probable prenatal depression had poorer satisfaction, duration, sleepiness, continuity, timing, and multidimensional sleep health than those without. We also found that pregnant people with more racial discrimination experiences had poorer satisfaction, sleepiness, and multidimensional sleep health than those with low to no experiences of racial discrimination.

The completion of the dissertation informs multidimensional sleep characteristics in pregnancy. The findings support the consideration of prenatal depression and racial discrimination as risk factors to improve sleep health during pregnancy under individual dimensions and multidimensional sleep health, which may further reduce adverse maternal health outcomes attributed to poor sleep health during pregnancy. (Figure 1)

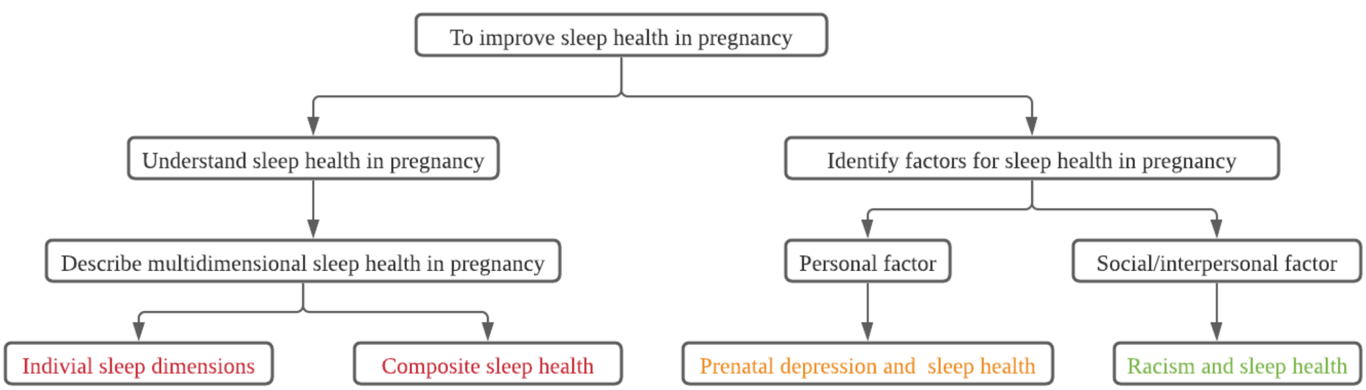

Figure 1. The Overall and Individual Dissertation Aims

1.2 Sleep Health in Pregnancy

In this section, we will discuss the epidemiology of sleep health during pregnancy. First, we will introduce the concept of multidimensional sleep health. Why is it important to characterize multidimensional sleep health in pregnancy? Then we will review the literature on risk factors and health consequences for poor sleep health during pregnancy. Finally, we will review the current research on sleep patterns during pregnancy and research gaps in describing multidimensional sleep health during pregnancy.

1.2.1 The Introduction of Multidimensional Sleep Health

<u>Sleep is a multidimensional pattern of sleep-wakefulness</u>

Sleep health was not well defined in sleep medicine. For example, Healthy People 2020 listed sleep health as one of the health objectives, but the definition was not specified. Instead, poor sleep health was only identified as sleep disorders, such as short sleep duration or sleep-disordered breathing (Healthy People 2020). Sleep quality is one of the most often used terms for measuring sleep in sleep medicine, but we do not have a general definition of sleep quality and global guidance to characterize poor, fair, or good sleep quality (Krystal & Edinger, 2008; Ohayon et al., 2017).

Buysse, 2014 indicated the need to define sleep health. According to the summary, sleep health is defined as *"a multidimensional pattern of sleep-wakefulness, adapted to individual, social and environmental demands, that promotes physical and mental well-being."* (Buysse, 2014). Under this definition, multidimensional sleep health covers several sleep dimensions: regularity, satisfaction, alertness, timing, efficiency, and sleep duration (Buysse, 2014). Multidimensional sleep health can be assessed through both objective and subjective measurements (Buysse, 2014; Buysse, 2010).

Multidimensional sleep health has been characterized and in association with health among non-pregnant populations

Sleep research has implemented the concept of multidimensional sleep health in non-pregnant populations. One recent study has explored the factors including timing, efficiency, duration, sleepiness, and regularity to include in multidimensional sleep health among older adults using the actigraphy data (Wallace et al., 2021). Prior studies have also provided evidence on characterizing multidimensional sleep health in non-pregnant populations and used it as a predictor for health outcomes (Dong et al., 2019; Wallace et al., 2019). For example, Dong et al.'s study characterized multidimensional sleep health among adolescents (n=176) to examine its association with mental and physical health outcomes. The results have shown the association between multidimensional sleep health and emotional (i.e., depression, anxiety), cognitive (i.e., academic performance) outcomes, and obesity among adolescents (Dong et al., 2019). A national, cross-sectional survey among Australian adults have found better multidimensional sleep health associated with better quality of life (OR=1.11, 95%CI: 1.08-1.14) and less chronic depressive symptoms (OR=1.20, 95%CI: 1.17-1.23) (Appleton et al., 2022) A study assessing sleep health through actigraphy and 1-week sleep diaries have examined the relationship between sleep health and gait speed among older adults (Tighe et al., 2021). In another study among older adults ages 65 to 99 years indicated multidimensional sleep as a significant predictor for all-cause and cardiovascular mortality (Wallace et al., 2019). The concept of multidimensional sleep health has also been applied as an outcome among non-pregnant population. A longitudinal study of middle-aged women across U.S. nation has found that depressive symptoms were associated with poorer multidimensional sleep health ($p<.0001$) and individual sleep dimensions including lower alertness ($p<.0001$) and satisfaction ($p<.0001$) (Bowman et al., 2021). While multidimensional sleep health has been examined in non-pregnant populations, the findings on multidimensional sleep health in pregnant populations are limited. In the later sections, we will list a few measurement tools for sleep health that are widely used in current sleep research and describe prior studies on multidimensional sleep health during pregnancy. We will also describe why it is important to describe multidimensional sleep health during pregnancy.

1.2.2 Measurement of Sleep Health

There are various methods to assess sleep, either through objective or subjective assessments. Objective assessments, such as polysomnography and accelerometers, are able to collect biological changes, sleep efficiency, timing, and duration during sleep. Subjective measurement tools are better at capturing one's sleep satisfaction and are able to assess sleep across a longer time period. In this section, we will be introducing a few sleep measurement tools below that have been applied in previous studies targeting pregnant populations.

Objective assessment

Polysomnography (In-home/In-lab)

Polysomnography is the gold standard of sleep measurement. It is a comprehensive sleep assessment consists of electroencephalogram (i.e., brain electrical activity), electrooculography (i.e., eye movement and wakefulness), electromyogram (i.e., detect limb movements), airflow and respiratory effort assessment, cardiac monitoring, and oxygenation measurement (i.e., monitor blood oxygen) (Jafari & Mohsenin, 2010; Rundo & Downey, 2019). The assessment normally lasts through a night. Polysomnography can measure individuals' physiological changes during nighttime sleep and detect different sleep stages that one is experiencing during the sleep (Bloch, 1997).

There are some limitations regarding the use of polysomnography. First, the application of polysomnography and data generated are complicated (Zou et al., 2006). Applying polysomnography to a large sample is also less feasible with higher cost and its complexity (Flemons & Littner, 2003). Second, when applying in-lab polysomnography, the environment is different from home, which may bias the usual sleep and the most impactful during the first night assessment (i.e., first-night assessment) (Byun et al., 2019; McCall & McCall, 2012). In-home polysomnography is a valid alternative for objective sleep assessment to reduce the environmental effect. It may have other limitations, such as signal loss, but this may be mitigated (Campbell & Neil, 2011).

Actigraphy

An actigraphy monitor (i.e., accelerometer) is a wearing device (wrist or ankle) that detects body movements and transforms the data to recorded movements, including physical activity and sleep, through commercially available software (Chen & Bassett, 2005). According to the clinical guidelines from the American Academy of Sleep Medicine (AASM), the recommended duration for sleep assessment using actigraphy should be at least 72 hours and up to 14 days (Smith et al., 2018). Prior studies have assessed the validity of actigraphy sleep assessment and found a high correlation with polysomnography in sleep duration and wake after sleep onset (Sadeh & Acebo, 2002). Furthermore, an accelerometer is a feasible sleep assessment tool and does not disturb sleep due to its size and convenience to wear. An accelerometer's cost is also reasonable for using it to measure sleep with larger sample size.

There are a few limitations of using actigraphy for sleep assessment. First, though actigraphy shows high concordance in total sleep time with polysomnography, it is likely to overestimate sleep in patients who experience poor sleep and frequent arousals. Second, since actigraphy measures sleep through movements, it is likely to detect individuals in sleep mode when laying down with little movement. As a result, actigraphy has limited ability in estimating sleep onset latency. It may also bias the results in assessing sleep among patients with limited mobility. Therefore, sleep studies that use actigraphy monitors will include a sleep diary to specify sleep and wake time for better assessment. Lastly, actigraphy is unable to detect each sleep stage that individuals were experiencing in sleep (Martin & Hakim, 2011).

In summary, actigraphy is a feasible and cost-effective tool to assess individuals' sleep through detecting the movements. It also has good agreement with polysomnography on measuring sleep duration, wake after sleep onset, and sleep efficiency.

Subjective assessment

Pittsburgh Sleep Quality Index (PSQI)

The Pittsburgh Sleep Quality Index is a self-rated questionnaire that assesses individuals' sleep quality over the past month (Buysse et al., 1989). It is a 19-item questionnaire in seven composite scores, with each scale from 0 to 3. The sum of each subscore in the seven sections yields a global PSQI score ranging from 0 to 21. The higher global PSQI score indicates poorer sleep quality (Buysse et al., 1989). Studies targeting diverse populations and pregnant people have widely applied the PSQI in assessing sleep quality (Cronbach's alpha=0.74) (Bertolazi et al., 2011; Cole et al., 2006; Qiu et al., 2016). The PSQI has been validated in the original study among psychiatric patients with a sensitivity of 89.6% and specificity of 86.5% at a cutoff of PSQI score >5 (Buysse et al., 1989). It is also a cutoff point that has been widely applied in multiple studies

(Sedov et al., 2018) Previous research has used a cutoff of global PSQI score > 8 to identify severe poor sleep quality and applied in clinical samples (Carpenter & Andrykowski, 1998). The PSQI has also been applied in various studies under diverse populations including general adult population, pregnant people, and older adults (Bertolazi et al., 2011; Cole et al., 2006; Qiu et al., 2016).

Epworth Sleepiness Scale (ESS)

The Epworth Sleepiness Scale is a self-rated scale measuring the individual's daytime sleepiness (i.e., alertness). It is an 8-item questionnaire with each item scores from 0 to 3 and an overall score ranging from 0 to 24. The higher ESS score indicates a higher degree of daytime sleepiness (Johns, 1991). Individuals with ESS score over 10 are considered to have excessive daytime sleepiness, and an ESS score of 16 or more suggests a high level of excessive daytime sleepiness (Johns & Hoking, 1997; Johns, 1991). The ESS has acceptable internal consistency (Cronbach's alpha=0.77) for pregnant people and is a validated tool to assess daytime sleepiness (93.5% sensitivity and 100% specificity) (Johns, 2000; Johns, 1992; Tsai et al., 2016).

Insomnia Severity Index (ISI)

The Insomnia Severity Index is a self-reported questionnaire that measures subjective insomnia severity (Morin, 1993). The ISI is a 7-item, four-point scale that measures sleep onset, sleep maintenance, impairments due to sleep problems, sleep problems, and concerns, with the total ISI score ranges from 0 to 28. An ISI score of 8 to 14 is considered subthreshold insomnia, 15 to 21 and 22-28 were classified as clinical insomnia in moderate and severe level, respectively (Morin, 1993). The scale has acceptable internal consistency (Cronbach's alpha=0.74) (Bastien et al., 2001). The ISI is also a validated tool for measuring individuals' insomnia in both community

(95.8% sensitivity and 78.3% specificity) and clinical samples (99.4% sensitivity and 91.8% specificity) with a cutoff score of 8 (Morin et al., 2011).

Sleep diary

A sleep diary is a self-reported tool for collecting information on sleep patterns. It requires participants to fill out the diary every day during the study period. General information obtained through a sleep diary includes bedtime, sleep time, awakenings, final wake time, time left the bed, and self-rated sleep quality (Carney et al., 2012). Sleep diaries have been widely used in clinical and research settings and often accommodate with accelerometers for sleep assessment (Martin & Hakim, 2011). A sleep diary is a reliable tool for assessing sleep quality (Cronbach's alpha=0.73) and has an acceptable agreement with polysomnography and adequate validity (92.3% sensitivity and 95.6% specificity) (Rogers et al., 1993; Schäfer & Bader, 2013).

In summary, each assessment tool was designed to characterize different sleep dimension. For example, the Pittsburgh Sleep Quality Index aims to measure one's sleep satisfaction while the Epworth Sleepiness Scale is used to measure sleepiness. These sleep assessment tools also aim to measure sleep at different time point. For example, polysomnography measures sleep at the specific night and sleep diary collects data on sleep concurrently during the week. Some other sleep assessment tools ask individuals to recall sleep in the past (i.e., PSQI). Therefore, selecting the scales that suit for assessing different sleep dimensions and assessment period of interest is critical. A validated assessment tool for measuring sleep under a multidimensional concept is necessary for better understanding sleep health.

1.2.3 The Epidemiology of Sleep Health During Pregnancy

Pregnancy is when women experience significant physical and mental health changes, especially during the first pregnancy (Signal et al., 2007). There are physical discomforts, mood changes, larger energy consumption, and social expectations during pregnancy and birth. Therefore, having sufficient sleep is crucial during this time. However, those changes in body, mind, and surroundings result in a high prevalence of pregnant people reporting insufficient sleep time and poor sleep quality.

Increased progesterone and estrogen levels during pregnancy result in a decreased time of deep sleep

Women experience hormonal changes in pregnancy that directly and indirectly affect sleep. For example, increased levels of reproductive hormones (i.e., estrogen and progesterone) and endocrinal changes (i.e., increased prolactin and plasma cortisol) during pregnancy are related to reduced rapid eye movement (REM) sleep (Sahota et al., 2003; Santiago et al., 2001). Therefore, it is more challenging to stay in a deep sleep during pregnancy. During the first trimester of pregnancy, the rapid increase in progesterone level also results in morning sickness, a common sleep problem reported in early pregnancy (Lee, 1998).

The dynamic nature of sleep health exists throughout pregnancy

Hormonal changes in early pregnancy and physical changes due to the enlarging uterus in late pregnancy result in the dynamic nature of sleep health throughout pregnancy. Women immediately experience hormonal changes that lead to morning sickness and frequent urination in the first trimester. During this time, poor sleep quality, frequent awakenings, and excessive daytime sleepiness are significantly more prevalent than during the pre-pregnancy state. As pregnancy progresses to the second and third trimester, women experience difficulties maintaining sleep due to joint pain and leg cramps (Lee, 1998). Sleep during this time is also affected by limited sleep position and frequent urination. Pregnant people reported more restless leg syndrome, snoring, and sleep disturbances during the later pregnancy phase (Lee, 1998).

<u>Adverse changes in sleep occur as early as in the first trimester and decline throughout pregnancy</u>

Sleep decline starts in early pregnancy. A longitudinal study of 300 Brazilian pregnant people from outpatient prenatal clinics found significant increases in the percentage of reporting excessive daytime sleepiness and specific awakening. The prevalence of excessive daytime sleepiness increased from 23% in the pre-pregnancy state to 38% in the first trimester. The percentage of women reported with nighttime awakenings also increased from 9% in the prepregnancy state to 72% during the first trimester (Lopes et al., 2004). Similarly, Hedman et al. conducted a longitudinal study that assessed sleep from prepregnancy throughout pregnancy. Another study of pregnant people from rural communities has found a significant increase in restless sleep from prepregnancy (10.1%) to the first trimester of pregnancy (15.4%) (Hedman et al., 2002).

Prior studies have also assessed the prevalence of poor sleep quality (i.e., global Pittsburgh Sleep Quality Index (PSQI) score>5) and compared pre-pregnancy pregnancy. Generally, the prevalence of poor sleep quality in pregnant people increases compared to their prepregnancy states. For example, A cross-sectional postal survey of 650 pregnant people in their third trimester reported over nine times increase in the prevalence of poor sleep quality (38%) compared to the prepregnancy state (4%) (Hutchinson et al., 2012). Another cross-sectional study compared sleep quality between pregnant (n=150 in each second and third trimester) and nonpregnant, childbearing age women (n=300) in Taiwan. The results indicated that pregnant people reported worse sleep quality, sleep efficiency, and more sleep disturbances than nonpregnant people.

Specifically, pregnant people had significantly higher global PSQI scores (6.69±3.33 in the second trimester and 7.07±3.37 in the third trimester) than nonpregnant people (5.92±3.17, $p<0.001$) (Ko et al., 2010).

The adverse changes also occur throughout pregnancy. A cross-sectional study with 2427 pregnant people who completed an internet-based survey has found that the prevalence of poor sleep quality increases from 72% during the second trimester to 83.5% during the third trimester (Mindell et al., 2015). Another cross-sectional study enrolled pregnant people across the first to the third trimesters from prenatal care settings indicated a significantly higher prevalence of perceived sleep disturbances by the end of pregnancy (91.9%) than the pregnant people in their first trimester (66.7%) (Mindell & Jacobson, 2000). The pattern is similar among overweight/obese pregnant people, where the prevalence of poor sleep quality increased from 37% to 63% across pregnancy, and the highest prevalence of poor sleep quality was reported during the third trimester of pregnancy (31-34 weeks gestation) (Conlon et al., 2020).

Sleep duration also decreases as the pregnancy progresses. For example, a cross-sectional study obtained postal survey data from women in their third trimester of pregnancy found that nighttime sleep's average duration decreased from 8.1 hours before pregnancy to 7.5 hours during the third trimester (Hutchinson et al., 2012). Similarly, a cross-sectional internet-based survey of pregnant people from the third trimester found the prevalence of short sleep duration (i.e., total nighttime sleep ≤ 6 hours) increased from 30.3% at the start to 51.4% at the end of pregnancy (Mindell et al., 2015). Specifically, women experience an extreme decrease in sleep duration before birth. A study conducted with a 5-day measurement of sleep among nulliparous pregnant people before delivery found that the average sleep duration decreased from 7.5 hours at baseline to 4.5 hours right before the birth labor (Beebe & Lee, 2007).

In summary, the negative changes in sleep (i.e., decreased sleep quality and sleep duration) are prevalent. Sleep problems emerge as early as in the first trimester and worsen as the pregnancy progresses. The high prevalence of poor sleep quality and short sleep duration raises the attention of examining risk factors for this health consequence in order to promote sleep health during pregnancy and prevent declined sleep health as women enter the later phase of pregnancy. In the next section, we will be discussing risk factors for poor or declining sleep health during pregnancy that were found in previous studies.

1.2.4 Factors Contributing to Poor Sleep Health During Pregnancy

Since poor sleep health is prevalent in pregnant populations, prior research has examined factors that may contribute to poor sleep health in pregnancy. Not only the physical and hormonal changes but also the behavioral changes and shifts in a social role to becoming a mother that contribute to one's poor sleep health during pregnancy. Several factors are associated with sleep during pregnancy. We will be introducing them from individual level to interpersonal relationships, and larger social and physical environment (e.g., neighborhood effects). (Figure 2) We will discuss the association between racial discrimination and sleep health in the later sections.

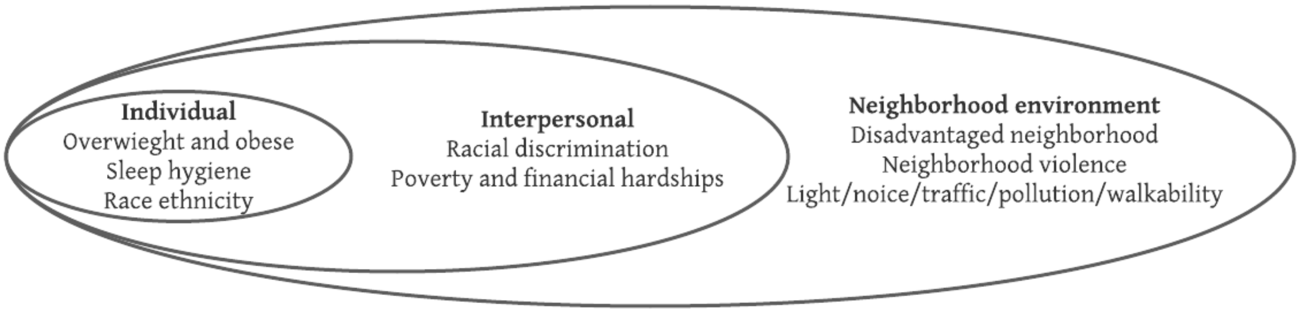

Figure 2. Different Levels of Factors Contributing to Poor Sleep Health During Pregnancy

Overweight and obese women are at higher risks for poor sleep health during pregnancy

Prepregnancy overweight and obesity negatively affect sleep during pregnancy. For example, in a longitudinal study of 2,366 Canadian pregnant people, the prevalence of poor sleep quality was 61.8% among overweight and obese women (i.e., Prepregnancy BMI$\geq$ 25 kg/m^2) compared to 57.5% among women with normal weight (i.e., Prepregnancy 18.5$\leq$BMI<25 kg/m^2). However, the results were no longer statistically significant after the adjustment of sociodemographic factors (Guinhouya et al., 2019). Furthermore, women with excessive gestational weight gain have poorer sleep quality than those with normal gestational weight gain. Gay et al. assessed mean global PSQI scores by gestational weight gain among low-income samples. Women with excessive gestational weight gain had higher global PSQI scores (7.3± 3.3) than women with normal gestational weight gain (6.4 ± 2.6) (Gay et al., 2017).

It is worth noting that snoring is prevalent among overweight and obese pregnant people. Snoring may disrupt one's sleep and results in poor sleep quality, decreased sleep time, fatigue or excessive sleepiness (Bhattacharyya, 2015) In a cross-sectional survey, women with a prepregnancy BMI over 25 were more likely to report snoring (78%) than those with normal BMI (51%) (Hutchinson et al., 2012). Similarly, in a case-control study, women with prepregnancy

BMI over 30 have a higher percentage of snoring episodes during nighttime sleep (32%) than the controls (1%) (Maasilta et al., 2001). Another longitudinal study reported a four-fold increase in the risk of snoring during pregnancy among obese women compared to women with normal weight (Guinhouya et al., 2019).

Poor sleep hygiene potentially affects women's sleep health during pregnancy

Sleep hygiene refers to modifiable behavioral and environmental factors, such as bedtime routine and bedroom temperature, that influence sleep (Hutchinson et al., 2012). Previous studies have widely discussed the influences of sleep hygiene on sleep health among non-pregnant populations, specifically among adolescents and young adults (i.e., college students) (Brown et al., 2002; Brick et al., 2010; LeBourgeois et al., 2005). Recent findings suggest that poor sleep hygiene is associated with poor sleep health during pregnancy and the intervention of sleep hygiene education in early pregnancy is beneficial for improving maternal sleep health (Ferraro et al., 2014). For example, an observational study from Taiwan found pregnant people who reported poor sleep are more likely to have higher arousal behaviors (i.e., time spent on screen in bed) during bedtime and more disturbed sleep environment (i.e., noisy bedroom). A systematic review on the management of sleep disorders suggested sleep hygiene changes (i.e., regular sleep schedule, moderate exercise and stretching, reduce the exposure to dietary stimulants) as one of the strategies to reduce insomnia levels in pregnancy (Nodine & Matthews, 2013).

Poor sleep health is prevalent across racial groups

Generally, prior research on racial differences in sleep during pregnancy tends to find that African American women have worse sleep than whites. However, the association between race and sleep is mixed. A biracial sample of 133 women found that the prevalence of poor sleep quality increases among multiparous African American women throughout pregnancy, from 58% in the first trimester to 70% in the third trimester. However, this pattern only applied among multiparous African Americans but not in white multiparous women, for whom the prevalence of poor sleep quality was 61% in the first trimester to 54% in the third trimester (Christian et al., 2019). Another cross-sectional study in Metro Detroit, US with 267 pregnant people found 38.4% reported short sleep duration among African Americans, which is significantly higher than whites (17.4%). Furthermore, 82.2% of African American women reported poor sleep quality compared to 74.8% among whites. These differences were not statistically significant between the two racial groups (Kalmbach et al., 2019). However, racial differences in sleep duration were observed in a nationally representative sample. A study using data from the National Health Interview Survey (2004-2017) found that African American pregnant people have a significantly higher prevalence of short sleep duration than white pregnant people (Prevalence ratio=1.35, 95%CI: 1.08-1.67) (Feinstein et al., 2020).

Poor sleep health is also highly prevalent and declined throughout pregnancy in other racial groups. A cross-sectional study of 400 pregnant Taiwanese women found that 65.5% reported poor sleep quality. (Hung et al., 2013). In a study of 192 Japanese women, 88% reported negative changes in sleep during pregnancy (Suzuki et al., 1994). Another prospective cohort study of 748 Korean pregnant people reported the prevalence of poor sleep quality around 98% throughout pregnancy (Ko et al., 2012).

In summary, poor sleep quality during pregnancy is prevalent across racial groups, ranging from 54% to 98%. Declined sleep health was seen among multiparous African American women (Christian et al., 2019). However, the results were mixed and racial differences were attenuated after adjusted for the experiences of racial discrimination.

<u>Socioeconomic disparities affect sleep health during pregnancy</u>

Women with low socioeconomic status (i.e., low income, educational level, unemployment) tend to have a higher prevalence of poor sleep quality during pregnancy. Kalmbach et al.'s conducted a cross-sectional study of 267 pregnant people from Metro Detroit for completing an online survey regarding sleep health has found poorer sleep quality (i.e., higher average global PSQI score) among women below the poverty line (i.e., annual household income < $20,000) than those above the poverty line (9.73±4.11 vs. 7.98±3.58). The prevalence of poor sleep quality was not significantly different between the two groups (82.2% VS. 74.8%). However, women below the poverty line had a significantly higher prevalence of clinically-defined poor sleep quality (i.e., PSQI>8) than the group above the poverty line (66.7% vs. 38.8%) (Kalmbach et al., 2019). Another longitudinal study of 170 pregnant people at 10-20 weeks gestation who resided in the greater Pittsburgh area found lower household income (<$50,000/year) was associated with poor sleep quality and sleep fragmentation (Okun et al., 2014). Populations experiencing poverty or low income are more likely to be stressed, leading to frequent nocturnal arousal (Grandner et al., 2010; Stamatakis et al., 2007). Lower household incomes are related to a higher level of poor sleep quality (Arber et al., 2009; Soltani et al., 2012). Unemployment status, low educational level, and poor health status are also strong determinants to poor sleep quality (Patel et al., 2010).

<u>Disadvantaged and noisy neighborhoods negatively affect sleep health during pregnancy</u>

A growing body of research found that neighborhood context affects an individual's health outcomes (Duncan & Kawachi, 2018). Research on the association between neighborhood-level factors such as neighborhood violence, social capital, noise, light, traffic and walkability and poor sleep health is novel. There are still limited findings on neighborhood effects on sleep health during pregnancy. Prior studies suggested that residing in a disadvantaged neighborhood is linked to one's social demographics, social connection, and environment (i.e., residential segregation, neighborhood noises) that potentially impact one's sleep health (Johnson et al., 2018). For example, a cross-sectional survey of a rural Japanese community sample found that the lower social capital neighborhoods have a 22% higher prevalence of short sleep duration than neighborhoods with higher social capital (Prevalence ratio=1.22, 95%CI: 1.08-1.38) (Win et al., 2018). A cross-sectional survey on maternal health in Baltimore, US found that mothers who reported high exposure to neighborhood violence are at higher odds of sleep disturbances than those with low exposure to neighborhood violence (OR=2.38 95%CI: 1.46-2.66) (Johnson et al., 2009). Environmental exposures in neighborhoods such as light and noise also contribute to poor sleep health, which includes insufficient sleep and excessive daytime sleepiness (Basner et al., 2008; Basner et al., 2010; Johnson et al., 2018). In a German sample of 24 adults, objective sleepiness increased with the number of noise events (β=0.0012, p=0.021) and the maximum sound level of noise events (β=0.0039, p=0.028) (Basner et al., 2008). A recent review indicated that stronger exposure to light, noise, poorer traffic, higher pollution, and lower walkability in a neighborhood are related to residents' sleep health (Johnson et al., 2018).

In summary, neighborhood-level effects, from social connection, poverty, and safety to environmental factors such as noise and light pollution, impact an individual's sleep health. In the next section, we will be discussing health consequences associated with poor sleep health during pregnancy. These found associations between poor sleep health and poor pregnancy and labor outcomes will highlight the importance of promoting sleep health during pregnancy.

1.2.5 Health Consequences Associated with Poor Sleep Health During Pregnancy

Poor sleep during pregnancy is not merely a common complaint. In fact, it is associated with a series of health outcomes. When poor sleep health occurs in pregnancy, it will relate to pregnancy and birth outcomes that may impact maternal and child health. Here in this section, we will be focusing on some pregnancy complications and labor outcomes that may directly influence maternal health.

Sleep loss is associated with increased inflammation, which will further induce gestational hypertension

Sleep loss is associated with the pathophysiological pathways to stress (Palagini et al., 2014). Women who experience sleep disturbance during pregnancy show an increased inflammatory response, which are related to an increased risk for pregnancy complications (Okun et al., 2007; Roca et al., 2020). For example, in a prospective study of 89 Japanese primiparous pregnant people, poor sleepers had higher morning systolic blood pressure (7.1±7.0 mmHg) than normal sleepers (3.0±5.6 mmHg, $p<0.01$). (Okada et al., 2019). Similar results apply in the US sample. Okun & O'Brien's study of 439 singleton pregnant people in the third trimester from prenatal clinics in Michigan, US has found that women with reported insomnia and habitual snoring are at higher odds of gestational hypertension than those without (OR=3.2, 95%CI: 1.0-10.6) (Okun et al., 2018). Other studies with a high-risk pregnant sample and a nulliparous pregnant sample supported that there is an association between sleep disorders (i.e., sleep-disordered breathing) and high blood pressure during pregnancy (Champagne et al., 2009; Facco et al., 2017).

Poor sleep negatively impacts glucose metabolism and increases the risk for gestational diabetes

Poor sleep is associated with glucose metabolism, leading to insulin resistance, glucose intolerance, and type 2 diabetes (Gottlieb et al., 2005; Spiegel et al., 2005; Zizi et al., 2010). While poor sleep is highly prevalent among pregnant people due to physical and hormonal changes, recent studies have examined the relationship between poor sleep and glucose metabolism during pregnancy. For example, a study of 169 pregnant people from Chicago, US found 4% increase in glucose levels with every hour of sleep loss during the second trimester of pregnancy (Reutrakul et al., 2011). Another US sample of 189 pregnant people also found that short sleep duration (<7 hours) was associated with higher glucose tolerance values (p=0.008) and a higher risk of gestational diabetes (p=0.009) (Facco et al., 2010) Studies targeting different populations also share similar results. A study of 686 Asian pregnant people found that self-reported poor sleepers (PSQI>5) and short sleep duration (<6 hours) were associated with higher odds of diagnosed with gestational diabetes (OR=1.75, 95%CI: 1.11-2.76, and OR=1.96, 95%CI: 1.05-3.66, respectively) (Cai et al., 2017).

While some studies suggested that poor sleep quality and short sleep duration are associated with higher risks of gestational diabetes, other studies found the impact of sleep duration on gestational diabetes among women with extreme sleep duration. A recent meta-analysis found that extreme sleep duration during the first and second trimesters was associated with incident gestational diabetes (OR=1.28, 95%CI: 1.10-1.49), but not short sleep duration (OR=1.58, 95%CI: 0.99-2.52) (Xu et al., 2018).

<u>The induced inflammatory responses from poor sleep during pregnancy are associated with poor labor outcomes</u>

Poor sleep leads to increased inflammation responses and further impacts labor outcomes. A cross-sectional study from Tehran, Iran, recruited 457 singleton women over 37 weeks gestation indicated a significant correlation between short sleep duration and types of delivery. The percentage of undergoing spontaneous vaginal delivery is higher among women with sufficient sleep (15.8%) than those who reported sleep duration less than 8 hours at night (12.3%, p=0.018) (Zafarghandi et al., 2012). Longitudinal studies that assessed sleep during the last month of pregnancy also share similar results. A prospective study of a US sample included 131 women in their last month of pregnancy indicated that short sleep duration (<6 hours) is related to 4.5 times higher odds in cesarean delivery (OR=4.54, 95%CI: 1.36-15.21) and significantly longer labor (29.0±12.5 hours) than women with over 7 hours of nighttime sleep (17.7±15.6, p=0. 025) (Lee & Gay, 2004) Another prospective study from Malaysia recruited singleton women admitted for labor induction found that self-reported sleep duration during the last month of pregnancy less than 6 hours was associated with a higher risk of cesarean delivery (RR=2.4, 95%CI: 1.1-5.0) (Teong et al., 2017). A longitudinal study of 550 Iran women in their 36th-week gestation indicated that women who reported poor sleep quality had significantly longer labor than normal sleepers (11.87±4.32 vs. 8.83±3.05 hours, p=0.016). The proportion of women receiving cesarean delivery is higher among women who reported poor sleep quality (63.1%) than normal sleepers (41.6%, p<0.001) (Naghi et al., 2011).

1.2.6 Current Research in Sleep Health During Pregnancy

<u>Prior research primarily used sleep efficiency and duration to represent sleep health during pregnancy, but the knowledge about sleep regularity, timing, and alertness are limited</u>

While there are multiple aspects to quantify an individual's sleep health, previous studies have commonly applied sleep efficiency, sleep duration, and sleep quality defined through validated scales to represent sleep health. However, the patterns on other sleep dimensions (i.e., sleep timing and regularity) are limited while there is an association between those sleep dimensions (i.e., later sleep timing) and pregnancy complications (i.e., gestational diabetes) (Facco et al., 2015). A recent systematic review from Ladyman & Signal included 24 articles that quantify sleep health during pregnancy. 50% of the studies targeted women in the third trimester of pregnancy. 13 out of 24 studies were based on a US sample (Ladyman & Signal, 2019).

Table 1 shows the sleep parameters assessed among previous studies quantifying pregnant people's sleep health based on Ladyman & signal's review. The table helps us understand what sleep dimensions are more discussed and what is not. We identify those sleep parameters based on multidimensional sleep health, which includes six dimensions: duration, efficiency, timing, regularity, alertness, and satisfaction (Buysse, 2014). Generally, previous studies commonly assessed sleep duration and efficiency among pregnant populations, which were covered in approximately 92 and 88% of the articles, respectively; followed by 62% in sleep quality and satisfaction, which were usually assessed through the Pittsburgh Sleep Quality Index (PSQI). One-fourth of the articles have included alertness as one of the parameters for sleep health assessment. 16.7% of the articles quantified sleep timing in the studies, and none of the studies have included sleep regularity for quantifying sleep health (Ladyman & Signal, 2019).

<u>There are limited findings on how each sleep dimension changes throughout pregnancy</u>

The dynamic nature of sleep exists throughout pregnancy, the causes of poor sleep health and the characteristics of each sleep dimension changes throughout pregnancy. For example, morning sickness is prevalent in early pregnancy and increases sleep disturbances in the first trimester (Ferraro et al., 2014). Frequent urination is common throughout pregnancy, which results in increased nighttime awakenings across all trimesters (Mindell et al., 2015) Physical changes in the third trimester limit one's sleep position and increase the prevalence of sleep-disordered breathing and restless leg syndrome (Mindell et al., 2015). The patterns of declined sleep quality and sleep duration indicate poor sleep health during pregnancy. However, we have limited knowledge on the patterns of other sleep dimensions such as alertness, sleep timing and regularity during pregnancy. Furthermore, sleep regularity and timing are critical components in behavioral training for sleep improvement, but these dimensions were not well characterized among pregnant populations. While sleep research have applied the concept of multidimensional sleep health in other populations such as adolescents and the elderly, the patterns of multidimensional sleep health in pregnancy are still unclear (Dong et al., 2019; Ladyman & Signal, 2019; Wallace et al., 2019). Understanding the patterns of sleep during pregnancy under multiple dimensions is important for characterizing sleep health during pregnancy, which is beneficial for better targeting sleep improvement during pregnancy. Thus, we will describe the overall multidimensional sleep health and changes in each sleep dimension from early to mid-pregnancy to better understand sleep patterns during pregnancy.

Table 1. Sleep Parameters Assessed Among Studies Quantifying Pregnant People's Sleep Health (Adapted from Ladyman & Signal, 2018)

	N	Assessment Timing	Sleep assessment	Duration	Efficiency	Timing	Regularity	Alertness	Satisfaction
Baker et al., 2016	172	First and second trimesters	Actigraphy; PSQI	Y	Y				Y
Brunneret al., 1994	9	All three trimesters	In-lab polysomnography	Y	Y				
Crowley et al., 2016	14	Second trimester	Actigraphy; PSQI		Y				Y
Ebert et al., 2015	161	First and second trimesters	Actigraphy	Y	Y				
Elek et al., 1997	24	Third trimester	Actigraphy; Visual Analog Scale-Fatigue	Y	Y				
Haney et al., 2014	161	First and second trimesters	Actigraphy	Y	Y				
Hertz et al., 1992	12	Third trimester	In-lab polysomnography; Stanford Sleepiness Scale	Y				Y	Y
Hux et al., 2017	103	First trimester	PSQI						Y
Lee, McEnany & Zaffke, 2000	31	Third trimester	In-home polysomnography; Profile of Mood States	Y	Y				
Lee, Zaffke & McEnany, 2000	33	First and third trimesters	In-home polysomnography	Y	Y				
Okun et al., 2015	143	First and second trimesters	Actigraphy; PSQI; Insomnia Symptom Questionnaire	Y	Y	Y			Y
Strange et al., 2009	220	Second trimester	PSQI; ESS	Y	Y			Y	Y
Tsai et al., 2017	204	All three trimesters	Actigraphy; PSQI; ESS	Y	Y			Y	Y
Tsai, Lin & Wu et al., 2016	274	Third trimester	Actigraphy; PSQI; ESS	Y	Y			Y	Y
Tsai, Lee & Lin et al., 2016	164	All three trimesters	Actigraphy; PSQI	Y	Y				Y
Tsai, Lee & Wu et al., 2016	197	Third trimester	Actigraphy; PSQI; Sleep Hygiene Practice Scale	Y	Y				
Tsai, Kuo & Lee et al., 2013	30	Third trimester	Actigraphy; PSQI	Y	Y				Y
Tsai, Lin & Kuo et al., 2013	120	Third trimester	Actigraphy; PSQI	Y	Y				Y
Tsai et al., 2012	38	Third trimester	Actigraphy; PSQI; Visual Analog Scale-Fatigue	Y	Y	Y		Y	Y
Tsai et al., 2011	30	Third trimester	Actigraphy; PSQI	Y	Y	Y			Y
Tzeng et al., 2015	139	Third trimester	PSQI; Fatigue Continuum Form	Y	Y			Y	Y
Waters & Lee, 1996	31	Third trimester	Polysomnography; Visual Analog Scale-Fatigue		Y				
Wilson et al., 2011	48	First and third trimester	In-lab polysomnography; Self-developed questionnaire	Y	Y				Y
Wolfson et al., 2003	38	Third trimester	Sleep diary	Y	Y	Y			
		Coverage*		**87.5%**	**91.7%**	**16.7%**	**0%**	**25%**	**62.5%**

*Coverage is calculated by the number of studies measured the specific sleep dimension divided by the overall number of studies listed in this table

Since poor sleep health is highly prevalent among pregnant people and is associated with poor pregnancy and labor outcomes, researchers have been examining risk factors for poor sleep health to inform possible sleep promotion strategies in pregnancy. There is a wide consensus that sleep and mental health are closely connected. For example, the diagnostic criteria of depression have included sleep disturbances as one of the symptoms. While sleep may be one of the symptoms of depression, there are limited findings on the direction of the association between sleep and mental health.

Due to physical, hormonal and social role changes in pregnancy, pregnant people are at risk for depressive episodes that occur specifically during pregnancy, which is known as prenatal depression. In the following sections, we will first introduce the epidemiology of prenatal depression and then go through current research on sleep and mental health during pregnancy. Finally, we will identify research gaps from prior research on the association between mental health and sleep health during pregnancy. Though prior studies may target at perinatal period, which includes the time during pregnancy to one year postpartum, we will be specifically discussing study results that focus on the prenatal period. We will specify the perinatal populations when the results were only available in the full perinatal period.

1.3 Prenatal Depression

Next, we will mention the epidemiology, measurement tools for prenatal depression. We will also discuss the relationships and hypothesized mechanisms between depression and sleep health

1.3.1 The Epidemiology of Prenatal Depression

Prenatal depression refers to the depression that occurs specifically during pregnancy. Hormonal changes among females at different life stages strongly affect the risk for affective disorders (Parry & Newtown, 2001). Specifically, women experience substantial physical and hormonal changes during pregnancy that may lead to body discomfort and increased vulnerability to depressive symptoms (Robert, 1996). Prenatal depression may be the first, new onset of a depressive episode for some women, while some with mental illness before pregnancy may at higher risks for experiencing depression during pregnancy (Nonacs & Cohen, 2002). Some depressive symptoms that pregnant people may experience include frequent crying, sleep disturbance, low energy, increased worry, loss of interest (American Psychiatric Association, 2013).

As prenatal depression is one of the unique mental health issues in pregnancy, the prevalence of prenatal depression has been widely assessed in different populations. A systematic review identified 21 articles assessing the prevalence of prenatal depression and reported the average prevalence of prenatal depression (i.e., assessed through the EPDS) for each trimester: 7.4% (95%CI: 2.2-12.6%) in the first trimester, 12.8% (95%CI: 10.7-14.8%) in the second trimester, and 12.0% (95%CI: 7.4-16.7%) in the third trimester (Bennett et al., 2004). Another systematic review included 26 articles with low-risk pregnant people over 17 years of age and recruited from prenatal clinics has found the lowest prevalence of prenatal depression (i.e., mainly assessed through the Beck Depression Inventory (BDI) or EPDS) in the second trimester (6.6%) and the highest in the third trimester (26.7%) (Okagbue et al., 2019). Based on these findings, the prevalence of prenatal depression was the highest in late pregnancy. Another systematic review included 28 articles from developed countries that assessed major and minor depression combined in pregnancy reported the prevalence in the first trimester was 11.0% and 8.5% in the second and the third trimester (Gavin et al., 2005). This shows a different trend than the previous systematic review. However, these mixed results may due to the different measurement or cutoffs of depression in pregnancy. Specifically, the Gavcin et al.'s review only included studies measuring both major and minor depression in pregnancy and excluded those with self-reported depressive symptoms only. In summary, the prevalence of prenatal depression is substantial.

1.3.2 Measurement of Prenatal Depression

In this section, we will be discussing some assessment tools for depression. Briefly, there are two types of assessment tool, one conducted through interviews and the other type as self-reported scales. Though the assessment tools such as Structured Clinical Interview for DSM-5, Beck Depression Inventory, and Self-rated Depression Scale, are applicable in general populations, these tools have also been applied in pregnant populations for assessing prenatal depression from previous studies. The following tools introduced were frequently used in prior research. In the dissertation analyses, we will be using the Edinburgh Postnatal Depression Scale (EPDS) for assessing women's depressive symptoms in early pregnancy.

<u>Interviews</u>

Structured Clinical Interview for DSM-5 (SCID)

The Standardized Clinical Interview for Diagnostic and Statistical Manual of Mental Disorder-Fifth edition (DSM-5) is a tool for diagnosing major depressive disorders. The trained interviewers will obtain interviewee's answers to the standardized questions and differentiate the normal or depressive reactions. The interviewers will identify whether or not the interviewees are meet the DSM-5 diagnostic criteria for depression (First et al., 2015).

Self-reported questionnaires

Edinburgh Postnatal Depression Scale (EPDS)

The Edinburgh Postnatal Depression Scale is one of the most often used self-reported screening tool for perinatal depression. It is a 10-item, four-point scale (scored 0 to 3) that assess perinatal women's depressive symptoms in the last 7 days. The overall EPDS score ranges from 0-30, with a higher score indicates a higher level of perinatal depressive symptoms (Cox et al., 1987) The scale has been widely validated in multiple language versions and applied in different populations worldwide (Cox et al., 1996; Heh, 2001; Garcia-Esteve et al., 2003; Adouard et al., 2005; Montazeri et al., 2007). The EPDS has adequate internal consistency in assessing depression among pregnant people (Cronbach's alpha=0.82) and is also a validated tool to assess depressive symptoms during pregnancy with diverse populations (Bergink et al., 2011; Rubertsson et al., 2011; Su et al., 2007). According to a recent paper validating EPDS among pregnant people, the cutoff score of 11 in the first trimester (79% sensitivity and 97% specificity) and a cutoff at 10 in the second trimesters (70% sensitivity and 96% specificity) performed with the best sensitivity and specificity for detecting women with depressive symptoms during pregnancy (Bergink et al., 2011).

Beck Depression Inventory (BDI)

The Beck Depression Inventory (BDI) is a self-reported scale that assesses depressive symptoms in the past two weeks from clinical and non-clinical samples (Beck et al., 1961) It is a 21-item questionnaire under a 4-point scale. The overall score of BDI can range from 0 to 63, with a higher score indicates more substantial depressive symptoms (Beck et al., 1961) Prior studies targeting non-clinical samples adopted a cutoff score at 10 as the detection of depression (70-86%

sensitivity and 57-87% specificity) (Wang et al., 2013). The BDI also performs sufficient internal consistency (Cronbach's alpha=0.85) (Wang et al., 2013).

Self-Rating Depression Scale (SDS)

The Self-Rating Depression Scale (SDS) is a self-reported scale consisting of 20 items that measure each depressive symptom's frequency (Zung, 1965). Participants will answer each item on a four-point scale for each item. The overall SDS score ranges from 20-80, and a standardized score ranges from 25-100 (multiplied by 1.25), with the higher score indicates more substantial depressive symptoms (Zung, 1965). The SDS has adequate internal consistency in both depressed (Cronbach's alpha=0.88) and non-depressed samples (Cronbach's alpha=0.93) (Gabrys & Peters, 1985). A standardized score between 50 to 69 is categorized as mild to major depression; individuals scored over 70 are likely with severe depression (Halfaker et al., 2011) The sensitivity and specificity of SDS were 80 and 78%, respectively, indicating adequate validity for assessing depression among pregnant people (Kitamura et al., 1999).

1.3.3 Prenatal Depression and Sleep Health During Pregnancy

<u>Research has widely discussed the shared biological and behavioral mechanisms between depression and sleep health</u>

The association between mental health and sleep is not merely a cause-effect relationship. Emerging evidence has supported a more complex bidirectional relationship between depression and sleep (Fang et al., 2019) Sleep regulated by the brain stem and thalamic nuclei regulation and limbic movement that controls the arousal behaviors are part of both sleep deprivation and depression mechanisms (Brown et al., 2012) Sleep deprivation is also one of the symptoms of multiple mental disorders (Perlis et al., 1997).

Studies have explained potential biological and behavioral pathways between sleep and depression:

1. Both insufficient sleep and depression increase the inflammation response and neurotransmitters level.

A wake-sleep schedule plays a critical role in regulating individuals' inflammatory responses (Irwin et al., 2008). Sleep deficiency will activate the sympathetic nervous system and β-adrenergic signaling, which will activate the inflammation response and further increase cellular inflammation (i.e., increases in inflammatory cytokines—IL-6) (Irwin & Cole, 2011; Irwin et al., 2018). Such increase in cellular inflammation is also commonly seen among depressed patients and more obvious in females (Gimeno et al., 2009; Miller et al., 2009). A randomized controlled trial found the treatment for reducing this inflammation response will also reduce depressive symptoms (Raison et al., 2013) Furthermore, abnormal REM sleep circles and depression share the same type of monoamine neurotransmitters (Irwin et al., 2018) Depressed patients often show the sign of reduced REM sleep and impaired sleep continuity, this tendency is related to a series of increased levels of monoamines (i.e., serotonin) (Steiger & Pawlowski, 2019).

2. Both sleep and depressive disorders shared a significant portion of genetic influences.

Recent studies have also found that dopamine-related genes are related to sleep duration (Harvey, 2000; Rhodes et al., 2019). A longitudinal twin study (n=7,500) indicated that the genetic factors (i.e., Chr7, rs186736700) are associated with insomnia symptoms and more females (Lind et al., 2015; Stein et al., 2018). Similarly, a family history of mental illness is also a significant risk factor for depression (Sullivan et al., 2000). Studies have found a great degree of concordance between sleep disorders and depression in both monozygotic and dizygotic twins (Gehrman et al.,

2011) The overlapping genetic influences on sleep were shared significantly with depression in both genders in a human sample (56% in females and 74% in males) (Lind et al., 2015).

3. Sleep deprivation is a major symptom among people with depression.

The relationship between depression and poor sleep health is strong with the overlapping symptoms on difficulties in initiating or maintaining sleep among individuals with depression (Hamilton, 1989; Yates et al., 2007). While sleep disturbances are typical symptoms of depression, it may also be the stress and depressive moods that leads to poor sleep health. The uncertainty of whether poor sleep health or depressive symptom precedes one another increases the difficulty in understanding the cause-effect relationship between sleep disturbances and depression (Franzen & Buysse, 2008). The prevalence of poor sleep health among people with depression has been widely assessed in previous studies. For example, a secondary analysis on a US-based sample with depression patients has found that individuals with recurrent depression had significantly higher percentage of complaints about sleep disturbances for 2 or more weeks (85.7%) than non-recurrent individuals (28.7%, $p<0.05$). A survey in UK on sleep difficulties and depressive among people with depression (n=513) showed that 97% of the participants reported any of the sleep disturbance symptoms (i.e., can't fall asleep, keep waking up at night, wake up early but can't get back to sleep, sleep for too long) (Paterson et al., 2009).

In summary, the high percentages of poor sleep health reported among individuals with depression supported the overlapping symptoms between these two health issues.

<u>The shared pathophysiological mechanisms in the relationship between sleep and prenatal depression similarly apply during pregnancy</u>

The pathophysiological pathways for poor sleep health during pregnancy aligned with the potential biological pathways mentioned above. Specifically, pregnant people are already at a higher inflammatory state (i.e, C-reactive protein and interleukin-6) than non-pregnant people (Carroll et al., 2019). Poor sleep during pregnancy is associated with increased inflammatory responses that result in inflated cytokine production (Carroll et al., 2019). Such an effect was more often seen in African American women compared to whites (Christian et al., 2018), There was a weak association between inflammatory markers and prenatal depression (Blackmore et al., 2011). Specifically, a study with 187 African American women found IL-6 significantly associated with depressive symptoms. However, the association was no longer significant among overweight/obese women (Cassidy-Bushrow et al., 2012). The biological mechanisms are similar to nonpregnant adults, except pregnant people already at a higher inflammatory state, which may increase the vulnerability to poor sleep and mental health.

<u>Previous studies have focused on how sleep influences prenatal depression during pregnancy, but little is known about the impacts of prenatal depression on poor sleep health</u>

There have been some studies focusing on how poor sleep health affects prenatal depression (Swanson et al., 2011; Field et al., 2007; Tomfohr et al., 2015). A study sample of mental health treatment-seeking women found insomnia symptoms affect their levels of depressive symptoms during pregnancy, specifically in the difficulties falling asleep (Swanson et al., 2011) Another longitudinal study supports a similar conclusion during mid to late pregnancy. Depressed women have a deteriorating sleep during the second and the third trimesters. They were also experiencing increased depressive symptoms during this time of pregnancy (Field et al., 2007). In summary, pregnant people experiencing a significant decline in sleep are more likely to see greater depression symptoms during pregnancy (Tomfohr et al., 2015). Under a study of 1825 Chinese pregnant people, the results indicated that sleep disturbances (difficulties in initiating and maintaining sleep) and poor sleep quality were associated with higher depression than people with good sleep quality (Zhang et al., 2021). Recent sleep research has targeted non-pregnant population and examined the association between depression and sleep with the implementation of multidimensional sleep health as an outcome. A recent study examined the longitudinal association between depressive symptoms and multidimensional sleep health among middle-aged women. The results indicated the association between higher depressive symptoms and poorer multidimensional sleep health, lower alertness, and satisfaction (Bowman et al., 2021).

Few studies are assessing how depression during pregnancy affect prenatal sleep health. A longitudinal study defined prenatal depression using the Structured Clinical Interview for DSM-IV diagnosis of major depressive disorder. The results found that depressed pregnant people were more likely to experience fragmented sleep. This association was more pronounced during the first and the second trimesters (Okun et al., 2011). Another study found more frequent nocturnal awakenings and difficulties in falling asleep in the third trimester among women with reported depressive symptoms (Ruiz-Robledillo et al., 2015). While poor sleep health is highly prevalent among pregnant populations, understanding whether prenatal depression is a risk factor for poor sleep health during pregnancy is necessary for targeting the high-risk subgroup to poor sleep health. Also, more sleep parameters require a more comprehensive assessment to understand the causality between mental health and sleep during pregnancy.

<u>In studies assessing the relationship between sleep and prenatal depression, none have assessed sleep timing and regularity or composite scoring to quantify multidimensional sleep health</u>

Table 2 listed articles that were assessing the relationship between sleep and prenatal depression. The Edinburgh Postnatal Depression Scale (EPDS) is a common scale in assessing prenatal depressive symptoms (Gao et al., 2019; Jomeen et al., 2007; Polo-Kantola et al., 2017; Tomfohr et al., 2015). To assess sleep health during pregnancy, 70% of the studies assessed sleep with sleep satisfaction or quality, followed by 30% measured sleep duration. Over half of the studies that assessed sleep quality applied PSQI for the measurement (Gao et al., 2019; Jomeen et al., 2007; Skouteris et al., 2008; Tomfohr et al., 2015). None of the studies assessing sleep and prenatal depression included sleep timing and regularity.

Table 2. Sleep Parameters Assessed Among Studies Assessing the Relationship Between Prenatal Depression and Sleep During Pregnancy

Studies	Study design	Study population	N	Assessment Timing	Mental health assessment	Duration	Efficiency	Timing	Regularity	Alertness	Satisfaction	Results
Field et al., 2007	Prospective	Low-income pregnant women	253	Second and third trimesters	SCID						Y	Depressed women had more sleep disturbances in the second (p=0.03) trimester
Gao et al., 2019	Longitudinal (postpartum)	Singleton pregnant women	1152	Second trimester	PPS (>0); EPDS (≥9)						Y	Poor sleep quality in the second trimester is associated with stress and depression among women over 30 years old (OR=4.12. 95%CI: 2.18-7.78).
Jomeen & Martin, 2007	Cross-sectional	Pregnant women without preexisting complications	148	14 weeks of gestation	EPDS (≥9)	Y	Y				Y	Depressed women had significantly higher PSQI score than non-depressed women (6.21±2.8 vs. 3.23±2.08, p<0.001).
Okun et al., 2011	Longitudinal	Pregnant women without preexisting depression	240	20, 30, 36 weeks of gestation	SCID; HDRS (≥18)	Y	Y					The strongest difference was observed at week 20. Non-depressed women had higher sleep efficiency (89.1%) compared to depressed women (78.2%) (p<.0001)
Polo-Kantola et al., 2016	Prospective	Pregnant women without preexisting complications	78	12-25, 31-39 weeks of gestation	EPDS	Y				Y	Y	Women with poor sleep quality had higher depression score (8.9±4.5) than women with normal sleep (4.1±3.3) (p<.001)
Ruiz-Robledillo 2015	Cross-sectional	Pregnant women from outpatient prenatal clinics	143	Third trimester	EPDS	Y				Y		Depressed women experienced more frequent awakenings (1.23±1.23 vs. 0.81±0.89/times) and took longer time to fall asleep (1.97±1.69 vs. 1.33±1.54/hour)
Skouteris et al., 2008	Longitudinal	Nulliparous and multiparous pregnant women	273	15-23, 23-31, 31-39 weeks of gestation	BDI (>3)						Y	There was a strong correlation between sleep quality in early pregnancy and depressive symptoms at later stage in pregnancy (p<0.001)

Table 2. **Sleep Parameters Assessed Among Studies Assessing the Relationship Between Prenatal Depression and Sleep During Pregnancy**

pregnancy (cont.)

Studies	Study design	Study population	N	Assessment Timing	Mental health assessment	Duration	Efficiency	Timing	Regularity	Alertness	Satisfaction	Results
Swanson et al., 2011	Cross-sectional	Pregnant women from an outpatient psychiatric clinic	257	Across all trimesters	EPDS							Women with clinically significant insomnia scores had higher odds of reported depression (OR=7.7, 95%CI: 3.76-15.78).
Tomfohr et al., 2015	Longitudinal	Pregnant women without preexisting complications	293	<22, 32 weeks of gestation	EPDS (≥12)						Y	Women reported decline in sleep health reported a larger proportion of EPDS ≥12 (31%) than women with consistently good sleep (3.4%)
Yu, 2017	Longitudinal	Pregnant women without preexisting complications	1653	8-13, 26-30, 34-38 weeks of gestation	Self-rating depression scale (≥53)	Y					Y	There were significant associations between sleep quality and depression during pregnancy in both cross-sectional (p<.0001) and longitudinal analyses (p<.0001)
Coverage						**30%**	**10%**	**0%**	**0%**	**10%**	**70%**	

*Structured clinical interview for depression diagnosis (SCID); Pregnancy Pressure Scale (PPS); Edinburgh Postnatal Depression Scale (EPDS); Hamilton Depression Rating Scale (HDRS); Beck Depression Inventory (BDI)

While public health research has been focusing on racial disparities in health outcomes, including sleep and mental health, experiences of racial discrimination are important underlying factors that influence one's sleep health and mental health. In the next section, we will briefly discuss what racial discrimination is and the role of racial discrimination in the association between depression and sleep health during pregnancy.

1.4 Racism and Racial Discrimination

Racism is a system that is structured to assign value and opportunity based on race. This can manifest as certain racial groups being seen as superior (e.g.., white supremacy) or inferior. It leads to negative beliefs (i.e., prejudice) and differential treatment (i.e., discrimination) towards groups by other individuals and social institutions (Bonilla-Silva, 1996; Grosfoguel, 2011; Grosfoguel, 2016; Williams, 1997). In the next sections, we will discuss the definition of racism and racial discrimination, measurement tools of racial discrimination, and previous findings on racial disparities in mental health and sleep health in pregnancy.

1.4.1 The Introduction of Racism and Racial Discrimination

Racism creates a global hierarchy of supremacy and inferiority based on race markers that develops prejudice and discrimination toward race

Racism is a system that is structured to assign value and opportunity based on race. This can manifest as certain racial groups being seen as superior (e.g.., white supremacy) or inferior

(Jones, 2000) (Bonilla-Silva, 1996; Grosfoguel, 2011; Grosfoguel, 2016; Jones, 2000; Williams, 1997).

Jones presented a theoretic framework that explain racism in three levels: Institutional racism, personally mediated racism, and internalized racism (Jones, 2000). Institutional racism exists through law legislation, policies, and residential segregation. Some examples of institutional racism include differential access to education and housing (Mendez et al., 2011; Mendez et al., 2013; Riley, 2018). Personally mediated racism indicates the prejudice and discrimination in the interpersonal life experiences based on one's race-ethnicity. The examples of personally mediated racism include lack of respect, suspicion towards criminal acts, and devaluation of individuals (McLemore et al., 2018). Internalized racism refers to the acceptance of the forms of discrimination by the individuals who are stigmatized and/or hold negative messages toward themselves (i.e., self-devaluation). The examples of internalized racism include self-devaluation and elevating "whiteness" as the norm (Jones, 2000). (Figure 3)

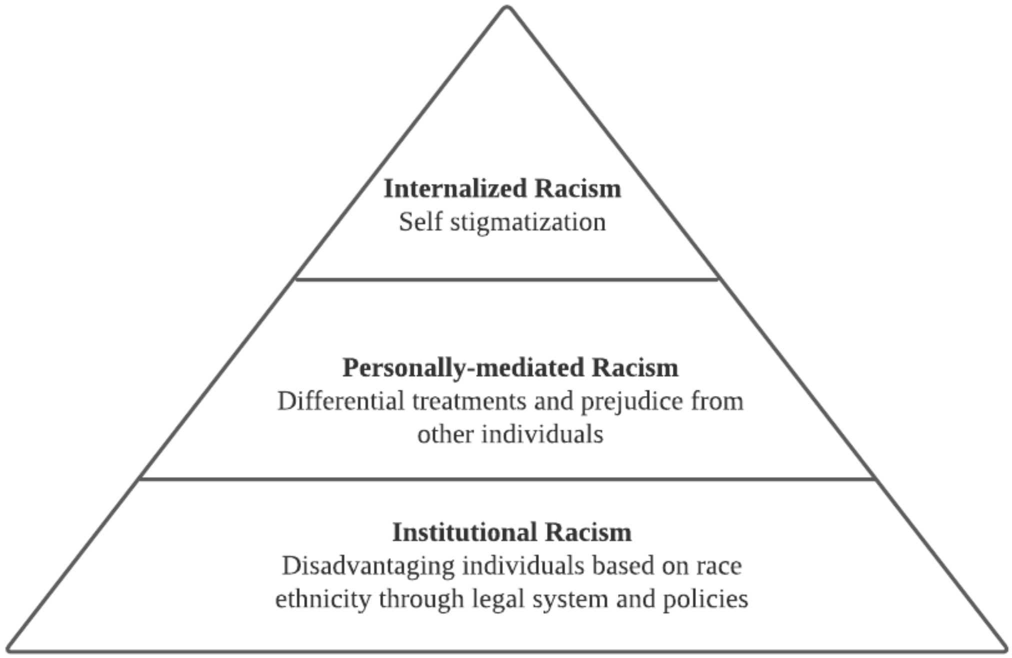

Figure 3. Levels of Racism (Adapted from Jones, 2000)

In this dissertation, we will focus on a combination of institutional and personally-mediated racism through the assessment of one's experiences of racial discrimination with interactions with other individuals and the systems (i.e., police, banking etc.). Racial discrimination refers to *unfair, differential treatment based on race, ethnicity, and inadequately justified factors other than race that disadvantages a racial group (*National Research Council, 2004) Racial discrimination is a product of the concept of racism and can refers to one's interpersonal experiences of differential treatment based on race (Williams, 1997; Ahmed et al., 2007; Bailey et al., 2017; McLemore et al., 2018). It can be considered chronic (e.g., daily life events) or acute (e.g., occur only under specific circumstances) including but not limited to receiving poor services and lack of respect, suspicions as a criminal, and devaluating one's achievement (Jones, 2000).

<u>Experiences of racial discrimination is common in the US, specifically among Black people and African Americans</u>

Racial discrimination is a relatively common occurrence in the United States, specifically among the Black population (William & William-Morris, 2000). For example, a cross-sectional sample of 3,716 Americans has found that around 75% of Black respondents reported experiences of racial discrimination (Lee et al., 2019). When looking at different domains of racial discrimination, over half of Black people reported experiencing discrimination in employment (57%), police interaction (60%), racial microaggressions (52%) (Bleich et al., 2019). Studies have also assessed the prevalence of racial discrimination among pregnant populations. A cross-sectional study of two study cohorts (i.e., the Asthma Coalition on Community, Environment, and Social Stress project (ACCESS) and Project Viva) has found the prevalence of experiencing racial discrimination was 44 and 78%, respectively, among Black and African American pregnant people (Ertel et al., 2012).

1.4.2 Measurement of Racial Discrimination

We included some scales from the studies that have been included in systematic review of racial discrimination and adverse birth outcomes (Alhusen et al., 2016; Giurgescu et al., 2011). In this section, we will introduce some measurement scales that are commonly applied in pregnancy studies and has been validated by previous literatures. We will not include the measurement scales that are open-ended questions, self-developed questionnaires, or scales that include more than the concept of racial discrimination (i.e., gender discrimination).

<u>Everyday Discrimination Scale</u>

The Everyday Discrimination Scale (EDS) is a nine-item scale that measures experiences of discrimination under the circumstances of being mistreated. The situations include being treated with less courtesy and respect, receiving poor service, other people’s perspectives of thinking you not smart, being dishonest, people are afraid of you, being called insulted, and being threatened or harassed (Williams et al., 1997). The EDS is a 6-point scale that measures the frequency from never to almost everyday experiences of each item, with the overall scores ranging from 0 to 54, with the higher scores indicating more frequent experience under these nine settings (Williams et al., 1997). The scale also asks about individual's perspective on the reasons for experiencing discrimination in specific domains. The scale has an acceptable internal consistency, with a Cronbach's alpha of 0.88 in adults (Williams et al., 1997).

Experience of Discrimination Scale

The Experiences of Discrimination (EOD) Scale is a nine-item scale that assesses the experience and frequency of discrimination based on race ethnicity under various settings, including education, employment, housing, healthcare, and police settings (Kreiger et al., 2005). The EOD scores the occurrence with a range from 0 to 9. For the frequency of each domain, it is a 4-point scale categorized as never, once, 2 to 3 times, and 4 times or more, with a score ranges from 0 to 45. The higher scores indicate higher experiences of racial discrimination (Kreiger et al., 2005). The EOD scale is a valid and reliable assessment tool for one's experiences of racial discrimination. The Cronbach's alpha was 0.79 in adults aged 25-64 and 0.74 among pregnant people (Kreiger et al., 2005; Mendez et al., 2014).

Perceived Racism Scale

The Perceived Racism Scale (PRS) is a 51-item, self-reported questionnaire that measures one's exposure to racism under multiple dimensions including individual, institutional, overt, covert, attitudinal, behavioral, and cultural domains. These domains were assessed through education, employment, and public settings (McNeilly et al., 1996). The scale further asks about individual's coping and emotional responses while experiencing racism in these domains. It is a

7-point scale for the measurement of frequency (i.e., 0: almost never, 7: several times a day) and 5-point scale on emotional and coping responses (i.e., 1: not at all, 5: extremely) (McNeilly et al., 1996). The scale has adequate internal consistency, with a Cronbach's alpha of 0.96 for assessing frequency of experiencing racism across all domains among Black sample and 0.93 in a Latino sample (McNeilly et al., 1996; Collado-Proctor, 1999).

Racism and Lifetime Experience Scale

The Racism and Lifetime Experience Scale (RaLES) is a series of self-reported scale that assess experiences of racism and individual's reactions and coping responses to the events. The RaLES includes 5 primary racism scales and 6 supplemental scales (Harrel et al., 1997). The primary racism scales measure the influences of race on one's life experiences and stress and the supplemental scales assess one's attitudes and responses to racism. The overall scale had acceptable internal consistency in both primary (Cronbach's alpha: 0.72 to 0.94). and supplemental scales (Cronbach's alpha: 0.49 to 0.85) among Black adult samples (Harrel et al., 1997).

In summary, the assessment of racial discrimination helps us understand the common situations and frequencies in which that individual may experience racial discrimination. The information is beneficial for raising the awareness of racial discrimination in particular situations and to reduce the incidents. One major disadvantage of the measurement tools for racism/racial discrimination is that the scales are subjective, and the individuals may have different definitions of feeling racially discriminated under the same settings. However, it is important to understand the perspectives of feeling racially discriminated as these may be the underlying stressors and therefore, are crucial to one's health."

1.4.3 Racial Discrimination and Sleep health During Pregnancy

Since racial differences exist in health outcomes, it is important to also examine racial discrimination in healthcare settings where people may be racially discriminated by receiving differential treatment, more likely being viewed as poorer health, or self-reported as poorer health based on race ethnicity. While pregnant people require more health monitoring and care during this time, it is important to identify racial discrimination in healthcare, which may contribute to racial differences in health outcomes. A US nationally representative sample of non-Hispanic white and Black samples reported 32% of Black participants experienced discrimination in clinical settings. Furthermore, 22% avoided healthcare due to anticipated discrimination (Bleich et al., 2019). Furthermore, racial discrimination in healthcare settings exist among Black and Hispanic people even for those who had similar income and socioeconomic levels as white people. Non-Hispanic Black and Hispanic people experienced more discrimination than white people who are at the similar income and socioeconomic levels. Specifically, Black people reported higher exposure to unfair treatment in clinical settings than whites and results in poorer perspective toward self-rated health than other racial groups (Colen et al., 2018). Therefore, experiences of racial discrimination are crucial for examining racial disparities in mental health and sleep health. Figure 4 shows the overall conceptual model of the association between racial discrimination and sleep health during pregnancy. The graph is revised based on the conceptual framework by Williams & Mohammed, (Williams & Mohammed, 2013). The authors discussed basic causes including biological, societal aspects and racism that differentiate social levels and link to health through multiple pathways: cultural (i.e., prejudice and discrimination), stress (i.e., racial discrimination), opportunities (education, employment, income), and resources (i.e., healthcare, housing, neighborhood) (Abdullah & Williams, 1997; Brown, 2011; Jackson, 2017). In the following sections, we will discuss some previous studies on experiences of racial discrimination (i.e., personally-mediated racism) and racial disparities in sleep health.

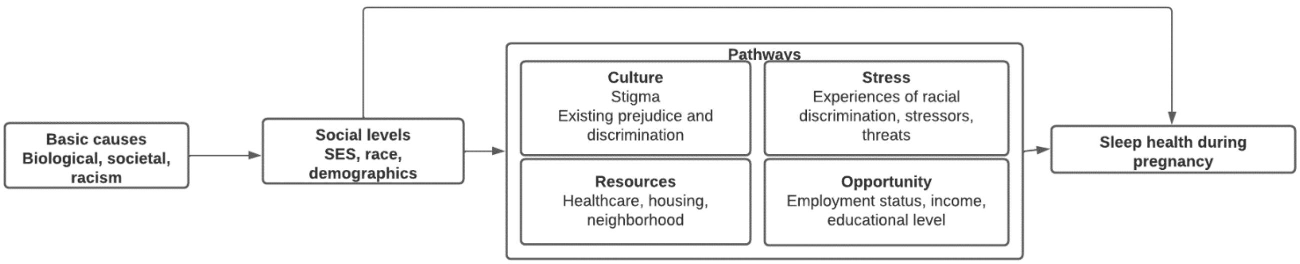

Figure 4. The Conceptual Framework of Racial Discrimination on Mental Health and Sleep Health During Pregnancy (Adapted from Williams & Mohammed, 2013)

<u>Racial discrimination is associated with poor sleep outcomes</u>

Studies have shown racial differences in sleep health, though the association is attenuated after adjusted for experiences of racial discrimination (Christian et al., 2019; Kalmbach et al., 2019). For example, a cross-sectional survey sample based in the Midwestern US has found racial differences were no longer significant after the adjustment for racism-related vigilance (i.e., preparation and anticipation of discrimination) in all three racial groups (Black, White, and Hispanic people). Furthermore, Black people reported a higher level of vigilance than whites (Hicken et al., 2013). These study results suggest an association between racial discrimination as an important determinant of one's sleep health (Clark et al., 2006; Hicken et al., 2013; William & Mohammed, 2009). However, the findings on racial discrimination as a potential risk factor for poor sleep health during pregnancy are limited. A study with both cross-sectional (n=640) and longitudinal data (n=133) on perinatal women's experiences of discrimination (i.e., Experiences of Discrimination Scale) and sleep quality (i.e., PSQI) found a cross-sectional association between everyday discrimination and sleep quality (β=0.078, 95%CI: 0.026, 0.129). Everyday discrimination was associated with daytime alertness (β=0.009, 95%CI: 0.002-0.019) among Black women (Francis et al., 2017). A previous systematic review has collected 17 studies on assessing the relationship between racial discrimination and sleep (Slopen et al., 2016). The majority of the studies measured interpersonal racism within work and healthcare settings. One study assessed institutional racism in the concept of pay cut among nurses and one evaluated racism-related vigilance as the exposure to sleep health (Greenberg, 2006; Hicken et al., 2013). The systematic review indicated that the measures of everyday experiences of racial discrimination and racism-related vigilance are positively associated with poor sleep quality or identified sleep difficulties (Slopen et al., 2016). Furthermore, these studies were focusing on non-pregnant populations, which highlights the need to further investigate the association between racial discrimination and sleep health among pregnant populations. Racial disparities in sleep health are more than just self-identified race ethnicity, the experiences of racial discrimination are social factors may be the underlying factors influencing one's health outcomes, including sleep health. Furthermore, sleep health was often measured through sleep quality. Franciset al.'s study on sleep health in pregnancy further included daytime sleepiness as one of the sleep outcomes in pregnancy (Francis et al., 2017). However, sleep health has been defined under a multidimensional concept (Buysse, 2014). It is crucial to know what risk factors are attributing to the changes of specific sleep dimensions and whether it affects the overall multidimensional sleep health in order to better target the social factors for sleep health improvement in pregnancy.

In summary, the experiences of racial discrimination are potential factors for poor sleep health. While pregnant people are experiencing substantial physical and hormonal changes, it is necessary to know whether the experiences of racial discrimination increase the risks for poor sleep health in pregnancy and consider the social factor for poor sleep health in pregnancy during the development of intervention for sleep health improvement in pregnancy, which further results in the prevention of adverse obstetric outcomes attributed by poor sleep health during pregnancy.

1.5 Research Gaps

Previous studies indicated that poor sleep health is highly prevalent among pregnant people. Also, poor sleep health in pregnancy is associated with a series of adverse pregnancy (i.e., gestational hypertension and diabetes) and birth outcomes (i.e., longer labor). Therefore, understanding sleep patterns during pregnancy is necessary. Emerging studies have supported that sleep health is a multidimensional concept, which can be characterized by sleep regularity, satisfaction, alertness, timing, efficiency, and duration. <u>While prior studies quantifying sleep patterns during pregnancy commonly used sleep efficiency, duration, and quality to describe sleep health, sleep timing and regularity were not well characterized among pregnant people. Furthermore, there are no studies describing sleep health during pregnancy using the composite scoring that includes multiple sleep dimensions to characterize pregnant people's sleep health.</u>

Prenatal depression is depressive episodes that specifically occur in prenatal period that are largely due to the substantial body and hormonal changes during pregnancy. Previous studies have assessed the patterns and prevalence of prenatal depression and suggested that mental health and sleep are more than a causal-effect relationship based on the shared pathophysiological mechanisms. The shared biological pathways mentioned in previous sections indicate a complicated relationship between mental health and sleep health, and this association also applies in pregnant populations. <u>Current research has been focusing on how poor sleep during pregnancy</u>

may influence prenatal depression. The findings on whether individuals with prenatal depression are at higher risk for poor sleep health during pregnancy are limited, which becomes a barrier for us to identify the management of prenatal mental health as a possible intervention factor for sleep health improvement in pregnancy. Furthermore, sleep quality and duration were the most commonly assessed parameters to represent sleep health in related studies. Sleep timing and regularity were not considered in related studies for quantifying sleep health during pregnancy.

Racial discrimination is the experiences of differential treatments and prejudice based on one's racial group and skin color that individuals have in interpersonal interaction on daily life basis. Previous studies have seen racial disparities in multiple health outcomes including sleep health. It has also been identified as a social factor that is urgent to solve that will result in reducing such disparities in health outcomes. However, there are limited findings on identifying the effect of racial discrimination in sleep health during pregnancy when pregnant people are likely to experience decline sleep health during this time and may further impact maternal and infant health. We don't know what sleep dimensions may be affected by the exposure to racial discrimination, nor do we know if the experience of racial discrimination affects the overall multidimensional sleep health in pregnancy. Identifying the association between racial discrimination and sleep health during pregnancy will be beneficial for identifying social factor that should be aware of in the developing interventions to improve sleep health during pregnancy, which may also further improve general maternal and infant health outcomes.

In summary, sleep health is fundamental to one's health and well-being. Studies targeting pregnant people have found declined sleep health due to the substantial physical and hormonal changes in pregnancy. Furthermore, the declined sleep health in pregnancy is associated with poor pregnancy and labor outcomes. Therefore, the main goal of this dissertation was to improve sleep health in pregnancy to reduce adverse maternal health outcomes attributed to poor sleep health. While previous studies have predominantly assessed sleep health by its quality and duration, the first goal is to understand sleep in pregnancy more comprehensively through the multidimensional concept of sleep health. Then the next step is to identify associated risk factors that should be considered in developing strategies to improve sleep health during pregnancy. The conceptual model revealed the associations that have been found to be associated with sleep health during pregnancy. Due to the close relationship between depression and sleep by shared biological pathways and symptoms, it is necessary to consider prenatal depression as a potential factor for poor sleep health during pregnancy. Additionally, the experiences of racial discrimination are chronic stressors that negatively affect health and well-being and may introduce racial differences in health. The findings on the effects of racial discrimination experiences on sleep health during pregnancy were limited. Therefore, we are identifying prenatal mental health and the experiences of racial discrimination as potential risk factors for poor sleep health during pregnancy. The successful completion of the dissertation will indicate the importance of improving mental health and racial discrimination as potential strategies to improve sleep health in pregnancy and hopefully world further reduce negative maternal health outcomes attributed to poor sleep health during pregnancy. (Figure 5, 6)

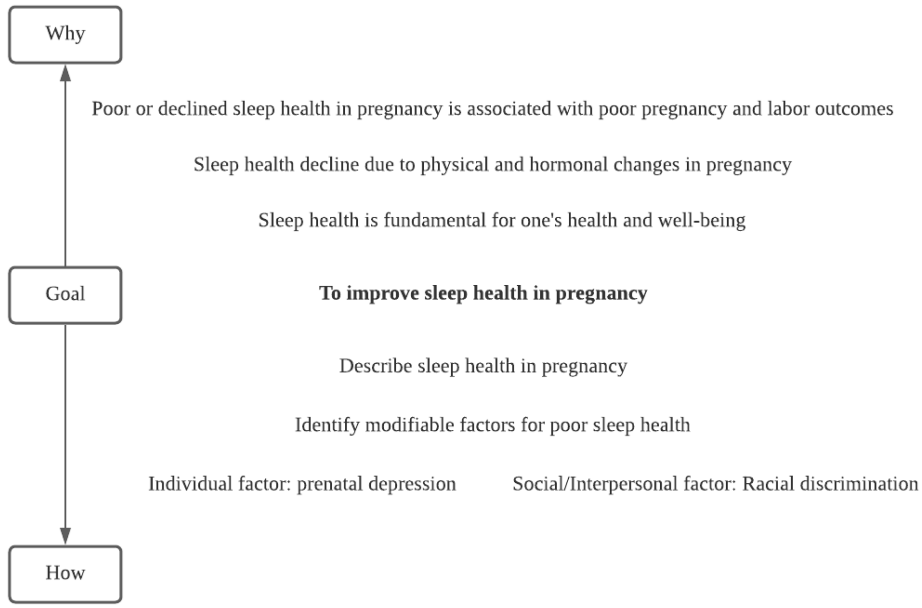

Figure 5. Concept Diagram of Research Gaps

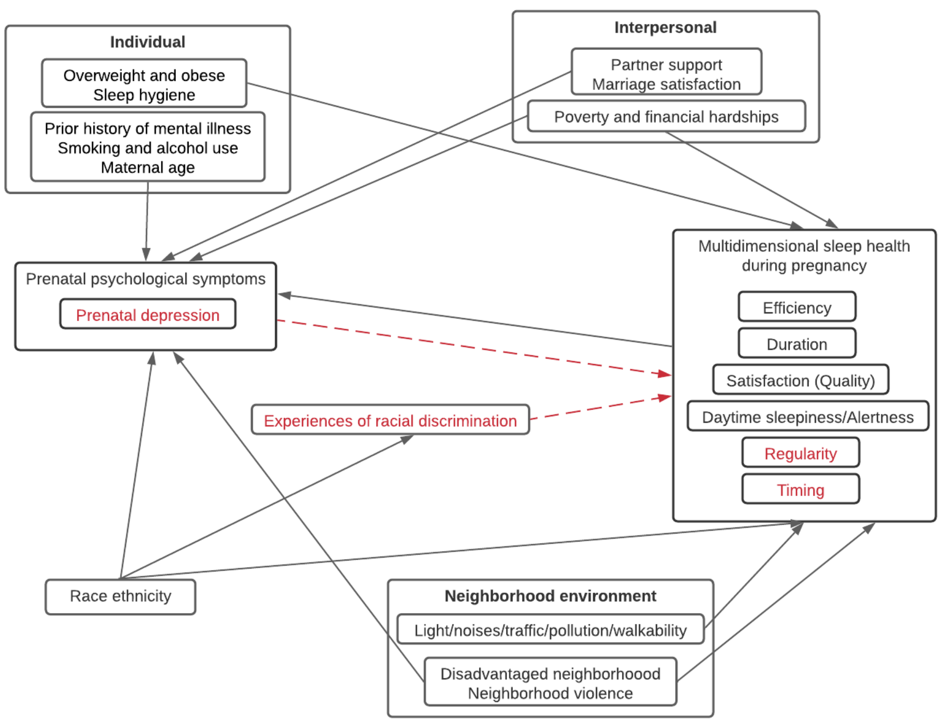

Figure 6. Overall Conceptual Model Based on Prior Studies and Variables, Associations of Interest

2.0 Proposed Research Aims

To fulfill the identified research gaps, we propose the following research questions and hypotheses for this dissertation:

Aim 1: To describe multidimensional sleep health and identify sleep patterns for each dimension from during pregnancy.

Sleep is a critical factor for an individual's health and well-being. Due to the significant physical and hormonal changes, poor sleep health is highly prevalent in pregnancy and is associated with adverse pregnancy and birth outcomes. Therefore, understanding sleep health during pregnancy is important. Prior studies have been assessing sleep patterns during pregnancy mainly through sleep duration and efficiency. However, emerging studies indicate that sleep health is a multidimensional concept. Understanding how different sleep dimensions change throughout pregnancy is necessary to better characterize sleep patterns during pregnancy. Furthermore, sleep dimensions such as sleep timing and regularity has not been characterized in pregnancy. Therefore, the first aim of this dissertation is to identify and describe the patterns of multidimensional sleep health in pregnancy with a sample of nulliparous women. We will describe changes in overall composite sleep health score as well as each dimension, specifically on timing and regularity, from early to mid-pregnancy.

Aim 2: To determine the association between early prenatal depression and sleep health during pregnancy.

Prenatal depression is not uncommon due to the substantial physical and social role changes in pregnancy. Depression and sleep health share similar pathophysiological mechanisms and therefore, the relationship between mental health and sleep is complicated. Prior studies have assessed how sleep impacts the risks for depression during pregnancy, but there are limited findings on how prenatal depression may increase the risks for poor sleep health.

The second aim of this dissertation is to examine the cross-sectional and longitudinal associations between early prenatal depression and multidimensional sleep health in pregnancy. We will fulfill the research gap of whether women with prenatal depressive symptoms during early pregnancy are at higher risks for poor sleep health during pregnancy. **We hypothesize** that women with self-reported prenatal depressive symptoms are more likely to have poor sleep health during early and mid-pregnancy.

Aim 3: To examine the association between lifetime experiences of racial discrimination and sleep health during pregnancy.

Based on the previous findings, racial differences exist in sleep health, and the effects of race ethnicity attenuate after the adjustment of racism. Therefore, racism may be an underlying risk factor for poor sleep health. However, studies exploring the relationship between racism and sleep health during pregnancy are limited. While poor sleep health in pregnancy may result in poor health and well-being of pregnant people and offspring, it is necessary to consider the social factors related to poor sleep health among pregnant people and raise the awareness of eliminating racism as a potential strategy to improve pregnant people's sleep health and well-being.

The third aim of this dissertation is to examine whether the self-reported experiences of racism is associated with sleep health during pregnancy. The completion of this research aim will fulfill the gap of identifying social factors contributing to racial disparities in sleep health in pregnancy and consider the experiences of racism in the interventions of sleep health improvement during pregnancy. **We hypothesize** that women with the experiences of racism are at higher risks for poor sleep health during pregnancy than women with no experience of racism.

3.0 Methods

3.1 Overview of the Project

Figure 7 shows the proposed aims in this dissertation. First, we will describe multiple sleep dimensions in pregnancy and characterize multidimensional sleep health using composite scoring. We will also describe sleep health by age and race. Then, we will identify whether women with self-reported prenatal depression during early pregnancy are at higher risks for poor or declined multidimensional sleep health during pregnancy. Lastly, we want to know whether experiences of racial discrimination are associated with multidimensional sleep health during pregnancy.

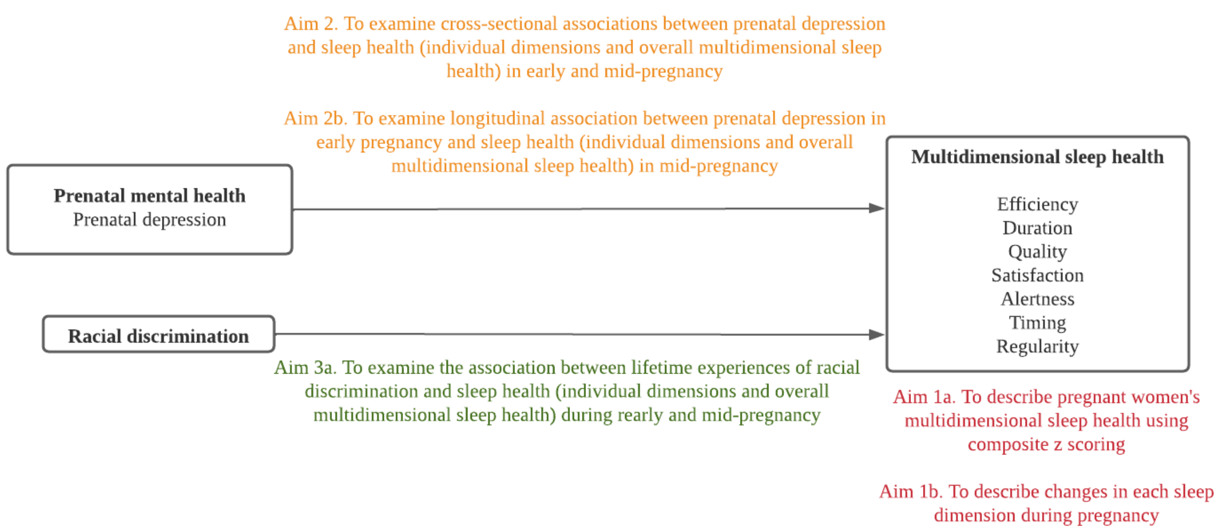

Figure 7. Proposed Research Aims

3.2 Study Population

The details of the study population were described in the protocol paper from the parent study (Haas et al., 2015). Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMom2b) is a multi-site prospective cohort study conducted through 2010 to 2013. The main goal of the nuMom2b study was to determine maternal genetic and physiologic characteristics related to adverse pregnancy and birth outcomes. Nulliparous women in the first trimester of pregnancy were enrolled from hospitals affiliated with eight research sites: Case Western University; Columbia University; Indiana University; University of Pittsburgh; Northwestern University; the University of California at Irvine; University of Pennsylvania; and the University of Utah. Pregnant people who plan to deliver their baby at the hospitals affiliated with the study sites were screened for eligibility. The eligibility criteria are (1) viable singleton pregnancy between 6 weeks+0 days and 13 weeks+6 days of gestation based on the ultrasound assessment (2) No previous pregnancy that lasted ≥ 20weeks through self-reported data and further verified through medical records, if available. Women with age under 13 or with a previous history of ≥ 3 spontaneous abortions and known fetal complications were excluded. The study has been approved by the institutional review boards with the protection of human subjects.

Figure 8 shows the participant flowchart from original cohort to the number of participants with complete self-reported sleep data. A total of 10,037 women were recruited for the parent study. A total of 8,799 (87.7% of total cohort) participants had self-reported sleep data from the first (n=6,875) or the third visit (n=6,914). 5,717 participants had complete self-reported sleep data of all six sleep dimensions from both visit 1 and 3. After excluding the samples with listed criteria, sleep survey data is available in 7,104 pregnant people and will be included in our analyses.

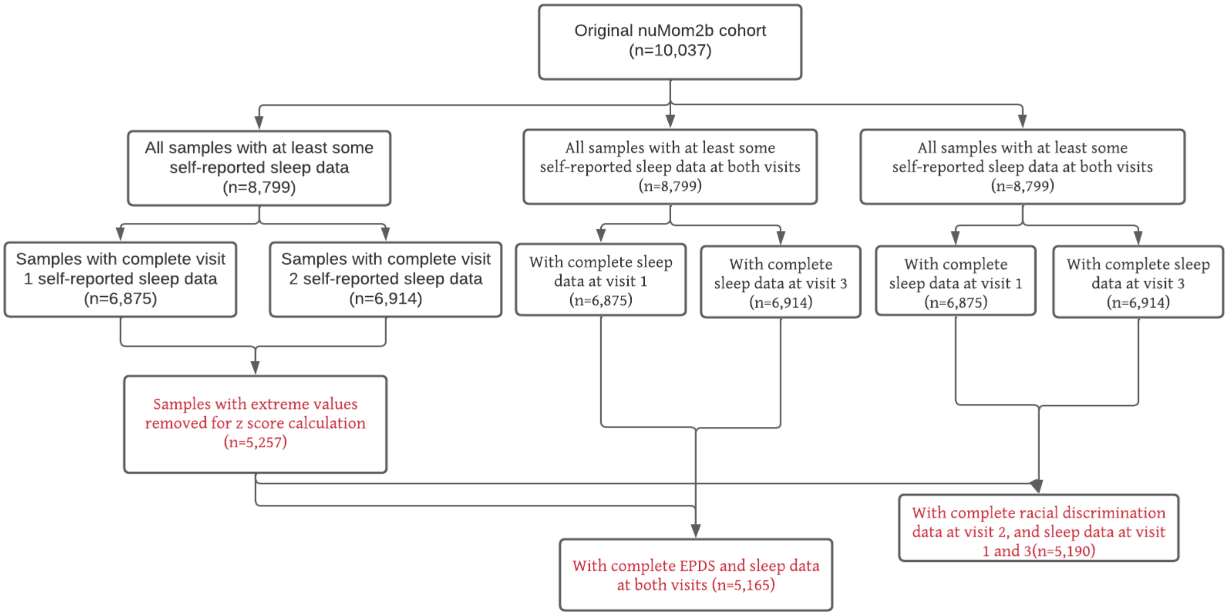

Figure 8. Participant Flowchart

3.3 Data Collection

There were three visits throughout the prenatal period. Participants signed the informed consent before study visits. Visit 1 was completed between 6 weeks+0 days and 13 weeks+6 days of gestation. Visit 2 was completed between 16 weeks+0 days and 21 weeks+6 days of gestation. Visit 3 occurred between 22 weeks+0 days and 29 weeks+6 days of gestation. The follow-up visits (visit 2 and 3) occurred at least 4 weeks after the latest visit (visit 1 and visit 2). The timings of data collection correspond to the regular prenatal care visits and before most preterm births. Research data were not available to the clinical caregivers (Haas et al., 2015).

Table 3 shows the time of data collection for the variables of interest in our study. Sociodemographic characteristics and prepregnancy health conditions were collected at the first study visit through detailed interviews. Further follow-up on the changes was recorded across all visits. Data on self-reported sleep questionnaires were collected in the first and third visits. Data collected for prenatal depression were available in visits 1 and 3 and individual's experiences of racial discrimination was collected at the second study visit.

Table 3. Data Availability for Completion of Study Aims

Variables	Visit 1	Visit 2	Visit 3
Sociodemographic characteristics	V	V	V
Prepregnancy-related variables (i.e., prepregnancy BMI, gravidity, gestational age at enrollment)	V		
Sleep survey questionnaire	V		V
Edinburgh Postnatal Depression Scale	V		V
Experiences of discrimination scale (EOD).		V	
Multidimensional Scale of Perceived Social Support	V	V	V

3.4 Measures of Interest

<u>Multidimensional sleep health</u>

We will use the data on self-reported sleep questionnaires from visit 1 and visit 3 to assess women's multidimensional sleep health. Multidimensional sleep health can be measured through both subjective and objective assessment (Buysse, 2014). A substudy of objective sleep assessment was conducted during the second visit. However, we will only use the self-reported sleep data for the following reasons: (1) The nature of subjective and objective sleep measurement differs. The differences in sleep during pregnancy is more apparent in self-reported data than through objective sleep measures (Zhang & Zhao, 2007). (2) The substudy's objective sleep measures were only available among participants ≥ 18 years of age and with no pre-existing hypertension and diabetes. The populations were different between the subjective and objective sleep measures in this study.

We will use the empirical thresholds for each sleep dimension from previous findings to report the percentage of good sleep health in each sleep dimension and to calculate composite sleep health score centering from these thresholds. To assess sleep regularity, we will calculate weekend-weekday differences in waketime, bedtime, and midpoint sleep. And to further define regular sleep, pregnant people with weekend-weekday differences in waketime, bedtime, and midpoint sleep less than 2 hours will be considered as regular sleep (Beauvalet et al., 2017). Satisfied sleep is self-rated "very good" or "good" sleep based on a question from the questionnaire asking: "Overall, was your typical night's sleep during the last 4 weeks: very good, good, fair, poor, very poor". Sleepiness is one of the parameters assessed for alertness. We will use ESS score to assess individuals' sleepiness in early and mis-pregnancy. Low sleepiness is assessed through an ESS score of 10 or less (Johns, 2000). We will assess sleep timing through the calculation of midpoint sleep between bedtime and waketime: bedtime + (wake time - bedtime). Appropriate sleep timing are individuals who had a midpoint sleep between 2 to 4 am (Dong et al., 2019) We will measure sleep continuity as one of the sleep parameters for efficiency. Continued sleep are individuals with wake after sleep onset for less than 40 minutes (Ohayon et al., 2017). Finally, we assessed sleep duration in a week by considering weekday and weekend sleep duration: ([weekday/workday duration × 5] + [weekend duration × 2]) / 7. Sufficient sleep duration is defined with two thresholds based on individual's age: 8 to 10 hours for individuals aged 13-17 and 7 to 9 hours for individuals aged 18 and over (Hirshkowitz et al., 2015). Table 4 shows the definition of each sleep dimension is described as followed. We will incorporate the definition of each sleep facet from previous studies that applied the concept of multidimensional sleep health in other populations and prior research under the same parent study (Facco et al., 2018; Dong et al., 2019). To calculate composite sleep health score, we will calculate the z scores for each dimension centering from the empirical threshold. Individuals with extreme performance (i.e., lower than Q1-3×IQR or higher than Q3+3×IQR) in each sleep dimension with extreme values were removed from the calculation of z scores. Then we will recode each dimension to the same direction that the higher score indicates better sleep health. Finally, we rescale the z score to a range of 0-1 for each dimension and sum up the scores from all dimensions. The composite sleep health score will range from 0-7 with the higher score indicates better sleep health.

Table 4. Definitions of Each Component of Multidimensional Sleep Health

Sleep dimension	Operationalization	Definition of good sleep health
Regularity	Weekend-weekday differences in waketime and bedtime (Roepke & Duffy, 2010)	< 2 hours (Beauvalet et al., 2017)
Satisfaction	From a self-reported question: "Overall, was your typical night's sleep during the last 4 weeks: very good, good, fair, poor, very poor".	Rated "good" or "very good"
Sleepiness	The Epworth Sleepiness Scale (ESS), 8-item, four-point scale with a score range from 0-24 (Johns, 1991)	ESS score ≤ 10 (Johns, 2000)
Timing	Midpoint sleep: bedtime + (wake time - bedtime) (Facco et al., 2017)	2 to 4 am (Dong et al., 2019)
Efficiency-Continuity	Wake time after sleep onset (WASO) = sum of time spent awake between first fall asleep and fully awake through nighttime sleep (Ohayon et al., 2017)	< 40 minutes (Ohayon et al., 2017)
Duration	Sleep duration: ([weekday/workday duration × 5] + [weekend duration × 2]) / 7 (Facco et al., 2018)	Age 18+: 7 to 9 hours Age 13-17: 8 to 10 hours (Hirshkowitz et al., 2015)

Prenatal depression

To understand how mental health in early pregnancy affects sleep health, we will utilize the data of prenatal depression from early (i.e., visit 1) and mid-pregnancy (i.e., visit 3) and examine whether early prenatal depression increases the risks for poor sleep health in pregnancy.

We will use the Edinburgh Postnatal Depression Scale (EPDS) data during the first and the third visits to assess prenatal depression. The EPDS is a 10-item self-reported scale for postnatal depression screening. A higher EPDS score indicates a greater level of depressive symptoms. The

EPDS is a valid tool to measure depressive symptoms with 86% sensitivity and 78% specificity (Cox et al., 1987). It has also been widely used among pregnant people for screening prenatal depression and across different populations (Bergink et al., 2011; Rubertsson et al., 2011; Su et al., 2007). To be consistent with the definition from prior research under the same parent study, an optimal cutoff at the sum of EPDS score ≥ 10 out of 30 will be defined as probable prenatal depression (Grobman et al., 2016).

Experiences of racial discrimination

In the nuMom2b study, the experiences of racial discrimination were assessed using the experiences of discrimination scale (EOD) (Krieger et al., 2005). The data were collected at the second study visit during the prenatal period asking about lifetime experiences of racial discrimination. The EOD Scale has acceptable internal consistency (Cronbach's alpha=0.74) in assessing one's experiences of racial discrimination under the study sample of Black people, Hispanics, and whites (Krieger et al., 2005).

In the nuMom2b study, the questionnaire asked individuals their all-time experiences on whether they encounter racial discrimination under nine situations, including at school, getting hired, at work, housing, medical care, getting service in a store or restaurant, getting credit, under public settings and from the police (Krieger et al., 2005) In the original scale, the questions include a binary yes/no response and frequency for each condition (i.e., Once, two or three times, Four times or more). In the nuMoM2b study, there were only binary responses to each question (Yes/No). We will add up the binary response (Yes=1/No=0) for each condition. The score will range from 0 to 9, with the higher score indicating a higher level of experiences in racial discrimination. We categorize individuals into with 3 or more situations of racial discrimination experiences or no experience of racial discrimination (Grobman et al., 2016).

Potential confounders

The covariates that we considered in the study were based on previous studies related to pregnancy, sleep health, and prenatal depression, as well as the prior studies that used the same parent study data (Grobman et al., 2016; Facco et al., 2018). Demographic characteristics include maternal age, race, ethnicity, educational level, family income, and insurance type will be considered as covariates in both second and third aims. To examine the association between early prenatal depression and sleep health during pregnancy, we will further control prenatal physical activity level and self-reported social support. Social support was assessed through the Multidimensional Scale of Perceived Social Support (MSPSS). The MSPSS is a self-reported, 12-item, 7-point scale that assesses individual's social support level through family, friends and significant other. The score ranges from 12 to 84 with the higher score indicates better social support (Ziment et al., 1990). The MSPSS is a valid instrument to assess individual's social support level in pregnancy with a reported Cronbach's alpha of 0.9≥ in a pregnant sample from Pakistan (n=1,154) (Mirabzadeh et al., 2013). Physical activity was assessed through a self-reported question: "During the past 4 weeks, did you participate in any physical activities or exercises like running, aerobics, gardening, ball games, or walking for exercise? - Yes, No".

We applied directed acyclic graphs (DAG) to identify the confounding effects of covariates and make decision on what confounders to be included in the adjusted model. DAGs allow researchers to identify causal relationships between variables through background knowledge, empirical literature findings, theories, and assumptions (Greenland et al., 1999; Tennant et al., 2021). The conventional approaches that rely on statistical criteria to identify model adjustment are unable to consider the assumptions of how each variable related and were unclear on why the variables were chosen in the model. Without this information, the interpretation of the results may be challenging and lacking theoretical assumptions (Arnold et al., 2020; Blakely et al., 2020). The statistical approach of deciding controlled factors in the model may introduce bias of mistakenly adding in risk factors to the model that are unable to interpret for meaningful causal relationship (Westreich & Greenland, 2013).

After identifying the minimum sufficient set of confounders for the adjusted model, we applied Spearman correlation to observe the correlation across the exposure variable and covariates. If some correlations were over 0.5, we further calculated the variance inflation factor (VIF) to identify potential multicollinearity issues. A VIF of 2.5 or higher indicates a potential multicollinearity issue.

3.5 Statistical Analysis Plan

Multidimensional sleep health during pregnancy

We will describe each sleep dimension at both time points after dichotomizing them into "good" and "poor" dimensions with the empirical thresholds mentioned in previous sections. To assess multidimensional sleep health and describe the percentage of women characterized as "good" sleep health in each sleep dimension. We will also describe the distribution of the total counts of "good" dimension of the sample. To calculate composite sleep health score, we will calculate the z scores for each dimension centering from the empirical threshold. Then we will recode each dimension to the same direction that the higher score indicates better sleep health. Finally, we rescale the z score to a range of 0-1 for each dimension and sum up the scores from all dimensions. The composite sleep health score will range from 0-7 with the higher score indicates better sleep health. We will also identify whether there are changes in sleep dimensions and composite sleep health score. We will use chi-square tests for categorical variables, paired t-tests for normally distributed continuous variables, and Wilcoxon sign-ranked tests for non-normally distributed variables.

Lastly, we will perform the descriptive statistics for each sleep dimension and composite sleep health score by different age groups and race-ethnicity groups. We decided the cutoffs for age groups based on the age groups defined in the guidelines for sleep health: teenagers (13 to 17 years), young adults (18 to 24 years), and adults (25 years and over) (Ohayon et al., 2017). We stratified the race-ethnicity groups into non-Hispanic white, non-Hispanic Black, Hispanic, Asian, and others (i.e., American Indian, Native Hawaiian, and multi-race).

Early prenatal depression and multidimensional sleep health during pregnancy

We will examine the associations between early prenatal depression and each sleep dimension and composite sleep health score from early to mid-pregnancy. We will first present the descriptive statistics by the presence of prenatal depressive symptoms through the cutoffs of the EPDS (i.e., ≥ 10 out of 30). Next, we will conduct the bivariable analyses to test the differences in sleep health at the first visit and covariates between each sleep dimension and composite sleep health scores using chi-square tests for the categorical variables and student's t-tests (parametric) or Mann-Whitney tests (non-parametric) for the continuous variables.

There will be three associations that we will examine: 1. Cross-sectional association between EPDS in early pregnancy and sleep health in early pregnancy, 2. Cross-sectional association between EPDS in mid-pregnancy and sleep health in mid-pregnancy, and 3. Longitudinal association between EPDS in early pregnancy and sleep health in mid-pregnancy. Finally, we will apply adjusted regression analyses (confounders identified through a DAG) to examine these three proposed associations between prenatal depression and each sleep dimension: linear regression for the continuous sleep variables and composite sleep health score and logistic regression for the dichotomized sleep dimensions. To help interpret the differences between exposure groups for ESS and composite sleep health scores, we standardized the scores centering from mean. This allows us to interpret how many standard deviations higher or lower the ESS and composite sleep health score is among exposed versus non-exposed groups.

<u>The association between lifetime experiences of racial discrimination and multidimensional sleep health in pregnancy</u>

First, we will describe the demographic characteristics, covariates, sleep health and percentages of women with or without the experiences of racial discrimination in the overall sample. We will conduct bivariable analysis on the association between the experiences of racial discrimination and sleep health in early and mid-pregnancy. We will apply student's t-tests for the normally distributed continuous variables, Mann-Whitney tests for non-normally distributed continuous variables and chi-square tests for the categorical variables. There are two associations that we will examine: 1. Experiences of racial discrimination and early pregnancy sleep health, and 2. Experiences of racial discrimination and mid-pregnancy sleep health. Finally, we will apply the adjusted (confounders identifies through a DAG) linear regression analyses to examine these three proposed associations between prenatal depression and each sleep dimension (before dichotomized into "good" and "poor" dimensions). Logistic regression analyses will be applied to assess these associations between racial discrimination experiences and each sleep dimension after dichotomized into "good" and "poor" dimensions. To help interpret the differences in scores including ESS and composite sleep health score between exposure groups, we standardized the scores centering from mean to interpret as how many standard deviations higher or lower in ESS and composite sleep health score among exposed versus non-exposed group.

4.0 Potential Limitations

There are some limitations in the study. First, we only have self-reported sleep data from the first and the third trimester of pregnancy. We are unable to assess pregnant people's sleep patterns fully. However, we still have a longitudinal assessment of sleep to indicate the changes from early to mid-pregnancy and understand how each sleep dimension is affected across trimesters. Second, we acknowledge the limited generalizability of our study sample with only nulliparous women. We are unable to assess or control the effect of parity on sleep health during pregnancy from our study sample. Since our samples were recruited through prenatal care facilities, we cannot observe sleep health among underserved women. Finally, since this is a secondary analysis from a observational study, we recognize that there are potential confounders that were not collected and thus, we are unable to control these factors in our study, such as environmental and neighborhood factors.

5.0 Public Health Implications and Innovation

Over two-thirds of pregnant people reported poor sleep health during pregnancy. Poor sleep health in pregnancy is a significant public health concern since pregnant people's health will further affect pregnancy outcomes and birth outcomes. The field of sleep research has been dominated by epidemiologic studies that measure sleep health during pregnancy with sleep efficiency and sleep duration in isolation. Other sleep parameters, such as sleep timing or regularity are not well characterized among pregnant people yet. Furthermore, studies on characterizing pregnant people's multidimensional sleep health are limited. Our approach is innovative because it will measure sleep in dimensions such as sleep timing and regularity, as well as sleep health under a multidimensional concept. We will extend the measurement of sleep health through the roles of daytime alertness, the regularity of sleep time, and sleep timing in pregnancy.

Since poor sleep health is an important health concerns among pregnant populations, researchers have been examining associated risk factors for poor sleep health and consider as intervening factors for improving sleep health during pregnancy. Therefore, our next two aims are to examine individual and social level factors that may potentially affect sleep health in pregnancy. Studies have found that depression and sleep health highly share the biological pathways, we do not know much about how depression may impact one's sleep health. Furthermore, research has found racial disparities in sleep health where Black people tend to report poorer sleep health than whites. However, such racial differences in sleep health no longer seen after controlling for racism-related variables. This suggests that racism and racial discrimination may be the potential factors for poor sleep health. Our results on identifying depression and racial discrimination will add to the body of research for considering the management of mental health and social factors to improve sleep health during pregnancy. Our findings will be innovative because we further access sleep health with multiple dimensions, which may indicate different level of impact of mental health and social factors on sleep health in pregnancy. (Figure 9)

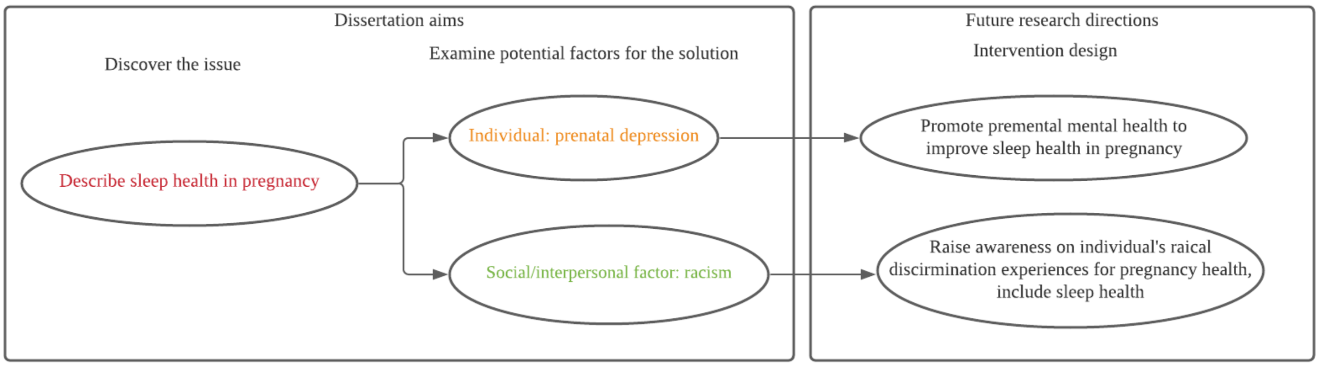

Figure 9. Dissertation Aims and Future Directions

The successful completion of our project will provide information on multidimensional sleep health during pregnancy and further identify the subgroup with higher risks for poor sleep health. This dissertation will contribute the knowledge on sleep health during pregnancy under a multidimensional concept and further support for better target on promoting mental health and eliminating racial discrimination as potential factors for sleep health improvement during pregnancy. The improvement of sleep health in pregnancy may further promote maternal health and well-being, and reduce adverse obstetric outcomes.

6.0 Aim 1. Multidimensional Sleep Health during Nulliparous Pregnancy: A Prospective Cohort Study

6.1 Abstract

Background

Poor sleep health (i.e., short sleep duration, low sleep efficiency) are common in pregnancy and are related to the increased risks for adverse obstetric outcomes. Sleep health has been defined under a multidimensional concept. In pregnancy, most studies characterized sleep by its efficiency and duration. While recent studies have found the association between late sleep timing and gestational diabetes, the characterization of multidimensional sleep health in pregnancy is limited.

Methods

We used self-reported sleep data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMoM2b) in early and mid-pregnancy (n=5,717). We measured satisfaction (self-rated sleep), daytime sleepiness (Epworth Sleepiness Scale score >10), timing (i.e., based on midpoint sleep), continuity (wake-after-sleep-onset, WASO), duration (hours/night), and bedtime, waketime regularity (weekend-weekday difference). We further created a composite sleep health score by summing the z scores centering from the dichotomizing cutoffs for each sleep dimension. The score ranges from 0 to 7 with the higher score indicates better sleep health. Finally, we described sleep health stratified by age and race-ethnicity groups.

Results

We found decreasing duration (0.2±1.1 hours) and increasing WASO (4.6±27.7) from early to mid-pregnancy ($p<.0001$). The percentage of women reported satisfied sleep also decreased by

5.2% ($p<.0001$). There was no difference in sleep timing ($p=0.3917$). We saw increased prevalence of regular bedtime and waketime from early to mid-pregnancy (5.3% and 3.9%, respectively, $p<.0001$). The composite sleep health score from the overall cohort decreased from 5.31±0.56 to 5.28±0.58. Teenagers had better satisfaction, duration, less awakening, but more sleepiness, later sleep timing than other age groups. The sleep health pattern was similar across racial groups.

Conclusion

While the composite sleep health scores were consistent from early to mid-pregnancy, there are changes in specific sleep dimensions. Sleep satisfaction, duration, and continuity declined while sleep timing was consistent and regularity improved from early to mid-pregnancy.

6.2 Background

Sleep health in pregnancy is important for promoting short and long-term maternal and fetal health. For example, short sleep duration, low sleep efficiency and poor sleep satisfaction, are related to the increased risks for pregnancy complications (i.e., gestational diabetes and hypertension) and labor outcomes (cesarean delivery, prolonged labor) (Cai et al., 2017; Champagne et al., 2009; Facco et al., 2010; Facco et al., 2017; Okun et al., 2007; Reutrakul et al., 2011; Roca et al., 2020; Xu et al., 2018). Sleep is crucial for body restoration that renormalize molecular, cellular, and cognitive functions (Vyazovskiy, 2015). Based on previous findings, poor sleep quality, short sleep duration and low sleep efficiency are highly prevalent among pregnant people. For example, a Canadian cohort of low-risk pregnant people (n=260) found that the prevalence of poor sleep quality (i.e., Pittsburgh Sleep Quality Index, PSQI>5) increased from 36% in the first trimester to 56% in the third trimester ($p=0.01$) (Naud et al., 2010). A cross-sectional study of 2,427 women found that the average nighttime sleep duration was 7.01 hours/night among those within the first two months pregnancy and 6.75 hours/night among those over 8 months pregnancy ($p<0.001$) (Mindell et al., 2015) A prospective study of 123 women reported a decreasing trend in sleep efficiency (i.e., percentage of time spent asleep in bed) from early (77.0±11.8%) to late pregnancy (74.1±13.1%, $p=0.007$) (Izci-Balserak et al., 2018).

Sleep health has been defined as "*a multidimensional pattern of sleep-wakefulness, adapted to individual, social and environmental demands, that promotes physical and mental well-being*." (Buysse, 2014). We can characterize the multidimensional nature of sleep by its regularity (e.g., consistency of sleep timing), self-reported satisfaction/quality, daytime alertness (e.g., daytime effects of sleep), timing (i.e., when sleep occurs), efficiency (i.e., time asleep while in bed), and duration (Buysse, 2014). Prior studies among in non-pregnant populations provide evidence that multidimensional sleep health is more strongly associated with health outcomes (i.e., mental health, cognitive outcomes, mortality) than individual sleep dimensions (Dong et al., 2019; Wallace et al., 2019). However, in pregnancy, there is limited data on multidimensional sleep health. For example, a scoping review of studies of sleep during pregnancy by Ladyman & Signal indicated that the sleep during pregnancy is most often characterized by its duration, efficiency, and quality, with limited data on alertness, regularity, or timing. Of the 24 studies reviewed, approximately 90% assessed sleep efficiency and sleep duration in pregnancy, and only 25% assessed alertness and 17% measured sleep timing, none of the study included in the review has assessed sleep regularity during pregnancy (Ladyman & Signal, 2018). The patterns on other sleep dimensions (i.e.,sleep timing and regularity) are limited while there is an association between those sleep dimensions (i.e., later sleep timing) and pregnancy complications (i.e., gestational diabetes) (Facco et al., 2017). Thus, no study has used a sleep health lens that considers all of these domains simultaneously in pregnant people. Given the multi-dimensional nature of sleep, which independently and likely interactively impact health outcomes, it is important to define and describe multidimensional sleep health to consider the intertwined contribution of multiple sleep dimensions and describe domains of sleep health and a combination of multiple sleep characteristics in pregnancy.

To fill this research gap, the objective of this study is to characterize multidimensional sleep health in early and mid-pregnancy in a community-based sample of nulliparous women. First, we provided estimates of sleep in individuals dimensions and the prevalence of "good" sleep health each dimensions. Next, we described overall multidimensional sleep health as a composite of good sleep health in all dimensions assessed. Lastly, we characterized sleep by age and race because sleep recommendations in some dimensions change by age (Ohayon et al., 2017). and prior studies have noted racial disparities in sleep (Williams et al., 2015; Feinstein et al., 2020).

6.3 Methods

Study design and settings

This study is a secondary analysis from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMoM2b). The primary aim of the nuMom2b study was to determine maternal characteristics (i.e., genetic and physiologic response to pregnancy and environmental factors) that predicts adverse pregnancy outcomes. nuMoM2b is a multi-site cohort study conducted from 2010 through 2013 with eight study sites: Case Western University; Columbia University; Indiana University; University of Pittsburgh; Northwestern University; the University of California at Irvine; University of Pennsylvania; and the University of Utah. There were three study visits during pregnancy. Visit 1 was between 6 weeks+0 days and 13 weeks+6 days of gestation, followed by visit 2 completed between 16 weeks+0 days and 21 weeks+6 days of gestation. Visit 3 was between 22 weeks+0 days and 29 weeks+6 days of gestation. The follow-up visits (visit 2 and 3) occurred at least 4 weeks after the latest visit (visit 1 and visit 2). The timings of data collection correspond to the regular prenatal care visits and before most preterm births. The study collected self-reported sleep data in the first and the third study visits. Participants signed the informed consent before the first study visits. We refer readers to Haas et al.'s protocol paper for additional details on study procedures (Haas et al., 2015).

Study sample

In the first trimester of pregnancy, nulliparous women who planned to deliver their baby at one of the affiliated hospital study sites were screened for eligibility. The eligibility criteria were (1) viable singleton pregnancy between 6 weeks+0 days and 13 weeks+6 days of gestation based on the ultrasound assessment (2) No previous self-reported pregnancy ≥ 20weeks gestational determined, which was further verified through medical records, if available. Exclusion criteria included 1) age under 13, 2) a previous history of ≥ 3 spontaneous abortions, and 3) known fetal complications. In this secondary analysis, we further excluded participants without complete self-reported sleep data on all six sleep dimensions (future described below) at both visits. The complete case sample size for our analysis was 5,717 nulliparous women. For the calculation of composite sleep health z score, individuals with extreme values were removed, a total of 5,257 nulliparous women were included for the composite sleep health scoring. (Figure 10).

Definition of sleep dimensions and multidimensional sleep health

We used self-reported sleep using validated questionnaires at visit 1 and visit 3. To assess multidimensional sleep health in pregnancy, we further dichotomized sleep health with the empirical thresholds that were based on the recommendations by the National Sleep Foundations or developed in prior studies. We calculated three indicators of weekly sleep regularity- bedtime, waketime and midpoint sleep regularity. All three indicators were calculated through the weekend-weekday differences in bedtime, waketime and midpoint sleep (Roepke & Duffy, 2010). We defined regular sleep with the weekend-weekday differences in bedtime and waketime less than 2 hours (Beauvalet et al., 2017). Sleep satisfaction was assessed through a self-reported question in the sleep health questionnaire: "Overall, was your typical night's sleep during the last 4 weeks: very good, good, fair, poor, very poor". We defined satisfied sleep with individuals rated their overall sleep in the last month as "good" or "very good". We used the Epworth Sleepiness Scale (ESS) to assess daytime sleepiness, a measure of alertness. The ESS is an 8-item scale with each item scores from 0 to 3 and an overall ESS score ranging from 0 to 24. The higher ESS score indicates a higher level of daytime sleepiness (i.e., poorer alertness) (Johns, 1991). Individuals with ESS score over 10 are considered to have excessive daytime sleepiness, and an ESS score of 16 or more suggests a high level of excessive daytime sleepiness (Johns & Hoking, 1997; Johns, 1991). The ESS has acceptable internal consistency (Cronbach's alpha=0.77) for pregnant people and is a validated tool to assess daytime sleepiness (93.5% sensitivity and 100% specificity) (Johns, 2000; Johns, 1992; Tsai et al., 2016). Low sleepiness was individuals who had a ESS score of 10 or less (Johns, 2000). Sleep timing was defined through midpoint sleep between bedtime and waketime, which was calculated through: bedtime + (wake time - bedtime) (Facco et al., 2017). Appropriate sleep timing were individuals with a calculated sleep timing between 2 to 4 am (Dong et al., 2019) Wake after sleep onset (WASO), is a measure of sleep continuity, a similar construct as sleep efficiency. WASO was estimated by the sum of time spent awake between first fall asleep and fully awake through nighttime sleep (Ohayon et al., 2017). We defined continued sleep as individuals with less than 40 minutes awaking through nighttime sleep (Ohyaon et al., 2017). Sleep duration was assessed through a weekly average sleep duration weighted by workdays and weekends: ([weekday/workday duration × 5] + [weekend duration × 2]) / 7 (Facco et al., 2018). Good sleep duration was individuals with a weighted average sleep duration of 8 to 10 hours among participants aged between 13 to 17 and 7 to 9 hours for participants over 18 years of age (Hirshkowitz et al., 2015). (Table 4) We further counted the numbers of "good" sleep dimensions and describe the changes of the counts from early to mid-pregnancy. We will describe the calculation of the composite sleep health score in the later section.

Demographic characteristics

Demographic and pregnancy-related variables were collected through detailed interviews at the first visit (Haas et al., 2015) We described the following variables: gestational age (weeks) and maternal age at enrollment (years), race-ethnicity (i.e., non-Hispanic white, non-Hispanic Black, Hispanics, Asians, American Indian, Native Hawaiian, Multiracial), educational level (i.e., less than high school degree, high school graduated or GED, some college, college graduated, beyond college degree), insurance type (i.e., governmental, military, personal income, other), poverty level (i.e., income as a percentage of 2013 federal poverty level), prepregnancy BMI (kg/m^2), and gravidity (i.e., 1, 2, 3 or more). Prepregnancy BMI was calculated by dividing self-reported pre-pregnancy weight in kg by self-reported height in meters squared.

Statistical analysis

First, to understand our sample, we described the demographic characteristics of our analytical sample. The categorical variables were presented as counts and percentages, and continuous variables were presented as mean ± standard deviation (SD). If the variables were not normally distributed, we presented the median and interquartile range of the variables.

Next, we described and compared each sleep dimension between early to mid-pregnancy using chi-square tests for categorical variables, paired t-tests for normally distributed continuous variables, and Wilcoxon sign-ranked tests for non-normally distributed variables. Then we describe sleep dimensions dichotomously in "good" and "poor" dimensions based on the empirical thresholds. We reported the percentage of participants with "good" sleep health in each sleep dimension. Chi-square tests were applied to compare the differences between the two visits. To assess the composite sleep health score, we calculated the z scores for each sleep dimension centering from the empirical thresholds. For sleep regularity, we included bedtime and waketime regularity for the composite scoring. Individuals with extreme values (i.e., lower than Q1-3×IQR or higher than Q3+3×IQR) in each sleep dimension with extreme values were removed from the calculation of z scores. After removing the samples with extreme values, we had 5,257 participants for calculating the composite sleep health score. We scaled the scoring for each dimension from 0 to 1 based on the calculated z score. The overall composite sleep health score ranged from 0 to 7 with the higher score indicates better sleep health (i.e., closer to our empirical thresholds) . (Table 4) Finally, we performed the descriptive statistics for each sleep dimension and composite sleep health score by different age groups and race-ethnicity groups. We decided the cutoffs for age groups based on the age groups defined in the guidelines for sleep health: teenagers (13 to 17 years), young adults (18 to 24 years), and adults (25 years and over) (Ohayon et al., 2017). We stratified self-reported race-ethnicity groups into non-Hispanic white, non-Hispanic Black, Hispanics, Asian, and others (i.e., American Indian, Native Hawaiian, and multi-race).

Since we applied complete case analysis in our study, we described the missingness of demographic characteristics and each sleep dimension. We also compared demographic and sleep characteristics of participants with and without complete sleep data at each visit.

We accepted a type 1 error ($\alpha=0.05$) for determining the significance level of the statistical testing. We also added the effect sizes of each sleep dimension change for the overall study sample. We presented the effect sizes with Cohen's d for the continuous variables and Phi coefficient for the categorical variables. For non-normally distributed, continuous variable, we used z score from the Wilcoxon's signed rank test divided by the square root of n for the calculation of the effect sizes. We used SAS version 9.4 for data management and analyses (SAS Institute, Cary, NC).

6.4 Results

Demographic characteristics

Among all samples with complete sleep data during early and mid-pregnancy (n=5,717), the average maternal age was 28.1±5.3 years and the average gestational age was 11.6±1.5 weeks. The majority of participants were non-Hispanic whites (70.9%), followed by Hispanic people (13.3%) and non-Hispanic Black people (6.9%). Over half of the participants had a normal prepregnancy BMI (54.8%). 62.9% of the samples were college or higher degree. Around 76.4% of our samples were pregnant for the first time. Most of the participants had commercial health insurance (79.4%) and with an income over 200% of federal poverty level (78.5%). (Table 5)

Sleep health in early and mid-pregnancy

There were changes in specific sleep dimensions between early and mid-pregnancy. Sleep health declined from early to mid-pregnancy in satisfaction, duration and continuity. The percentage of good sleep satisfaction decreased 5.2% ($p<.0001$), the average sleep duration decreased 0.17±1.13 hours ($p<.0001$), and the average WASO increased 4.63±27.73 minutes ($p<.0001$) from early to mid-pregnancy. The percentages of good sleep satisfaction from early to mid-pregnancy had a large effect size (ϕ=0.55) while the average sleep duration and WASO had small effect sizes in the observed changes (Cohen's d=0.15 and -0.17, respectively).

Sleep timing was similar at early and mid-pregnancy (p=0.39). There were improvements in sleepiness and regularity. The average ESS score decreased by 1.20±3.68 (p<.0001) with a medium effect size (Cohen's d=0.32). The differences in bedtime, waketime, and midpoint sleep between weekday and weekend were shortened by 0.12 to 0.16 hours from early to mid-pregnancy (p<.0001). However, the effect sizes were small in the changes of regularity dimensions.

When describing the percentages of good sleep health in each sleep dimension, there were 1.5% decrease in good sleep duration (p<.0001) and 5.1% decrease in good WASO (p<.0001). Around 71% of the participants reported good sleep timing at both early and mid-pregnancy (p<.0001). There were 8.9% increase in percentage of participants with no excessive daytime sleepiness (p<.0001), and an increase of 2.0 to 5.3% in good sleep regularity from early to mid-pregnancy (p<.0001). All changes in the percentages of good sleep dimensions had medium to large effect sizes (ϕ above 0.3 as medium effect and above 0.5 as large effect) . (Table 6)

Multidimensional sleep health

For the multidimensional sleep health, the distribution of numbers of good dimensions were similar between early and mid-pregnancy. Out of 7 sleep dimensions, 28.2% of the participants reported good sleep health in 5 dimensions followed by 23.9% reported 6 good dimensions in early pregnancy. In mid-pregnancy, 29.2% reported good sleep health in 5 dimensions followed by 23.5% reported 6 good dimensions. The average composite sleep health scores were similar between early and mid-pregnancy. The average score in early pregnancy was 5.31±0.56 and 5.28±0.58 in mid-pregnancy (p<.0001). (Table7)

Then we categorized participants based on the early-mid pregnancy difference in composite sleep health. 1484 (28.2%) had over 0.25-point improvement in composite sleep health z score from early to mid-pregnancy, 1708 (32.5%) had over 0.25-point decline in composite sleep health z score from early to mid-pregnancy.

Sleep health by age groups

Age group 13-17 showed improvement in satisfaction, duration, and WASO from early to mid-pregnancy while these dimensions declined in the other age groups, specifically in age group 25 or more. The percentage of good sleep satisfaction from early to mid-pregnancy increased in age group 13-17 (5.9%, $p=0.0046$) but decreased in age group 25 or more (7.2%, $p<.0001$). The average sleep duration decreased the most in age group 25 or more (0.79 ± 0.97 hour, $p<.0001$). Similarly, the proportion of good duration decreased the most in age group 25 or more (1.9%, $p<.0001$). The average WASO decreased from early to mid-pregnancy in age group 13-17 (4.79 ± 24.96 minutes), though the decrease is not statistically significant ($p=0.1180$). The largest increase in WASO was age group 25 or more (5.29 ± 26.63 minutes, $p<.0001$). The proportion of good WASO increased by 8.8% in age group 13-17 ($p=0.0088$), but decreased in age group 18-24 (3.6%, $p<.0001$) and 25 or more (5.8%, $p<.0001$). Age group 13-17 had a delay in sleep timing (Median (IQR): Early: 3:21 (1:45), Mid: 3:37 (1:46), $p=0.0088$) and a 7.4% decline in the proportion of good sleep timing from early to mid-pregnancy ($p=0.0534$). The average differences in waketime between weekdays and weekends were over 2 hours in age group 13-17 in early pregnancy (2.34 ± 1.97). There was an improvement in waketime regularity in mid-pregnancy (1.87 ± 1.78), but the difference was not significant ($p=0.0988$) Both age groups 18-24 and 25 or more had improvement in the proportion of regular bedtime (18-24: 1.6%, 25 or more: 2.4%), waketime (18-24: 4.0%, 25 or more: 5.7%), and midpoint sleep (18-24: 2.3%, 25 or more: 4.5%) from early to mid-pregnancy. (Table8) (Figure 11)

For the multidimensional sleep health, the largest proportion in the counts of good sleep dimensions in early pregnancy were 5 good dimensions in all three age groups (13-17: 32.4%, 18-24: 26.4%, 25 or more: 28.7%) However, age group 13-17 had the largest proportion of participants with 4 good dimensions in mid-pregnancy (36.8%) while the other two age groups still had the largest proportion in 5 good dimensions (18-24: 29.1%, 25 or more: 29.2%). When we look at the composite sleep health scores considering the variability to the dichotomizing thresholds, age group 25 or more had the highest score at both early and mid-pregnancy (Early: 5.34±0.54, Mid: 5.29±0.57) the decline was significant (p<.0001), The composite sleep health score improved by 0.20±0.73 from early to mid-pregnancy in age group 13-17 (Early: 5.12±0.63, Mid: 5.32±0.56, p=0.0385). There was no difference in composite sleep health score in age group 18-24 from early to mid-pregnancy (Early: 5.23±0.59, Mid: 5.24±0.60, p=0.3391). (Table7)

Sleep health by race-ethnicity

Most racial groups showed decreasing proportion of good sleep satisfaction from early to mid-pregnancy except non-Hispanic Black people. While there were 1.27% increase in good satisfaction among non-Hispanic Black sample (p<.0001), non-Hispanic white sample had the largest decline in the proportion of good satisfaction from early to mid-pregnancy (6.4%, p<.0001). Sleep duration decreased and WASO increased from early to mid-pregnancy across all racial groups. Hispanics had the largest decline in sleep duration (0.21±1.31 hour, p<.001) and non-Hispanic whites had the largest decline in the proportion of good sleep duration (4.79%, p<.0001). Non-Hispanic whites had the largest increase in WASO (5.25±27.55 minutes, p<.0001) and the largest decrease in good WASO (5.85%, p<.0001) Midpoint sleep was similar between early and mid-pregnancy for all racial groups. All racial groups showed improvement in regular bedtime, waketime, and midpoint sleep. Asians had the largest improvement in the all three regularity measures and the largest improvement in good bedtime (5.72%, $p=0.0001$) and midpoint regularity (4.58%, $p<.0001$). Non-Hispanic whites had the largest improvement from early to mid-pregnancy in the proportion of good waketime regularity (6.33%, $p<.0001$). (Table9) (Figure 12)

Each racial group had similar pattern of the counts of good sleep dimensions at early and mid-pregnancy. Most of the racial groups had the highest percentages in 5 good dimensions while Asians had the highest percentages in 6 good dimensions (Early: 28.7%, Mid: 35.2%). Similar results were found in composite sleep health scores, which were similar at early and mid-pregnancy in each racial group. Asians had the highest average score at both early (5.48 ± 0.51) and mid-pregnancy (5.46 ± 0.51). Non-Hispanic Black women had the lowest average composite sleep health score at both early (5.17 ± 0.58) and mid-pregnancy (5.19 ± 0.60). (Table7) (Figure 12)

Comparison of samples with some self-reported data versus complete-case samples

There were 10,037 participants in the original nuMom2b cohort, (Haas et al., 2015) of which, 8,799 participants had self-reported sleep data in at least one dimension in early or mid-pregnancy. Of participants with some sleep data, 6,875 had data in early pregnancy and 5,717 additionally had complete follow-up sleep data in mid-pregnancy. There were no differences in demographic characteristics between participants in the entire study cohort or participants with some sleep data, except for race ethnicity, educational level, poverty level. Specifically, participants in the final analytic sample had a lower percentage of African Americans, higher education, higher income. (Appendix Table 1)

We've also compared the differences in sleep health between participants with some sleep data and our final analytic sample. There was no difference in each sleep dimension between participants with some sleep data and our final analytic sample in both early and mid-pregnancy. (Appendix Table 2)

6.5 Discussion

In this community-based cohort study of nulliparous pregnant people, we characterized multi-dimensional sleep in early and mid-pregnancy. Though we did not see differences in composite sleep health scores from early to mid-pregnancy, the observed changes in specific sleep dimensions indicated that sleep health differs throughout pregnancy. Specifically, participants reported sleep decline in satisfaction and duration, increased WASO, and improvement in sleep regularity and sleepiness from early to mid-pregnancy. Participants did not report any differences in sleep timing. When we stratified sleep health at early and mid-pregnancy by age, the youngest age group (i.e., age 13-17) had improved satisfaction, decreased WASO and increased sleep duration but later sleep timing, and more irregular sleep compared to the other age groups. When we stratified sleep health by race ethnicity, non-Hispanic whites had the largest decline in the proportion of good sleep satisfaction, good sleep duration and the largest increase in WASO. Understanding the pattern of each sleep dimension is beneficial for targeting specific sleep dimensions on sleep improvement at different timepoints of pregnancy.

Our findings on changes in sleep satisfaction, WASO, and sleepiness aligned with previous studies that described sleep pattern in pregnancy. A cross-sectional study collected sleep data from 2,427 women across all gestational ages through an online survey showed similar trend in sleep duration, WASO, and sleepiness from early to mid-pregnancy. Specifically, the average sleep duration decreased by 0.7 hours from 2 months to 8 months pregnancy, the ESS score was the highest at 3 months pregnancy (10.17±4.74) and the lowest at 6 months pregnancy (9.32±4.85), the duration of waking increased by 19.7 minutes from 2 months to 8 months pregnancy (Mindell et al., 2015). Similarly, a longitudinal study of 325 women completed sleep questionnaires from early to late pregnancy found decreased sleep satisfaction and duration in early pregnancy and then decline in the second trimester. The average sleep duration decreased significantly from 8.7 hours in the first trimester to 8.4 hours in the second trimester. Sleep satisfaction was assessed through the proportion of women reported restless sleep. The proportion of women reported restless sleep increased from 15.4% in the first trimester to 20.3% in the second trimester (Hedman et al., 2002). Though we found similar trend in sleep satisfaction, duration, WASO and sleepiness comparing our study to prior findings, our sample showed better sleep health compared to other study samples. It is likely due to the differences in sample characteristics. While prior research found that multiparous women experienced poorer sleep health than nulliparous women, our nulliparous sample may be characterized with better sleep health than prior studies that included multiparous women in the sample (Christian et al., 2019)

Previous findings on sleep timing, regularity in pregnancy were limited. Our study showed that around 70% of women had good sleep timing at both study visits. There were some improvements on sleep regularity when defined as a function of bedtime, but not waketime. While almost 90% of women were able to maintain regular bedtime during pregnancy, only around 60% could maintain regular waketime in pregnancy. Waketimes on weekends were later than on weekdays at early and mid-pregnancy. The observed difference is likely due to the awakenings at night that delay waketime to reach sufficient sleep, specifically on non-work days when individuals had time to reach sufficient sleep before waking up (i.e., social jetlag) (Wittmann et al., 2006). Furthermore, late sleep timing may be a potential risk factor for gestational diabetes

(Facco et al., 2015). Therefore, future studies should describe changes in sleep timing and regularity throughout pregnancy and include these dimensions when examining sleep-related risk factors for adverse obstetric outcomes.

Another novel aspect of our study was describing multidimensional sleep health in pregnancy using the composite scoring. The description of multidimensional sleep health gives us the opportunity to measure sleep dimensions altogether and to consider all dimensions on the same scale to better define sleep health. We assessed composite sleep health score through the distance to the dichotomizing cutoff of each sleep dimension. Our results showed similar composite scores from early to mid-pregnancy while there were changes in specific sleep dimensions. The findings aligned with prior research that sleep health deteriorates starting from early pregnancy, with the dynamic changes in each sleep dimension. For example, Lee's review on the alteration of sleep in pregnancy indicated poor sleepiness in early pregnancy was likely due to morning sickness and hormonal changes. Enlarged uterus in later pregnancy limited sleep position and led to frequent urination that caused increases in awakenings and shorter sleep duration in late pregnancy (Lee, 1998).

The results of sleep health stratified by maternal age were consistent with prior studies. The youngest age group (i.e., age 13 to 17) showed better sleep satisfaction and longer sleep duration than other age groups. Furthermore, the youngest age had increased percentage of good sleep satisfaction, increased sleep duration from early to mid-pregnancy while the age group 25 and over showed declines in these sleep dimensions. Advanced maternal age is a risk factor for poor sleep health during pregnancy. For example, a cross-sectional study from China indicated that increased maternal age contributes to poor sleep quality during pregnancy (Yang et al., 2018). Sedov et al.'s meta-analysis on sleep quality during pregnancy reported that older samples had a higher prevalence of poor sleep quality (Sedov et al., 2018) A meta-analysis of 24 articles by Sedov et al. reported higher prevalence of poor sleep quality (i.e., PSQI≥5) among samples with older maternal age (Sedov et al., 2018). Likewise, a longitudinal study from Finland collected self-reported sleep data from 325 pregnant people has found that women over 30 years of age were more likely to report decreased sleep duration throughout pregnancy (Hedman et al., 2002). In our study, we found that age group 13-17 had more sleepiness, later sleep timing and more irregular sleep than other age groups. Though previous studies describing sleep timing and regularity in pregnancy by different maternal age is scarce, these results aligned with prior studies explaining the mechanisms of more sleepiness and irregular sleep time in younger populations. Longer screen time before sleep among adolescents and hormonal differences between adolescents and adults are potential reasons for more sleepiness and irregular sleep among adolescents (Carskadon et al., 1997; Carskadon et al., 1999). However, these results were based on non-pregnant adolescents. Future studies on sleep health among pregnant adolescents are necessary to better describe sleep health among pregnant people at younger age.

Based on our findings, non-Hispanic whites had the largest decline in the proportion of good sleep satisfaction, and the largest increase in WASO among all racial groups from early to mid-pregnancy. Our results contrast with previous finding on racial disparities in sleep health. Generally, previous studies showed poorer sleep quality and sleep duration in pregnancy among non-Hispanic Black women compared to non-Hispanic whites. For example, a longitudinal study with a biracial sample of 133 pregnant people has found poorer sleep quality (i.e., PSQI score) among Black women compared to white women (Christian et al., 2019). Another nationally representative sample in the U.S. with 2,349 pregnant people has found higher prevalence of self-reported short sleep duration among non-Hispanic Black participants than whites (Feinstein et al., 2020). The differences between our results and previous finding may be associated with deviation in sample characteristics and measurements. Our assessment of sleep satisfaction was not the same as sleep quality assessed through PSQI. Furthermore, our sample was limited to nulliparous women with better education and income levels. While racial disparities in sleep health exist, some studies noted that the effects were attenuated after controlling for demographic factors (i.e., education, income) and racism-related variables (i.e., racism-related vigilance) (Hicken et al., 2013). Racial disparities in sleep health are not merely racial differences. Specifically, racial discrimination may be an underlying factor for poor sleep health (Hicken et al., 2013; William & Mohammed, 2009). Future studies should not only describe sleep health in pregnancy through self-identified race ethnicity, but also through the experiences related to better understand racial differences in sleep health during pregnancy.

There are some strengths of our study. This is the first study to our knowledge that uses a multi-dimensional sleep framework to describe sleep during pregnancy. Furthermore, we described sleep timing and regularity in pregnancy, which have not been widely assessed when describing sleep patterns in pregnancy.

There are also some limitations to our study. First, as a secondary analysis, we only have self-reported sleep data available in the first and the third study visits, covering the first and the second trimesters. We are unable to characterize multidimensional sleep health in prepregnancy or late pregnancy states. Therefore, while previous studies indicated sleep deteriorates in late pregnancy with significant body discomfort, we cannot capture sleep health in later pregnancy (Hedman et al., 2002; Hutchison et al., 2012). However, we still have a longitudinal assessment of sleep to indicate the changes from early to mid-pregnancy and understand how each sleep dimension differs between the first and second trimesters. Second, the empirical cutoffs we used for dichotomizing sleep dimensions were based on general populations but not specifically on pregnant populations. More studies on exploring thresholds for each sleep dimension is necessary to establish thresholds for good sleep health in pregnant populations. Third, our data was limited to self-reported sleep data. While nuMom2b study had a substudy that collected actigraphy data on sleep health in pregnancy, the substudy has different subsample and it did not overlap the self-reported assessment. Furthermore, self-reported data offers better assessment on sleep satisfaction and sleepiness (Zhang & Zhao, 2007). Future studies may include both subjective and objective assessment in describing multidimensional sleep health during pregnancy. Fourth, we described sleep health in pregnancy among nulliparous women. The results are not representative of multiparous populations. Furthermore, we are unable to assess the effects of parity, which has been identified as an important factor for poor sleep health in pregnancy (Christian et al., 2019; Lee et al., 2000). Future studies on assessing multidimensional sleep health in pregnancy should include multiparous women to describe sleep health in pregnancy by parity. Lastly, our statistically significant results do not necessarily reflect clinical meaningfulness on the changes of sleep health during pregnancy. While the clinically significant level of sleep health is not yet clear, we should interpret our results with cautions. More studies are needed to better establish the clinically meaningful changes in sleep health during pregnancy.

6.6 Conclusion

The majority of our study sample were characterized in 4 to 5 good sleep health dimensions out of all 7 sleep dimensions. Furthermore, the composite sleep health scores were consistent from early to mid-pregnancy. However, there are changes in specific sleep dimensions. Sleep satisfaction, duration, and continuity declined while sleep timing was consistent and regularity improved from early to mid-pregnancy. Future studies should identify the risk factors for poor sleep health in pregnancy under a multidimensional concept to seek solution for improving sleep health in pregnancy and further reduce the risks for poor obstetric outcomes.

6.7 Aim 1 Tables and Figures

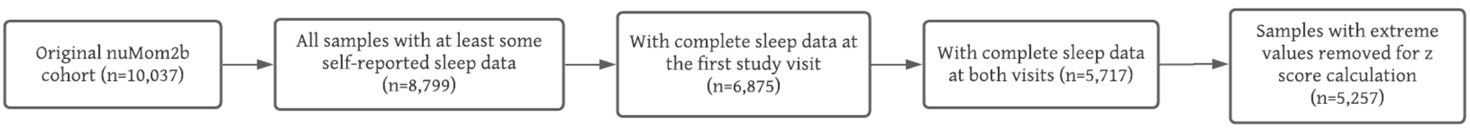

Figure 10. Aim 1 Participant Flowchart

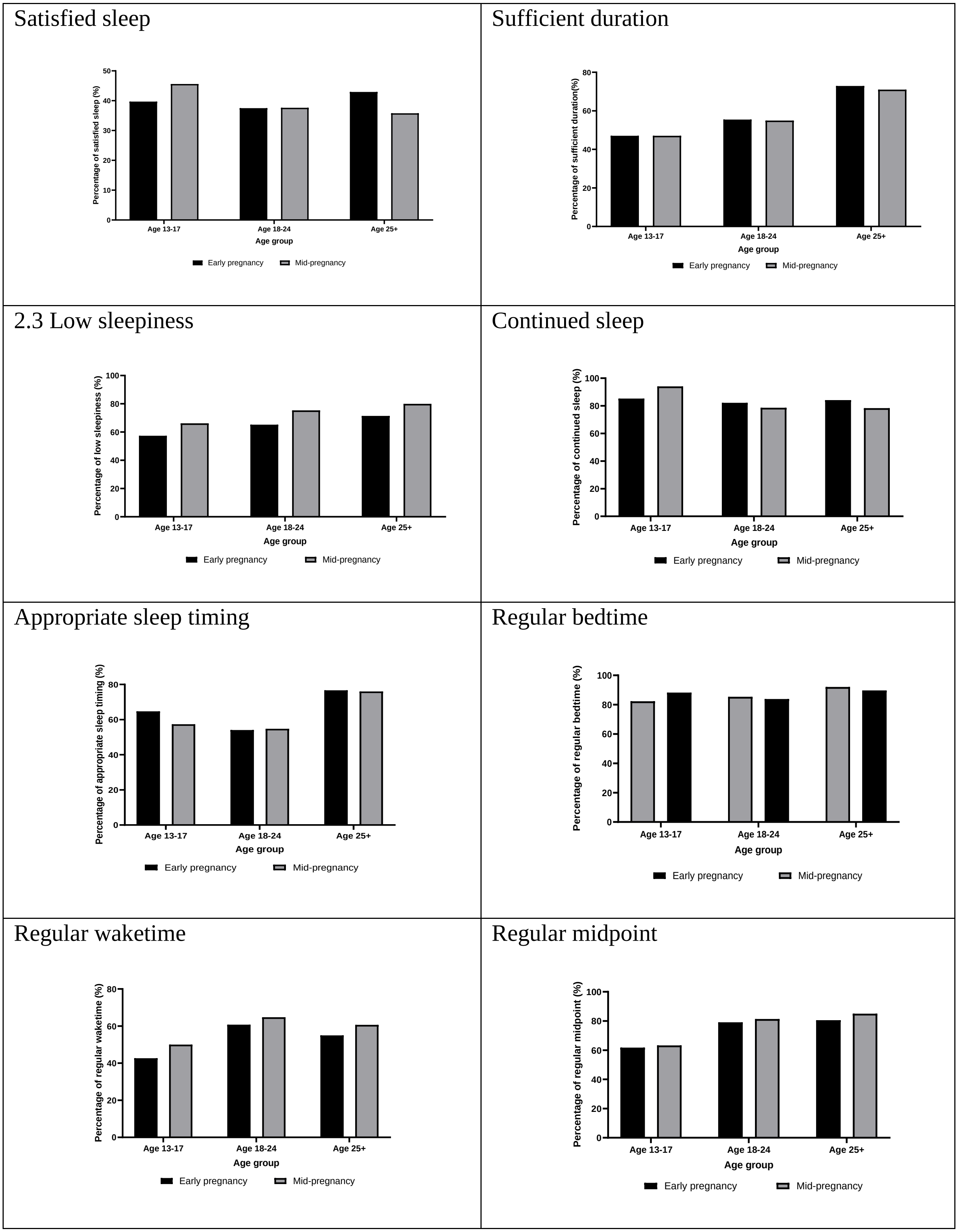

Figure 11. Percentage of Categorized Sleep Dimensions in Early and Mid-pregnancy by Age Groups

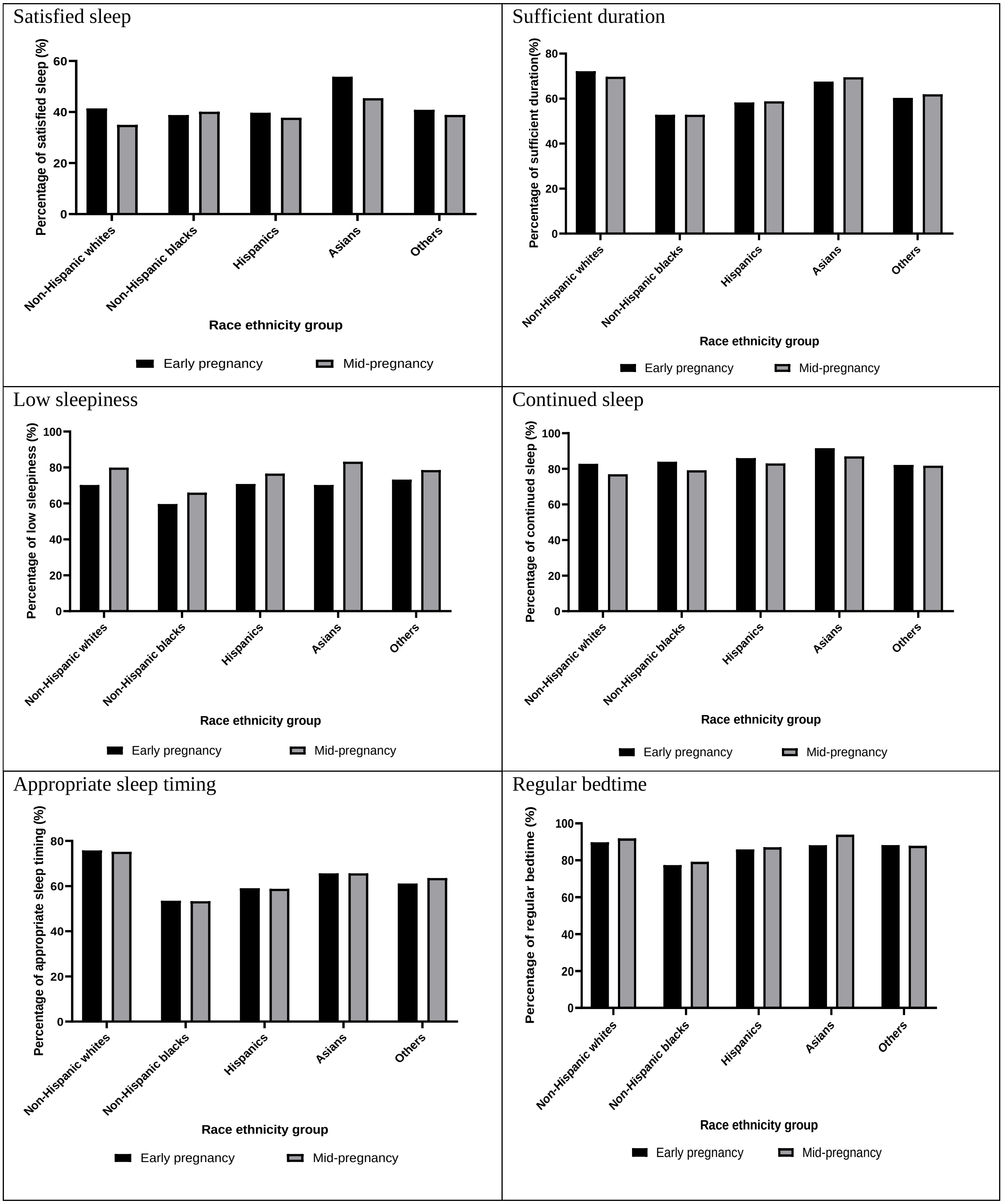

Figure 12. Percentage of Categorized Sleep Dimensions in Early and Mid-pregnancy by Race Ethnicity Groups

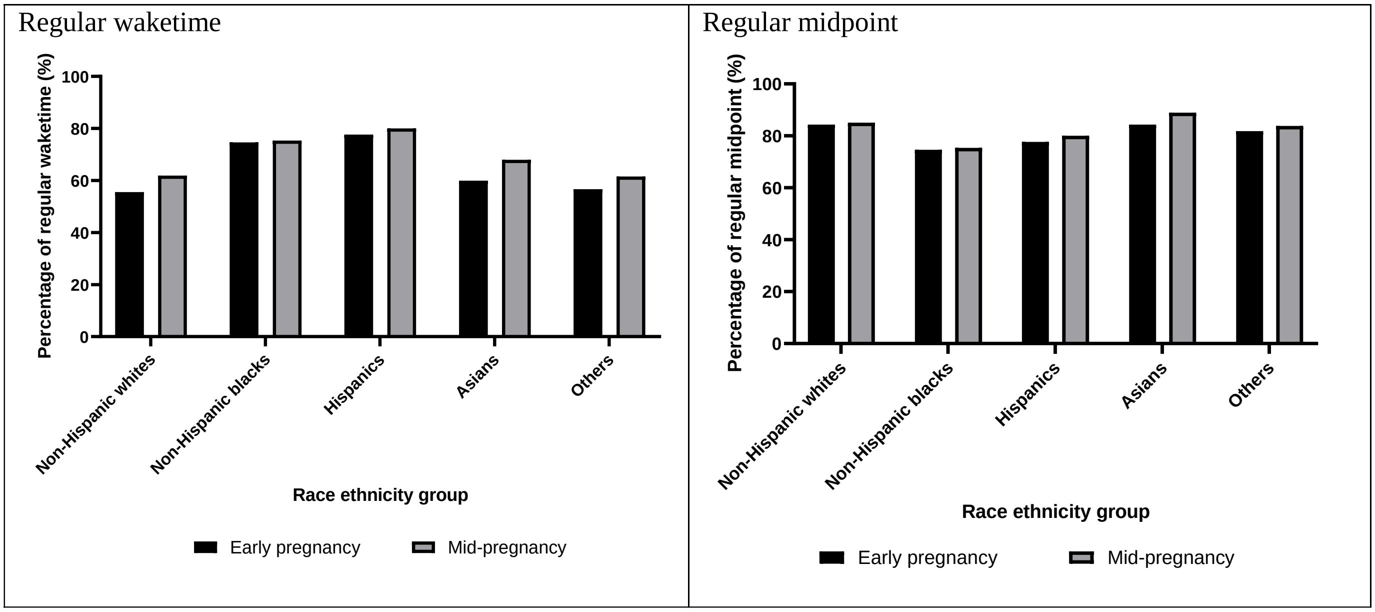

Figure 12. Percentage of Categorized Sleep Dimensions in Early and Mid-pregnancy by Race Ethnicity Groups (cont).

Table 5. Aim 1 Demographic Characteristics of the Study Sample

	Complete case (n=5,717)
Variables	Mean ± SD
Gestational age at enrollment (weeks)	11.59±1.49
Maternal age at enrollment (years)	28.08±5.23
Variables	N (%)
Race ethnicity	
Non-Hispanic White	4054 (70.91)
Non-Hispanic Black	394 (6.89)
Hispanic	760 (13.29)
Asian	262 (4.58)
Other[a]	247 (4.32)
Prepregnancy BMI categories	
<18.5 kg/m^2 (Underweight)	114 (2.02)
18.5-<25 kg/m^2 (Normal weight)	3096 (54.77)
25-<30 kg/m^2 (Overweight)	1419 (25.10)
30-<35 kg/m^2 (Obese)	593 (10.49)
35+ kg/m^2 (Morbidly obese)	431 (7.62)
Educational level	
Less than high school degree	218 (3.81)
High school graduated or GED	440 (7.70)
Some college	922 (16.13)
Assoc/Tech college	541 (9.46)
Completed college	1946 (34.04)
Beyond college degree	1649 (28.85)
Gravidity	
1	4368 (76.40)
2	1043 (18.24)
3+	306 (5.35)
Insurance type (May be more than one type)[b]	
Governmental	1004 (17.64)
Military	43 (0.76)
Commercial	4519 (79.39)
Personal income	1165 (20.47)
Other	64 (1.12)

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other
[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size
*p<0.05; **p<0.01

Table 5. Aim 1 Demographic Characteristics of the Study Sample (cont.)

	Complete case (n=5,717)
Variables	N (%)
Income in percentage of federal poverty level (%)	
>200%	3933 (78.53)
100-200%	613 (12.24)
<100%	462 (9.23)

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other
[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size
*p<0.05; **p<0.01

Table 6. Aim 1 Description and Changes of Sleep Dimensions from Early to Mid-pregnancy

	Early pregnancy	Mid-pregnancy	Difference [a]			
Sleep dimensions	Mean ± SD	Mean ± SD	Mean ± SD	Effect size	t statistic	p-values
Duration (hr)	7.96±1.19	7.79±1.22	0.17±1.13	0.15	11.43	<.0001**
Epworth Sleepiness Scale (ESS) Score	7.68±3.98	6.49±3.95	1.20±3.68	0.32	24.57	<.0001**
Wake after sleep onset (WASO, min)	22.71±26.12	27.34±28.43	-4.63±27.73	-0.17	-12.63	<.0001**
Midpoint sleep (a.m.) [b]	3:10 (1:16)	3:09 (1:19)	0:00 (0:35)	0.01 [c]	0.82 [c]	0.3917 [c]
Weekend-weekday difference in bedtime (hr)	0.97±1.29	0.86±1.21	0.12±1.13	0.10	7.80	<.0001**
Weekend-weekday difference in waketime (hr)	1.73±1.38	1.59±1.33	0.15±1.24	0.12	8.86	<.0001**
Weekend-weekday difference in midpoint sleep (hr)	1.39±1.64	1.22±1.40	0.16±1.49	0.13	10.01	<.0001**
Percentage of good sleep health	n (%)	n (%)	%	Effect size	X^2 statistic	p-values
Good sleep satisfaction	2376 (41.56)	2078 (36.35)	5.21	0.55	1739.72	<.0001**
Sufficient duration	3904 (68.29)	3816 (66.75)	1.54	0.32	588.54	<.0001**
Low sleepiness	3986 (69.72)	4496 (78.64)	-8.92	0.38	826.46	<.0001**
Continued sleep	4785 (83.70)	4493 (78.59)	5.11	0.39	857.38	<.0001**
Appropriate sleep timing	4056 (70.95)	4034 (70.56)	0.39	0.56	1763.53	<.0001**
Regular bedtime	5045 (88.25)	5163 (90.31)	-2.06	0.37	777.57	<.0001**
Regular waketime	3215 (56.24)	3519 (61.55)	-5.31	0.45	1136.13	<.0001**
Regular midpoint	4572 (79.97)	4794 (83.86)	-3.89	0.43	1072.93	<.0001**

[a] Differences were calculated by early minus mid-pregnancy; the differences in percentages were the percentage of good sleep health in early pregnancy minus mid-pregnancy

[b] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours

[c] The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test and the effect size was calculated through z score divided by the square root of n

*p<0.05; **p<0.01

Table 7. Aim 1 Composite Sleep Health score of the Overall Sample, by Age and Race Ethnicity

	Early (Mean ± SD)	Mid (Mean ± SD)	Difference (Mean ± SD) [a]	Effect size	t statistic	p-value
Overall sample (n=5,257)	5.31±0.56	5.28±0.58	0.03±0.54	0.06	4.00	<.0001**
Age	Early (Mean ± SD)	Mid (Mean ± SD)	Difference (Mean ± SD) [a]	Effect size	t statistic	p-value
13-17 (n=60)	5.12±0.63	5.32±0.56	-0.20±0.73	0.09	5.75	0.0385
18-24 (n=1,252)	5.23±0.59	5.24±0.60	-0.02±0.59	-0.03	-0.92	0.3391
25+ (n=3,945)	5.34±0.54	5.29±0.57	0.05±0.52	-0.27	-2.11	<.0001**
Race ethnicity	Early (Mean ± SD)	Mid (Mean ± SD)	Difference (Mean ± SD) [a]	Effect size	t statistic	p-value
Non-Hispanic White (n=3,754)	5.32±0.55	5.28±0.58	0.04±0.53	0.08	4.81	<.0001**
Non-Hispanic Black (n=331)	5.17±0.58	5.19±0.60	-0.02±0.63	-0.03	-0.49	0.6253
Hispanics (n=699)	5.26±0.59	5.27±0.60	-0.01±0.57	-0.01	-0.23	0.8164
Asians (n=245)	5.48±0.51	5.46±0.51	0.02±0.54	0.04	0.58	0.5604
Others (n=228)	5.31±0.57	5.29±0.55	0.02±0.56	0.04	0.66	0.5073

[a] Differences were calculated by early minus mid-pregnancy

*p<0.05; **p<0.01

Table 8. Aim 1 Changes of Sleep Dimensions Between Study Visit 1 and 3 by Age

13-17 (n=68)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	8.37±1.42	8.57±1.37	-1.03	0.3074
Epworth Sleepiness Scale (ESS) Score	8.67±4.09	7.34±4.46	2.60	0.0115*
Wake after sleep onset (WASO, min)	21.22±25.61	16.43±20.96	1.58	0.118
Midpoint sleep (a.m.) [a]	3:21 (1:45)	3:37 (1:46)	-363.5	0.0163*
Weekend-weekday difference in bedtime (hr)	0.89±0.73	1.02±1.44	-0.60	0.5486
Weekend-weekday difference in waketime (hr)	2.34±1.97	1.87±1.78	1.67	0.0988
Weekend-weekday difference in midpoint sleep (hr)	1.57±1.21	1.35±1.20	1.21	0.2289
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	27 (39.71)	31 (45.59)	8.02	0.0046**
Sufficient duration	32 (47.06)	32 (47.06)	0.89	0.3447
Low sleepiness	39 (57.35)	45 (66.18)	7.24	0.0071**
Continued sleep	58 (85.29)	64 (94.12)	12.32	**0.0088****
Appropriate sleep timing	44 (64.71)	39 (57.35)	3.73	0.0534
Regular bedtime	60 (88.24)	56 (82.35)	2.46	**0.1414**
Regular waketime	29 (42.65)	34 (50.00)	2.95	0.0861
Regular midpoint	42 (61.76)	43 (63.24)	3.17	0.0749
18-24 (n=1,411)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	8.27±1.50	8.14±1.57	3.29	0.0010**
Epworth Sleepiness Scale (ESS) Score	8.10±4.18	6.75±4.24	12.11	<.0001**
Wake after sleep onset (WASO, min)	24.09±29.81	27.21±31.08	-3.79	0.0002**
Midpoint sleep (a.m.) [a]	3:44 (1:43)	3:41 (1:38)	25159.50	0.0910
Weekend-weekday difference in bedtime (hr)	1.01±1.40	0.90±1.16	2.83	0.0048**
Weekend-weekday difference in waketime (hr)	1.59±1.53	1.47±1.42	2.86	0.0044**
Weekend-weekday difference in midpoint sleep (hr)	1.34±1.91	1.18±1.52	3.38	0.0020**
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	529 (37.49)	531 (37.63)	207.56	<.0001**
Sufficient duration	783 (55.49)	775 (54.93)	104.46	<.0001**
Low sleepiness	920 (65.20)	1063 (75.34)	145.10	<.0001**
Continued sleep	1160 (82.21)	1109 (78.60)	224.50	<.0001**
Appropriate sleep timing	763 (54.08)	773 (54.78)	360.93	<.0001**
Regular bedtime	1183 (83.84)	1205 (85.40)	112.20	<.0001**
Regular waketime	857 (60.74)	914 (64.78)	196.62	<.0001**
Regular midpoint	1116 (79.09)	1148 (81.36)	174.70	<.0001**

[a] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours. The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test

[b] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

*p<0.05; **p<0.01; Bolded p-values were results from Fisher's exact tests

Table 8. Aim 1 Changes of Sleep Dimensions Between Study Visit 1 and 3 by Age (cont.)

25+ (n=4,238)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	7.85±1.04	7.66±1.04	12.73	<.0001**
Epworth Sleepiness Scale (ESS) Score	7.53±3.90	6.39±3.83	21.35	<.0001**
Wake after sleep onset (WASO, min)	22.27±24.77	27.56±27.57	-12.94	<.0001**
Midpoint sleep (a.m.) [a]	3:01 (1:06)	3:17 (1:08)	20281.5	0.7891
Weekend-weekday difference in bedtime (hr)	0.96±1.26	0.84±1.23	7.99	<.0001**
Weekend-weekday difference in waketime (hr)	1.77±1.31	1.62±1.29	8.95	<.0001**
Weekend-weekday difference in midpoint sleep (hr)	1.40±1.55	1.23±1.36	10.07	<.0001**
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	1820 (42.94)	1516 (35.77)	605.11	<.0001**
Sufficient duration	3089 (72.89)	3009 (71.00)	431.56	<.0001**
Low sleepiness	3027 (71.43)	3388 (79.94)	680.09	<.0001**
Continued sleep	3567 (84.17)	3320 (78.34)	624.57	<.0001**
Appropriate sleep timing	3249 (76.66)	3222 (76.03)	1306.45	<.0001**
Regular bedtime	3802 (89.71)	3902 (92.07)	720.53	<.0001**
Regular waketime	2329 (54.96)	2571 (60.67)	940.02	<.0001**
Regular midpoint	3414 (80.56)	3603 (85.02)	923.68	<.0001**

[a] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours. The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test

[b] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

*p<0.05; **p<0.01; Bolded p-values were results from Fisher's exact tests

Table 9. Aim 1 Changes of Sleep Dimensions Between Study Visit 1 and 3 by Race Ethnicity

Non-Hispanic Whites (n=4,054)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	7.92±1.05	7.75±1.07	11.11	<.0001**
Epworth Sleepiness Scale (ESS) Score	7.66±3.89	6.41±3.83	22.83	<.0001**
Wake after sleep onset (WASO, min)	23.45±25.84	28.69±28.34	-12.12	<.0001**
Midpoint sleep (a.m.) [a]	3:02 (1:08)	3:00 (1:09)	128160.5	0.0730
Weekend-weekday difference in bedtime (hr)	0.97±1.27	0.85±1.22	7.30	<.0001**
Weekend-weekday difference in waketime (hr)	1.75±1.33	1.59±1.29	8.73	<.0001**
Weekend-weekday difference in midpoint sleep (hr)	1.38±1.49	1.23±1.36	9.15	<.0001**
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	1679 (41.42)	1418 (34.98)	559.30	<.0001**
Sufficient duration	2927 (72.20)	2826 (69.71)	407.55	<.0001**
Low sleepiness	2848 (70.25)	3242 (79.97)	600.39	<.0001**
Continued sleep	3357 (82.81)	3120 (76.96)	598.18	<.0001**
Appropriate sleep timing	3073 (75.80)	3048 (75.19)	1256.77	<.0001**
Regular bedtime	3638 (89.74)	3726 (91.91)	679.50	<.0001**
Regular waketime	2251 (55.53)	2508 (61.86)	929.01	<.0001**
Regular midpoint	221 (84.35)	3449 (85.08)	889.64	<.0001**
Non-Hispanic Black (n=394)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	7.98±1.78	7.89±1.91	1.11	0.2688
Epworth Sleepiness Scale (ESS) Score	8.62±4.38	7.61±4.35	4.59	<.0001**
Wake after sleep onset (WASO, min)	23.60±30.90	26.74±32.20	-2.10	0.0366*
Midpoint sleep (a.m.) [a]	3:39 (1:42)	3:44 (1:42)	-621.00	0.7775
Weekend-weekday difference in bedtime (hr)	1.12±1.40	1.06±1.47	0.80	0.4267
Weekend-weekday difference in waketime (hr)	1.68±1.70	1.54±1.67	1.46	0.1499
Weekend-weekday difference in midpoint sleep (hr)	1.45±1.96	1.34±2.05	1.81	0.0704
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	153 (38.83)	158 (40.10)	63.04	<.0001**
Sufficient duration	208 (52.79)	208 (52.79)	34.82	<.0001**
Low sleepiness	235 (59.64)	260 (65.99)	71.18	<.0001**
Continued sleep	331 (84.01)	312 (79.19)	71.01	<.0001**
Appropriate sleep timing	211 (53.55)	210 (53.30)	74.18	<.0001**
Regular bedtime	305 (77.41)	312 (79.19)	36.93	<.0001**
Regular waketime	233 (59.14)	243 (61.68)	33.11	<.0001**
Regular midpoint	294 (74.62)	297 (75.38)	44.13	<.0001**

[a] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours. The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test

[b] Other racial ethnicity groups include American Indian, Native Hawaiian, Multiracial, and other

*p<0.05; **p<0.01; Bolded p-values

Table 9. Aim 1 Changes of Sleep Dimensions Between Study Visit 1 and 3 by Race Ethnicity (cont.)

Hispanics (n=760)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	8.25±1.43	8.04±1.40	4.47	<.0001**
Epworth Sleepiness Scale (ESS) Score	7.50±4.29	6.43±4.37	6.98	<.0001**
Wake after sleep onset (WASO, min)	20.52±25.67	23.50±27.94	-2.95	0.0032**
Midpoint sleep (a.m.) [a]	3:34 (1:37)	3:33 (1:37)	-7291.00	0.2047
Weekend-weekday difference in bedtime (hr)	0.97±1.29	0.85±1.06	2.75	0.0062**
Weekend-weekday difference in waketime (hr)	1.70±1.46	1.62±1.42	1.67	0.0954
Weekend-weekday difference in midpoint sleep (hr)	1.40±1.91	1.22±1.41	2.80	0.0053**
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	302 (39.74)	287 (37.76)	114.41	<.0001**
Sufficient duration	443 (58.29)	447 (58.82)	73.73	<.0001**
Low sleepiness	538 (70.79)	582 (76.58)	99.68	<.0001**
Continued sleep	654 (86.05)	631 (83.03)	89.97	<.0001**
Appropriate sleep timing	449 (59.08)	447 (58.82)	247.33	<.0001**
Regular bedtime	653 (85.92)	662 (87.11)	56.73	<.0001**
Regular waketime	434 (57.11)	438 (57.63)	104.37	<.0001**
Regular midpoint	590 (77.63)	608 (80.00)	105.95	<.0001**
Asians (n=262)	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	7.81±1.66	7.67±1.11	2.29	0.0229*
Epworth Sleepiness Scale (ESS) Score	7.58±3.83	6.18±3.88	5.68	<.0001**
Wake after sleep onset (WASO, min)	15.97±19.81	20.51±23.57	-3.31	0.0011
Midpoint sleep (a.m.) [a]	3:24 (1:20)	3:33 (1:11)	-678.00	0.5523
Weekend-weekday difference in bedtime (hr)	0.93±1.55	0.74±1.18	2.52	0.0122*
Weekend-weekday difference in waketime (hr)	1.67±1.43	1.47±1.31	2.78	0.0058**
Weekend-weekday difference in midpoint sleep (hr)	1.30±1.48	1.06±1.14	3.40	0.0008
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	141 (53.82)	119 (45.42)	29.87	<.0001**
Sufficient duration	177 (67.56)	182 (69.47)	18.59	<.0001**
Low sleepiness	184 (70.23)	218 (83.21)	18.50	<.0001**
Continued sleep	240 (91.60)	228 (87.02)	45.22	**<.0001** **
Appropriate sleep timing	172 (65.65)	172 (65.65)	72.52	<.0001**
Regular bedtime	231 (88.17)	246 (93.89)	23.80	**0.0001** **
Regular waketime	157 (59.92)	178 (67.94)	46.84	<.0001**
Regular midpoint	221 (84.35)	233 (88.93)	61.44	**<.0001** **

[a] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours. The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test

[b] Other racial ethnicity groups include American Indian, Native Hawaiian, Multiracial, and other

*p<0.05; **p<0.01; Bolded p-values were results from Fisher's exact tests

Table 9. Aim 1 Changes of Sleep Dimensions Between Study Visit 1 and 3 by Race Ethnicity (cont.)

Others (n=247) [b]	Early	Mid		
Sleep dimensions	Mean ± SD	Mean ± SD	t statistics	p-values
Duration (hr)	7.90±1.27	7.76±1.43	1.55	0.1220
Epworth Sleepiness Scale (ESS) Score	7.32±3.72	6.45±3.63	3.66	0.0003
Wake after sleep onset (WASO, min)	23.02±28.37	28.20±27.57	-1.07	0.2854
Midpoint sleep (a.m.) [a]	3:20 (1:40)	3:19 (1:30)	658.00	0.5397
Weekend-weekday difference in bedtime (hr)	0.89±1.19	0.83±0.99	0.59	0.5543
Weekend-weekday difference in waketime (hr)	1.62±1.28	1.53±1.17	1.10	0.2713
Weekend-weekday difference in midpoint sleep (hr)	1.45±2.49	1.13±0.91	0.97	0.3306
Percentage of good sleep health	n (%)	n (%)	X^2 statistics	p-values
Good sleep satisfaction	101 (40.89)	96 (38.87)	46.73	<.0001**
Sufficient duration	149 (60.32)	153 (61.94)	17.70	<.0001**
Low sleepiness	181 (73.28)	194 (78.54)	27.01	<.0001**
Continued sleep	203 (82.19)	202 (81.78)	47.42	<.0001**
Appropriate sleep timing	151(61.13)	157 (63.56)	53.71	<.0001**
Regular bedtime	218 (88.26)	217 (87.85)	15.36	**0.0007**
Regular waketime	140 (56.68)	152 (61.54)	43.01	<.0001**
Regular midpoint	202 (81.78)	207 (83.81)	9.63	0.0019**

[a] Timings (i.e., midpoint sleeps) were presented in medians of time and interquartile ranges in hours, the difference between two timepoints were the median and IQR in hours. The test statistics of midpoint sleep in a.m. was presented based on the Wilcoxon signed-rank test

[b] Other racial ethnicity groups include American Indian, Native Hawaiian, Multiracial, and other

*p<0.05; **p<0.01; Bolded p-values were results from Fisher's exact tests

7.0 Aim 2. The Association Between Prenatal Depression and Sleep Health in Nulliparous Pregnancy

7.1 Abstract

Background

Poor sleep health in pregnancy is crucial to maternal and infant health. It increases the inflammatory responses, affects metabolism, and is associated with various adverse pregnancy outcomes While research has been identifying risk factors for poor sleep health in pregnancy, the close relationship between depression and sleep suggests that prenatal depression may potentially impact sleep health in pregnancy. However, the findings on prenatal depression as a risk factor for poor sleep health in pregnancy are limited.

Methods

We used self-reported Edinburgh Postnatal Depression Scale (EPDS) and sleep data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMoM2b) in early and mid-pregnancy. 5,165 participants had complete EPDS and sleep data from both timepoints. We identified total EPDS score of 10 or higher as probable prenatal depression. We measured satisfaction, daytime sleepiness, timing, continuity, duration, and bedtime, waketime regularity, and used composite sleep health score to measure multidimensional sleep health. We assessed the cross-sectional association between prenatal depression and sleep health in early and mid-pregnancy and longitudinal association between prenatal depression in early pregnancy and sleep health in mid-pregnancy.

Results

There are cross-sectional and longitudinal associations between prenatal depression and lower odds of characterized as "good" sleep health in satisfaction, duration, daytime sleepiness, good sleep continuity, and good sleep timing in both early and mid-pregnancy. Pregnant people with probable prenatal depression also had lower composite sleep health score in early and mid-pregnancy than people without (Early: β=-0.19, $p<.0001$; Mid: β=-0.27, $p<.0001$; Longitudinal: β=-0.14, $p<.0001$).

<u>Conclusion</u>

Prenatal depression may be a potential factor that affects sleep health in pregnancy. More findings on the relationships between prenatal depression and multidimensional sleep health are warranted to better understand how mental health management can improve individual sleep dimensions and overall multidimensional sleep health during pregnancy, which can further reduce adverse maternal health outcomes attributed to poor sleep health.

7.2 Background

Sleep is a recurring, dynamic state that reduces body consciousness and interaction with the environment while maintaining body restoration towards muscular, immune, and nervous systems (National Institute of Neurological Disorders and Stroke, 2019) The renormalization of molecular, cellular, and cognitive functions occurs during sleep (Vyazovskiy, 2015). Therefore, sleep is fundamental to one's health and well-being. Specifically, it is important to examine sleep health in pregnancy due to substantial physical and hormonal changes. Prior studies have examined factors associated with poor sleep health in pregnancy, including overweight and obese, poor sleep hygiene (i.e., high arousal behaviors, disturbed sleep environment), Black race, low socioeconomic levels, and disadvantaged neighborhood (Gay et al., 2017; Tsai et al., 2016; Feinstein et al., 2020; Kalmbach et al., 2019; Johnson et al., 2009).

Poor sleep health in pregnancy is crucial to maternal and infant health. It increases the inflammatory responses, affects metabolism, and is associated with various adverse pregnancy outcomes (Okun et al., 2009). Poor sleep quality and short sleep duration affect glucose metabolism and lead to a higher risk of insulin resistance and gestational diabetes. An Asian cohort of 686 pregnant people reported 1.75 times higher odds of gestational diabetes among pregnant people with poor sleep quality (95%CI: 1.11-2.76) and 1.96 times higher odds of gestational diabetes among pregnant people with short sleep duration (95%CI: 1.05-3.66) (Cai et al., 2017). Another study also found 96.4% reported poor sleep quality among high-risk pregnant people (i.e., gestational hypertension and gestational diabetes) (Saadati et al., 2018). Poor sleep health in pregnancy is also related to higher risks of prolonged labor and cesarean delivery. A prospective study of a US sample included 131 women in their last month of pregnancy indicated that short sleep duration (<6 hours) is related to 4.5 times higher odds in cesarean delivery (OR=4.54, 95%CI: 1.36-15.21) and significantly longer labor (29.0±12.5 hours) than women with over 7 hours of nighttime sleep (17.7±15.6, p=0. 025) (Lee & Gay, 2004).

Sleep health has been defined as a multidimensional behavior that can be assessed through: sleep quality, duration, efficiency, sleepiness, timing, and regularity (Buysse, 2014). Sleep dimensions other than sleep quality and duration may also impact maternal health. For example, while examining the risks for poor pregnancy outcomes, later sleep timing (I.e., midpoint sleep later than 5 am) has 2.4 times higher odds of gestational diabetes (Facco et al., 2017). However, the findings on sleep dimensions other than sleep quality and duration were limited. While there are potential effects of multiple sleep dimensions on maternal health, understanding multidimensional sleep health during pregnancy and identifying associated risk factors are essential for developing interventions on promoting sleep health in pregnancy. Understanding how intervening factors may improve specific or multidimensional sleep health during pregnancy is critical to further lowering the risks for adverse pregnancy outcomes associated with poor sleep health.

Prenatal depression is the depression episode that occurs specifically during pregnancy (American Psychiatric Association, 2013) With substantial physical and hormonal changes in pregnancy, the prevalence of prenatal depression ranges from 7 to 13%, where the lowest prevalence was seen in the first trimester (7.4%) (Bennett et al., 2004). There are also systematic reviews targeting pregnant people at prenatal clinics or from developed countries and reported 6.6 to 26.7% of prevalence in prenatal depression (Gavin et al., 2005; Okagbue et al., 2019). Prior studies have identified a close relationship between depression and sleep health, specifically on explaining its highly overlapping biological mechanisms (Fang et al., 2019). While sleep deficiency activates the inflammation response and increases cellular inflammation, studies have also seen such increased cellular inflammation among patients with depression and more obvious in females (Gimeno et al., 2009; Miller et al., 2009). Recent sleep research has targeted non-pregnant population and examined the association between depression and sleep with the implementation of multidimensional sleep health as an outcome. A recent study examined the longitudinal association between depressive symptoms and multidimensional sleep health among middle-aged women. The results indicated the association between higher depressive symptoms and poorer multidimensional sleep health, lower alertness, and satisfaction (Bowman et al., 2021). However, the findings examining prenatal depression as a potential risk factor for poor sleep health in pregnancy were limited. Furthermore, sleep outcomes were not considered under a multidimensional concept while we seek improvement in multidimensional sleep health during pregnancy. With the goal of identifying risk factors to improve prenatal sleep health, it is crucial to consider prenatal depression as a potential factor that we can include for sleep improvement in pregnancy.

Hence, this study is to identify whether prenatal depression is a risk factor for poor sleep health under the multidimensional concept in pregnancy. We first examined the cross-sectional association between prenatal depression and multidimensional sleep health in early and mid-pregnancy. Then, we assessed the longitudinal association between prenatal depression in early pregnancy and sleep health in mid-pregnancy. We hypothesized that pregnant people with self-rated prenatal depression are at higher risks for poor sleep health throughout pregnancy. We also hypothesized that pregnant people with self-rated prenatal depression in early pregnancy may also be at higher risk of poor sleep health in mid-pregnancy. The findings from this study will be beneficial for sleep interventions targeting the pregnant population to consider improving mental health as one of the possible strategies for sleep health improvement during pregnancy. The study will also suggest that the management of mental health could improve specific sleep dimensions and multidimensional sleep health during pregnancy. The successful implementation of mental health factor management will be beneficial for reducing adverse pregnancy outcomes attributed to poor sleep health in pregnancy

7.3 Methods

Study design and settings

We used the data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMom2b). The nuMom2b study is a multi-site prospective cohort study conducted from 2010 to 2013 to assess the relationship between maternal characteristics (genetic and physiologic factors) and adverse obstetric outcomes. There were 8 research sites, including Case Western University, Columbia University; Indiana University, University of Pittsburgh; Northwestern University; the University of California at Irvine; University of Pennsylvania; and the University of Utah. There were 3 time points of data collection during pregnancy. The first visit was completed between 6 weeks+0 days and 13 weeks+6 days of gestation, the second visit was conducted between 16 weeks+0 days and 21 weeks+6 days of gestation, and the third study visit was between 22 weeks+0 days and 29 weeks+6 days of gestation. The second and the third visits occurred at least 4 weeks apart from the last study visit. Participants signed the informed consent before the first study visits. The study has been approved by the Institutional Review Boards with the Protection of Human Subjects of all study sites. Haas et al.'s protocol paper described additional details on study procedures (Haas et al., 2015).

Study sample

Pregnant people who planned to deliver at the hospitals affiliated with the study sites were screened for eligibility. The inclusion criteria are: (1) a viable, singleton pregnancy between 6 weeks+0 days to 13 weeks+6 days of gestation based on the ultrasound assessment, (2) no previous pregnancy that lasted 20 weeks based on self-reported data and verified through medical records, if available. Exclusion criteria included pregnant people under age 13, or with a previous history of 3 or more spontaneous abortions and known fetal complications were excluded. Further details about the inclusion and exclusion criteria were listed in the Haas et al. protocol paper (Haas et al., 2015). There are 10,037 participants in the overall nuMom2b cohort. In our study, we further excluded women with no baseline sleep or EPDS data. 8,317 participants have some sleep and Edinburgh Postnatal Depression Scale (EPDS) data, 5,229 have complete sleep data, and 5,165 have a complete sleep and EPDS data. (Figure 13)

Exposure- Prenatal depression

We used the Edinburgh Postnatal Depression Scale (EPDS) data that was collected during the first and the third visits to identify whether individuals are experiencing probable prenatal depression. The EPDS is a 10-item, 4-point self-reported scale for postnatal depression screening. The score ranges from 0 to 30 with a higher EPDS score indicates a greater level of probable prenatal depression. The EPDS is a valid tool to measure postpartum depression with 86% sensitivity and 78% specificity (Cox et al., 1987). It has also been widely used among pregnant people for screening prenatal depression and across different populations (Bergink et al., 2011; Rubertsson et al., 2011; Su et al., 2007).

While sleep health is the primary outcome of interest in the study, one of the questions in the EPDS was related to sleep: "*I have been so unhappy that I have had difficulty sleep*." To better distinguish our exposure and outcome of interest, we excluded this question when summing the EPDS score (Dørheim et al., 2009). We defined probable prenatal depression for individuals who had a sum of EPDS score ≥ 10. This cutoff has been applied in studies using same parent study and related to sleep and depression in pregnancy (Dørheim et al., 2009; Grobman et al., 2016). Though dichotomizing individuals into with or without probable prenatal depression may sacrifice the continuum nature of mental health, the application of EPDS cutoff provides us information for identifying high-risk groups with poor mental health and helps improve sleep health during pregnancy.

Outcome- Sleep health in pregnancy

We used self-reported sleep questionnaires collected at the first (early pregnancy) and the third (mid-pregnancy) study visits. We assessed sleep through the following dimensions: regularity, satisfaction, sleepiness, timing, wake after sleep onset (WASO), and duration. We also described the percentages of pregnant people characterized as “good” sleep health in each dichotomized dimension. We assessed sleep regularity through bedtime, waketime, and midpoint sleep differences between weekdays and weekends (Roepke & Duffy, 2010). A weekend-weekday difference less than 2 hours were defined as good bedtime, waketime, and midpoint sleep regularity (Beauvalet et al., 2017). Sleep satisfaction was assessed through a self-rated question: "Overall, was your typical night's sleep during the last 4 weeks: very good, good, fair, poor, very poor". Participants who rated "very good" or "good" were considered having satisfied sleep. We used the Epworth Sleepiness Scale (ESS) to assess daytime sleepiness, a measure of alertness. The ESS is an 8-item scale with each item scores from 0 to 3 and an overall ESS score ranging from 0 to 24. The higher ESS score indicates a higher level of daytime sleepiness (i.e., poorer alertness) (Johns, 1991). The ESS has acceptable internal consistency (Cronbach's alpha=0.77) for pregnant people and is a validated tool to assess daytime sleepiness (93.5% sensitivity and 100% specificity) (Johns, 2000; Johns, 1992; Tsai et al., 2016). We define good sleep health in this domain as a ESS score of 10 or lower (i.e., no excessive daytime sleepiness). For simplicity we will refer to good sleep health in this domain as low sleepiness (Johns et al., 1991). Sleep timing was defined through midpoint sleep. Midpoint sleep is the halfway point between sleep onset and the final time waking up to start the day. It was calculated through: bedtime + (wake time - bedtime) (Facco et al., 2017).

Midpoint sleep between 2 to 4 am was considered as good sleep timing (Dong et al., 2019). Wake after sleep onset (WASO), is a measure of sleep continuity, a similar construct as sleep efficiency. WASO was estimated by the sum of time spent awake between first fall asleep and fully awake through nighttime sleep (Ohayon et al., 2017). For simplicity, we define good sleep continuity as a WASO less than 40 minutes WASO (Ohayon et al., 2017). Sleep duration was estimated by taking a weighted average of workday/weekday and non-workday/weekend sleep duration: ([weekday/workday duration × 5] + [weekend duration × 2]) / 7 (Facco et al., 2018). Since the recommendation of sufficient sleep duration differs between adolescents and adults, we applied different cutoffs to define good sleep duration based on participants' age. For participants aged between 13 to 17 years, a weighted sleep duration between 8 to 10 hours was considered good sleep duration. For participants aged 18 or higher, a weighted sleep duration between 7 to 9 hours was considered good sleep duration (Hirshkowitz et al., 2015). (Table 4)

After describing each sleep dimension, we created a composite sleep health score by summing the calculated z scores of each dimension centering from our identified empirical cutoffs (Brindle et al., 2019). Next, we recoded the z score of each dimension to reflect the higher score indicates better sleep health. Then, we scaled each recoded z score into a range of 0 to 1, with 1 indicating better sleep health in the respective sleep dimensions. Finally, we summed the scaled sleep health score and created a composite sleep health score for each individual. We included bedtime and waketime regularity to calculate the composite sleep health score. There are a total of 7 dimensions and score ranges from 0 to 7 with the higher score indicates better sleep health.

<u>Covariates</u>

We identified covariates through previous literatures including studies using data from the same parent study (Grobman et al., 2016; Facco et al., 2018). Demographic characteristics that were considered as covariates include: maternal age, race and ethnicity, educational level, insurance type and income level. Demographic characteristics were collected through self-reported questionnaires at the baseline visit. We described maternal age in the following categories: 13-17, 18-34, 35-39 and 40+ years. Five categories for race ethnicity: non-Hispanic white, non-Hispanic Black, Hispanic, Asian, and Other race ethnicity including American Indian, Native Hawaiian, and multiracial individuals. Educational level includes less than high school graduate, high school graduated/GED, associate or tech degree, some college, college graduated, and degree beyond college. There are some pregnancy-related and health behavioral variables included as covariates as well: gestational age at enrollment, prepregnancy BMI, gravidity, tobacco use and exercise. Gestational age was identified through ultrasound assessment, prepregnancy BMI was self-reported and gravidity was self-reported and further verified through medical records, if available. Subjects were overweight if prepregnancy BMI was between 18.5-25 kg/m^2 and obese if prepregnancy BMI was between 30-35 kg/m^2. Individuals with prepregnancy BMI of 35 kg/m^2 or higher were considered morbidly obese. We applied prepregnancy BMI in the adjusted model under the continuous form (kg/m2) instead of the overweight/obese categories. There are age and racial differences in body fat composition (Jackson et al., 2002; Wang et al., 1994) Therefore, BMI cutoffs for defining overweight and obese categories should be specific for the target population (Deurenberg et al., 1998; Hübers et al., 2017; Prentice & Jebb, 2001). Applying the same cutoffs for all pregnant people with different ages (adolescents and adults) and racial groups in our sample would bias the results. Tobacco use was measured in two domains, ever used tobacco and 3 months prior to pregnancy. Physical activity was assessed through a self-reported question: "During the past 4 weeks, did you participate in any physical activities or exercises like running, aerobics, gardening, ball games, or walking for exercise? - Yes, No". We also included social support a psychosocial covariate. Social support was assessed through the Multidimensional Scale of Perceived Social Support (MSPSS). The MSPSS is a self-reported, 12-item, 7-point scale that assesses individual's social support level through family, friends and significant other. The score ranges from 12 to 84 with the higher score indicates better social support (Ziment et al., 1990) The MSPSS is a valid instrument to assess individual's social support level in pregnancy with a reported Cronbach's alpha of 0.93 in a pregnant sample from Pakistan (n=1,154) (Mirabzadeh et al., 2013).

We applied directed acyclic graphs (DAG) to identify the confounding effects of covariates and make decision on what confounders to be included in the adjusted model. DAGs allow researchers to identify causal relationships between variables through background knowledge, empirical literature findings, theories, and assumptions (Greenland et al., 1999; Tennant et al., 2021). Based on the findings from previous literature, sleep health during pregnancy is associated with advanced maternal age, larger gestational age, pre-pregnancy weight, sleep hygiene, physical activity, and tobacco use. Social and demographic factors for sleep health include educational level, income level, and lacking social support. There are also racial/ethnic differences in sleep health during pregnancy. Residing in disadvantaged neighborhoods is an environmental factor that associates with poor sleep health but not considered as confounder with limited evidence on its association to prenatal depression. Prenatal depression is associated with young or advanced maternal age, race/ethnicity, prepregnancy obesity, and prior history of mental illness. Behavioral factors such as exercise and tobacco use could also impact prenatal depression. Some social and demographic factors for sleep health include educational level, income level, and lacking social support. The identified minimal sufficient adjustment sets from the DAG includes: maternal age, race ethnicity, educational level, poverty level, social support, smoking, and physical activity. We included the variables in the multivariate analysis for adjustment. (Figure 14) While DAGs were generated based on conceptual theories, there may be additional covariates that could potentially be added to the DAG such as marriage status and experiences of domestic violence. These are the underlying factors that may contribute to both occurrence of prenatal depression and poor sleep health during pregnancy. The DAGs that we applied in the dissertation were based on empirical literature and context expertise of the mentoring team."

To identify multicollinearity issues, we applied Spearman correlation to identify the correlation across variables. Maternal age, educational level, and poverty level had correlation over 0.5. (Appendix c) We further explored the variance inflation factor (VIF) and all variables had VIF less than 2.5. (Appendix Table 4) The multicollinearity issue was minor and all confounders in the minimum sufficient set were included for model adjustment. DAG represents the assumed causal relationship between the exposure, outcomes, and covariates. The DAG is created based on empirical literature and context expertise of the mentoring team. There may be various assumption within the assumed causal relationship. For example, the causal relationship between prepregnancy BMI and prenatal depression may go in both directions. Therefore, we further conducted sensitivity analysis to assess the adjusted estimates for the association between prenatal depression and sleep health with the removal of prepregnancy BMI in the adjusted model. (Appendix Table 5)

Statistical analysis

We first presented the demographic characteristics and the descriptive statistics of each sleep dimension and composite sleep health score of the overall sample and by the probable prenatal depression status (i.e., EPDS $\geq$ 10 out of 30). We also presented the demographic characteristics under the sample with some missing data to identify the differences in samples resulted from different level of data completeness. Next, we conducted bivariable analyses to examine the association between EPDS score, covariates and sleep health at early and mid-pregnancy with student's t-tests for the normally distributed continuous variables, Mann-Whitney tests for non-normally distributed continuous variables and chi-square tests for the categorical variables. We examined three associations: 1. Cross-sectional association between EPDS and sleep health in early pregnancy, 2. Cross-sectional association between EPDS and sleep health in mid-pregnancy, and 3. Longitudinal association between EPDS in early pregnancy and sleep health in mid-pregnancy. Finally, we applied the adjusted (confounders identifies through a DAG) linear regression analyses to examine these three proposed associations between prenatal depression and each sleep dimension (before dichotomized into "good" and "poor" dimensions). To help interpret the difference between exposure groups for ESS and composite sleep health scores, we standardized the scores. This allows us to interpret as how many standard deviations higher or lower in ESS and composite sleep health score among pregnant people with probable prenatal depression compared to pregnant people without probable prenatal depression. Logistic regression analyses were applied to assess these associations between prenatal depression and each sleep dimension after dichotomized into "good" and "poor" dimensions. Finally, we conducted and presented both crude and adjusted linear regression models for prenatal depression and composite sleep health score. We reported the odds ratios and 95% confidence intervals for each modeling analysis to present the estimated risks for poor sleep health among women with probable prenatal depression.

With the understanding that the sample with incomplete sleep data may show different characteristics than the complete case sample. We presented the appendix tables to describe and observe the differences in demographic characteristics and sleep health for each dimension within the sample with some but not complete sleep data.

We accepted a type 1 error (α=0.05) for determining the significance level of the statistical testing. We used SAS version 9.4 for data management and analyses (SAS Institute, Cary, NC).

7.4 Results

Participant characteristics

Among the study sample with complete EPDS and sleep data, the average maternal age was 28.16 years with the baseline gestational age of 11.60 weeks. 71.48% of our sample were self-reported non-Hispanic whites, followed by 13.18% Hispanic, and 6.33% non-Hispanic Black. 55.60% had normal weight (i.e., Prepregnancy BMI between 18.5 and 25 kg/m^2). Around 64.21% had a degree of college or higher. Over 80% had commercial insurance and 79% were over 200% of federal poverty level.

In early pregnancy, 531 (10.28%) participants had EPDS score 10 or higher and 4634 (89.72%) had EPDS lower than 10. There were significant differences in maternal age, race ethnicity, educational level, smoking status, social support score, exercise, insurance type, and poverty level. Pregnant people with EPDS $\geq$10 in early pregnancy were younger (26.08±5.54 vs. 28.40±5.09 years, $p<.0001$), had a lower average percentage of poverty level (353.48±283.28 vs. 507.52±299.26%, $p<.0001$), a lower percentage of non-Hispanic whites (63.09 vs. 72.44%, $p<.0001$), a higher percentage had prepregnancy overweight and obesity (39.58 vs. 34.42%, $p=0.0144$), a lower percentage of reported college degree and beyond (40.87 vs. 66.89%, $p<.0001$), a lower average social support score (69.7±14.3 vs. 75.5±13.6, $p<.0001$), and a lower percentage of having commercial insurance (68.26 vs. 81.39%, $p<.0001$) than individuals with EPDS <10. As for the health behaviors, pregnant people with EPDS $\geq$10 were at higher percentage of using tobaccos, both lifetime tobacco use (51.22 vs. 40.50%, p<.0001) and within 3 months prior to pregnancy (27.12 vs. 12.43%, p<.0001) and a lower percentage of reported exercise (66.10%) than individuals with EPDS <10 (76.31%, p<.0001). (Table 10)

We compared the demographic characteristics between the sample with some but not complete sleep data (n=3,105) and the complete case sample. The differences of each demographic characteristic factor were similar between two samples, except race ethnicity, insurance type, and income level. The sample with some but not complete sleep data had lower percentages of non-Hispanic whites, but higher percentages of non-Hispanic Black, Hispanic, and Asian. We observed a difference in insurance status, where the sample with some data observed lower percentages of commercial insurance than the complete case sample. The percentage of income over 200% of federal poverty level was also lower among sample with some but not complete data versus the complete case sample. (Appendix Table 6)

Prenatal depression in early and mid-pregnancy

Among the sample with complete data on sleep and prenatal depression status in early and mid-pregnancy, the average EPDS score decreased from 4.90±3.51 in early pregnancy to 4.71±3.47 in mid-pregnancy. The count and percentage of EPDS ≥10 decreased from 531 (10.28%) participants in early pregnancy to 463 (8.96%) participants in mid-pregnancy. The EPDS score ranged from 0 to 23 in early pregnancy and 0 to 25 in mid pregnancy. 4.96% of pregnant people went from EPDS<10 in early pregnancy to probable prenatal depression (EPDS≥10) in mid-pregnancy and 6.27% of pregnant people went from probable prenatal depression in early pregnancy to EPDS<10 in mid-pregnancy. (Table 11)

When we looked at the sample with some but not complete EPDS and sleep data, the score reduced from 5.95±3.99 in early pregnancy to 5.69±4.00 in mid-pregnancy. The percentage of participant with probable prenatal depression was 555 (17.87%) participants in early pregnancy and 533 (17.28%) participants in mid-pregnancy. The sample with complete EPDS and sleep data had lower EPDS score and lower percentages of EPDS ≥10 than the sample with some but not complete data at both early and mid-pregnancy. (Appendix Table 7)

Sleep health in early and mid- pregnancy

Among the sample with complete EPDS and sleep data, the average sleep duration was 8.03±1.05 hours in early pregnancy and 7.88±1.08 hours in mid-pregnancy. The average ESS score decreased from 7.62±3.93 in early pregnancy to 6.41±3.88 in mid-pregnancy. The average WASO increased from 19.39±18.91 minutes in early pregnancy to 23.56±20.17 minutes in mid-pregnancy. The midpoint sleep was similar between early and mid-pregnancy (3:08 in early pregnancy and 3:07 in mid-pregnancy). The weekend-weekday differences in bedtime, waketime, and midpoint sleep were all slightly less in mid-pregnancy compared to early pregnancy. The weekend-weekday difference in bedtime was 0.82±0.65 hours in early pregnancy and 0.73±0.65 hours in mid-pregnancy. We observed the largest weekend-weekday difference in waketime. The weekend-weekday difference in waketime was 1.63±1.14 hours in early pregnancy and 1.50±1.08 in mid-pregnancy. The weekend-weekday difference in midpoint sleep was 1.20±0.76 hours in early pregnancy and 1.08±0.73 hours in mid-pregnancy. When we looked at the sleep dimensions categorized by the specified cutoffs, the percentages of satisfied sleep decreased from 43.19% in early pregnancy to 37.89% in mid-pregnancy. The percentage of sufficient sleep duration was 70.53% in early pregnancy and 68.94% in mid-pregnancy. Similar to the decrease in ESS score, the percentage of no excessive daytime sleepiness increased from 70.32% in early pregnancy to 79.36% in mid-pregnancy. Similar to the results of increased average WASO, there was also an increase in the percentage of good sleep continuity from early to mid-pregnancy. The percentage of participants characterized as good sleep continuity decreased by 5.06% from early to mid-pregnancy. The percentages of sleep timing were similar with a 0.33% decrease from early to mid-pregnancy. Similar to the results of decreased weekend-weekday differences in bedtime, waketime and midpoint sleep, the percentages of regular bedtime, waketime, and midpoint sleep all increased from early to mid-pregnancy. (Table 12)

The sample with some but incomplete EPDS and sleep data had shorter duration, higher sleepiness score, later midpoint sleep, and larger weekend-weekday differences in bedtime, waketime, and midpoint sleep than the sample with complete EPDS and sleep data. The change of each sleep dimension from early to mid-pregnancy was similar to the complete case sample. There were declines in sleep satisfaction, duration, and sleep continuity. There was improvement in excessive daytime sleepiness and sleep regularity from early to mid-pregnancy. (Appendix Table 8)

<u>Cross-sectional association between prenatal depression and sleep health in pregnancy</u>

For the crude cross-sectional association between prenatal depression and sleep health in early pregnancy, individuals with EPDS ≥10 had higher ESS score (8.92 ±4.30 vs. 7.63 ±4.01, p<.0001), longer WASO (26.84 ±34.49 vs. 19.93 ±24.81 minutes, p<.0001), and later midpoint (3:37 vs. 3:11 a.m., p<.0001) than individuals with EPDS <10. Pregnant people with EPDS ≥10 had lower weekend-weekday differences in waketime (1.58±1.42 vs. 1.75±1.42 hours, p=0.0011) and midpoint sleep (1.21±1.10 vs. 1.35±1.24 hours, p=0.0010) than pregnant people with EPDS <10. After dichotomizing sleep dimensions by specified cutoffs, we found pregnant people had lower percentages in satisfied sleep (21.34% vs. 42.68%, p<.0001), sufficient duration (54.39% vs. 65.89%, p<.0001), no excessive daytime sleepiness (58.18% vs. 69.91%, p<.0001), good sleep continuity (79.10% vs. 86.19%, p<.0001), good sleep timing (55.97% vs. 68.39%, p<.0001), and regular bedtime (84.28% vs. 87.56%, p=0.0101) than individuals reported EPDS <10. The composite score was also lower among pregnant people with EPDS ≥10 (5.08±0.56 vs. 5.34±0.55, p<.0001). (Table 13)

We found similar results for the cross-sectional association in mid-pregnancy. While we did not see a difference in the average sleep duration in early pregnancy, pregnant people with prenatal depression in mid-pregnancy had shorter sleep duration (7.66±1.73 vs. 7.90±1.22 hours, p<.0001), higher ESS score (8.12 ±4.44 vs. 6.39±3.97, p<.0001), longer WASO (31.73 ±37.36 vs. 25.41 ±28.71 minutes, p<.0001), and later midpoint (3:39 vs. 3:12 a.m., p<.0001) than individuals with EPDS <10. There was no significant difference in weekend-weekday differences in bedtime, waketime, and midpoint sleep by EPDS score in mid-pregnancy. After dichotomizing sleep dimensions by specified cutoffs, we found pregnant people had lower percentages in satisfied sleep (17.39% vs. 38.25%, p<.0001), sufficient duration (50.58% vs. 64.48%, p<.0001), no excessive daytime sleepiness (64.13% vs. 79.34%, p<.0001), good sleep continuity (73.49% vs. 80.77%, p<.0001), good sleep timing (54.26% vs. 67.09%, p<.0001), and regular bedtime (85.87% vs. 89.63%, p=0.0020), and regular midpoint sleep (80.28% vs. 83.81%, p=0.0155) than individuals reported EPDS <10. The composite score was also lower among pregnant people with EPDS ≥10 (5.00±0.64 vs. 5.31±0.56, p<.0001). (Table 13)

We also described the sleep health by EPDS status among samples with some but not complete EPDS and sleep data for each sleep dimension. We found that the sample with some but not complete sleep data had lower percentage of satisfied sleep, higher average ESS score, later sleep timing than the sample with complete EPDS and sleep data. The pregnant people with some data and EPDS ≥10 had late midpoint sleep in mid-pregnancy (Median=4:10; Inter quartile range, IQR=2:10), which was later than our defined good sleep timing (i.e., 2 to 4 a.m.). We also found larger weekend-weekday differences in bedtime, waketime, and midpoint sleep among pregnant people with some data and EPDS <10. (Appendix Table 9)

After the adjustment of potential confounders, prenatal depression was associated with ESS score, WASO, midpoint sleep, weekend-weekday differences in waketime and midpoint in early pregnancy. Pregnant people with EPDS ≥10 had 0.31 standard deviations higher in ESS score (p<.0001), 8.37 minutes more in WASO (p<.0001), 12.57 minutes later in midpoint sleep (p=0.0112) in early pregnancy than pregnant people with EPDS <10. Pregnant people with EPDS ≥10 had 0.16 hours less in weekend-weekday difference in waketime (p=0.0089) and 0.14 hours less in weekend-weekday difference in midpoint sleep (p=0.0098) during early pregnancy than pregnant people with EPDS <10. Pregnant people with EPDS≥10 had 0.34 standard deviation lower composite sleep health score than pregnant people reported EPDS<10 in in early pregnancy (p<.0001). . (Table5) After categorized the sleep dimensions by specified cutoffs, there were associations between prenatal depression and sleep satisfaction, duration, excessive daytime sleepiness, sleep continuity, and sleep timing. Pregnant people with EPDS ≥10 had 47% lower odds of reporting satisfied sleep (OR=0.53, 95%CI: 0.46-0.62), 20% lower odds of having sufficient sleep duration (OR=0.80, 95%CI: 0.67-0.95), 40% lower odds of having no excessive daytime sleepiness (OR=0.60, 95%CI: 0.51-0.70), 41% lower odds of having good sleep continuity (OR=0.59, 95%CI: 0.48-0.71), and 19% lower odds of having good sleep timing (OR=0.81, 95%CI: 0.68-0.97). We did not observe significant association between prenatal depression and any sleep regularity dimensions in the adjusted models. (Table14)

In mid-pregnancy, we observed significant association between prenatal depression and sleep duration, ESS score, WASO, and midpoint sleep. Pregnant people with EPDS ≥10 had 0.29 hour less in sleep duration (p<.0001), 0.38 standard deviations higher in ESS score (p<.0001), 6.44

minutes more in WASO (p<.0001), 18.93 minutes later in midpoint sleep (p=0.0002) during mid-pregnancy than pregnant people with EPDS <10. Pregnant people with EPDS≥10 had 0.47 standard deviation lower composite sleep health score than pregnant people reported EPDS<10 in in mid-pregnancy (p<.0001). (Table5) After categorized the sleep dimensions by specified cutoffs, there were associations between prenatal depression and sleep satisfaction, duration, excessive daytime sleepiness, sleep continuity, and sleep timing in mid-pregnancy. Pregnant people with EPDS ≥10 57% lower odds of reporting satisfied sleep (OR=0.43, 95%CI: 0.36-0.52), 34% lower odds of having sufficient sleep duration (OR=0.66, 95%CI: 0.55-0.79), 50% lower odds of having no excessive daytime sleepiness (OR=0.50, 95%CI: 0.41-0.59), 39% lower odds of having good sleep continuity (OR=0.61, 95%CI: 0.51-0.73), and 21% lower odds of having good sleep timing (OR=0.79, 95%CI: 0.66-0.95) in mid-pregnancy than pregnant people with EPDS <10. (Table 15)

<u>Longitudinal association between prenatal depression in early pregnancy and sleep health in mid-pregnancy</u>

In the crude longitudinal association between prenatal depression in early pregnancy and sleep health in mid-pregnancy, we found significant differences in sleep duration, ESS score, WASO, midpoint sleep, and weekend-weekday difference in waketime between pregnant people with EPDS ≥10 and EPDS <10. Pregnant people reported with EPDS ≥10 tended to have shorter sleep duration (7.77±1.70 vs. 7.89±1.32 hours, p=0.0455), higher ESS score (7.82±4.44 vs. 6.39±3.97, p<.0001), longer WASO (31.37±36.70 vs. 25.28±28.27 minutes, p<.0001), and later midpoint sleep (3:38 vs. 3:12 a.m., p<.0001). Pregnant people with EPDS ≥10 had smaller weekend-weekday difference in waketime compared to people with EPDS <10 (1.48±1.47 hours vs. 1.60±1.38 hours, p=0.0229). When we looked at the sleep dimensions after categorized by specified cutoffs, there are differences in sleep satisfaction, duration, daytime sleepiness, sleep continuity and sleep timing. Pregnant people with EPDS ≥10 had lower percentages of satisfied sleep reported (24.03% vs. 37.70%, p<.0001), sufficient sleep duration (51.30% vs. 64.66%, p<.0001), no excessive daytime sleepiness (65.66% vs. 79.48%, p<.0001), good sleep continuity (73.94% vs. 80.85%, p<.0001), and good sleep timing (53.69% vs. 67.48%, p<.0001) in mid pregnancy than pregnant people with EPDS <10. Pregnant people with EPDS ≥10 also had significantly lower composite sleep health score in mid-pregnancy than those who rated EPDS <10 (5.11 ±0.59 vs. 5.30 ±0.57, p<.0001). (Table16)

We also described the difference in the longitudinal associations between prenatal depression in early pregnancy and sleep health in mid-pregnancy among participants with some but not complete sleep data and complete case sample. We observed less differences in sleep health by EPDS status between two samples compared to the cross-sectional findings. The sample with some but not complete sleep data still showed later sleep timing and larger weekend-weekday differences in bedtime, waketime, and midpoint sleep. Subjects who had some but not complete sleep data and a EPDS ≥10 in early pregnancy had the latest sleep timing in mid-pregnancy. Subjects with some but not complete sleep data and a EPDS <10 in early pregnancy had the largest average weekend-weekday differences in bedtime, waketime, and midpoint sleep in mid-pregnancy. (Appendix Table 10)

After we adjusted for the confounders, there were longitudinal associations between prenatal depression in early pregnancy and duration, ESS score, WASO, and midpoint sleep in mid-pregnancy. Pregnant people with EPDS ≥10 in early pregnancy had 0.18 hour less of sleep duration (p=0.0005), 0.36 standard deviations higher in ESS score (p<.0001), 6.29 minutes longer in WASO (p<.0001), and 10.45 minutes later in midpoint sleep in mid-pregnancy than those who have EPDS <10 in early pregnancy (p=0.0306). Pregnant people with EPDS≥10 in early pregnancy had 0.24 standard deviations lower in composite sleep health score in mid-pregnancy than pregnant people with EPDS<10 (p<.0001). . (Table17) After dichotomizing the sleep dimensions by specified cutoffs, pregnant people with EPDS ≥10 had 34% lower odds of reporting satisfied sleep (OR=0.66, 95%CI: 0.58-0.76), 37% lower odds of having sufficient sleep duration (OR=0.73, 95%CI: 0.61-0.87), 54% lower odds of having no excessive daytime sleepiness (OR=0.46, 95%CI: 0.38-0.55), 34% lower odds of having good sleep continuity (OR=0.66, 95%CI: 0.55-0.79), and 26% lower odds of having good sleep timing (OR=0.74, 95%CI: 0.62-0.88). (Table18)

7.5 Discussion

Based on our findings, prenatal depression is associated with some but not all sleep dimensions. Pregnant people with probable prenatal depression had less satisfying sleep, more daytime sleepiness, less sleep continuity, and later sleep timing in all three associations (cross-sectional association in early and mid-pregnancy, longitudinal association). There were cross-sectional association in mid-pregnancy and longitudinal associations between prenatal depression and sleep duration. There were only cross-sectional associations between prenatal depression and weekend-weekday differences in waketime and midpoint sleep in early pregnancy.

Previous findings suggested that there are associations between depression and sleep health in general populations (Field et al., 2007; Swanson et al., 2011; Yu et al., 2017). A prospective populational study with 24,715 adults has seen a nearly 7-fold increase of risks in developing insomnia (measured as the inability to get back to sleep after nighttime awakenings) among depressed individuals (OR=6.7, 95%CI; 5.46-8.26) (Sivertsen et al., 2012). Another Chinese sample of 10704 adults aged 45 and older has found that depressed individuals are more likely to experience short sleep duration than non-depressed individuals (RR=1.20, 95%CI: 1.02-1.43) (Sun et al., 2018). While most of the studies were targeting non-pregnant populations, our results under a pregnant population reflected similarly to previous findings among non-pregnant populations. We found individuals with probable prenatal depression were less likely to have satisfying sleep, sufficient sleep duration, and continued sleep. The associations exist cross-sectionally and longitudinally in early and mid-pregnancy. There were some observed differences in weekend-weekday differences in waketime and midpoint sleep by EPDS status during early pregnancy. However, we did not see the differences after categorizing weekend-weekday differences in bedtime, waketime, and midpoint sleep by specified cutoffs, either cross-sectionally or longitudinally. The discrepancies in results before and after categorizing by specified cutoffs suggest the need of considering the most appropriate assessment of sleep regularity in pregnancy.

One novel approach in this study was to include the concept of multidimensional sleep health as the sleep outcome. While previous studies have introduced the multidimensional concept into the definition of sleep health, studies have been using multidimensional sleep health as a sleep outcome under adolescent and elder populations (Buysse, 201; Dong et al., 2019; Ladyman & Signal, 2019; Wallace et al., 2019). There were limited findings on assessing sleep dimensions such as timing and regularity as well as the overall multidimensional sleep health as sleep outcomes during pregnancy. We observed later sleep timing among individuals with probable prenatal depression than those without throughout pregnancy. However, we did not see much difference in bedtime or waketime regularity between depressed and non-depressed pregnant people. There were cross-sectional and longitudinal associations between prenatal depression and composite sleep health score. However, we are unable to specify whether the differences were clinically meaningful. Future studies should consider the most appropriate assessment of sleep regularity and observe the clinical meaningfulness of changes in individual sleep dimensions and multidimensional sleep health during pregnancy (Fischer et al., 2021).

In our study sample, the average EPDS score was low compared to other pregnant samples. We've seen higher average within a French sample of high-risk pregnant people reported an average EPDS score of 9.3 (Adouard et al., 2005). We've also seen similar average to our study sample among Swedish pregnant people reported an average EPDS of 5.75 (Rubertsson et al., 2011). There are few reasons related to differences in average EPDS score across study samples. Our average score may be low with a removal of one question in EPDS that is related to sleep. Other potential reasons for lower EPDS score may be the differences in sample characteristics. Our study sample had high percentage of higher educational degree (college degree and beyond), higher income level (income over 200% of poverty line), and healthy pregnancy (no known fetal complications). While the observed results may be attenuated, the selection of this population still provided crucial information on prenatal depression and sleep health among nulliparous pregnant people, who had first-time experience in pregnancy.

While our study goal was to examine the association between prenatal depression and sleep health during pregnancy, it is worth noting that depression and sleep highly shared the biological pathways and symptoms (Brown et al., 2012; Fang et al., 2019; Perlis et al., 1997). Some research has suggested the bidirectional nature of depression and sleep (Gimeno et al., 2009; Hamilton, 1989; Irwin et al., 2018; Miller et al., 2009; Raison et al., 2013; Yates et al., 2007). Future studies should consider the bidirectional relationship between prenatal depression and sleep health in pregnancy to better examine the effects of mental health on sleep health among pregnant people.

There are a few strengths to our study. First, to our knowledge, this is the first study that assesses the impact of prenatal depression on sleep health in pregnancy, specifically through the multidimensional sleep health concept that incorporates multiple sleep dimensions as the outcomes of interest. Second, we assessed the association in both cross-sectional and longitudinal relationships. The assessments are beneficial for understanding the different effects of prenatal depression on sleep health at different time points of pregnancy. Third, we included multiple sleep dimensions and the multidimensional concept in sleep outcomes. This provides us the information on how prenatal depression may be associated with some individual sleep dimensions or the multidimensional sleep health during pregnancy.

There are also a few limitations to our study. First, this is a secondary analysis of an observational study. There are residual confounders that we are unable to capture, including personal and family history of depression. Second, our sleep health assessment is based on self-reported questionnaire data. While the nuMom2b study had a substudy that collected actigraphy data on sleep health during pregnancy, the substudy has different inclusion and exclusion criteria on sample selection. Furthermore, self-reported data offer a better assessment of sleep satisfaction and sleepiness. Future studies may include subjective and objective assessments in assessing multidimensional sleep health during pregnancy.

7.6 Conclusion

In conclusion, there are cross-sectional and longitudinal associations between prenatal depression and sleep satisfaction, duration, sleepiness, continuity, sleep timing, and overall multidimensional sleep health. There was no association found between prenatal depression and sleep regularity. Prenatal depression may be a potential factor that affects sleep health in pregnancy under some sleep dimensions. Our results provide evidence on considering mental health management for managing sleep health in pregnancy. Future studies should investigate the appropriate measurement of sleep regularity during pregnancy. More findings on the relationships between prenatal depression and multidimensional sleep health are warranted to better understand how mental health management can improve individual sleep dimensions and overall multidimensional sleep health during pregnancy, which can further reduce adverse maternal health outcomes attributed to poor sleep health.

7.7 Aim 2 Tables and Figures

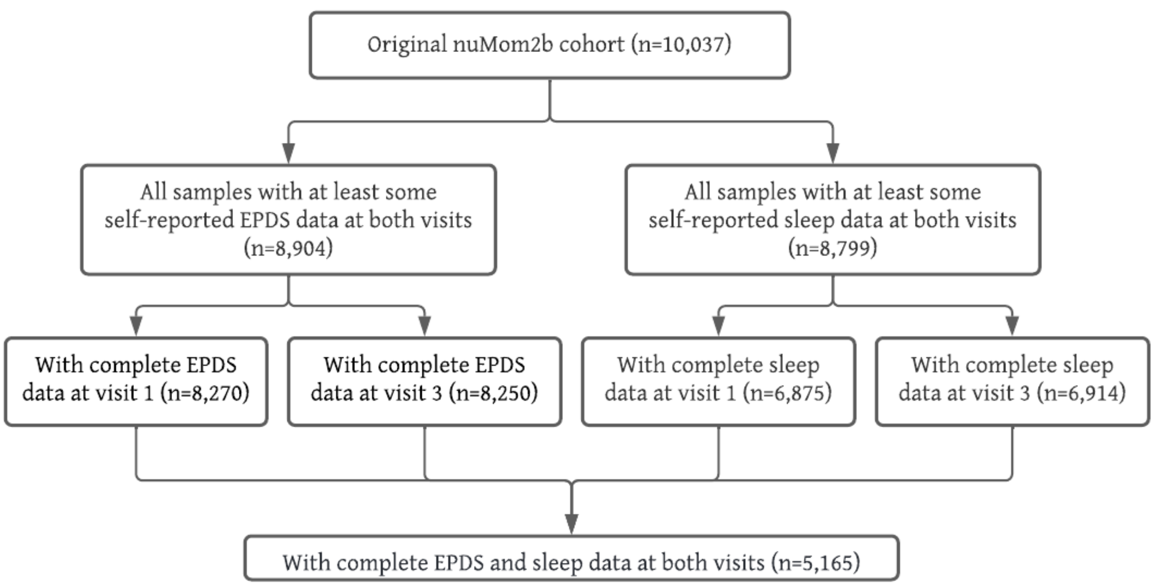

Figure 13. Aim 2 Participant Flowchart

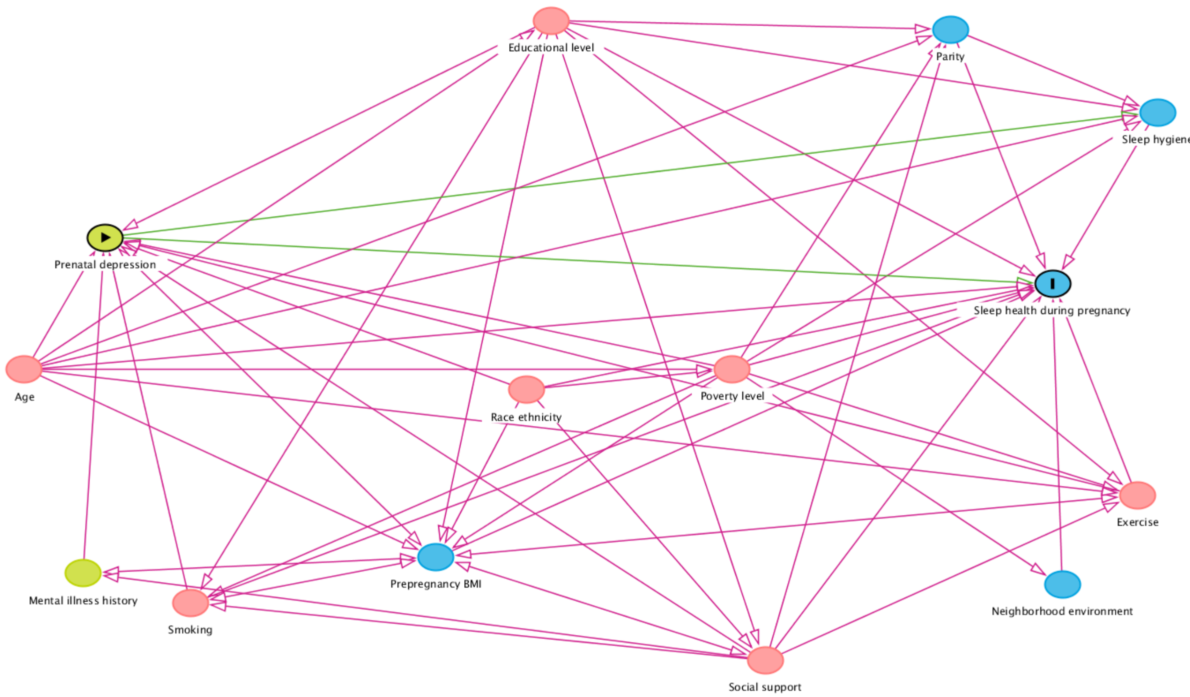

Figure 14. DAG for Prenatal Depression, Sleep Health, and Covariates

Table 10. Aim 2 Demographic Characteristics of the Study Sample- Overall and by Baseline EPDS Status

	Overall (n=5,165)	Baseline EPDS ≥10 (n=531)	Baseline EPDS <10 (n=4634)	
Variables	Mean ± SD	Mean ± SD	Mean ± SD	p-value
Gestational age at screening (weeks)	11.60±1.48	11.59±1.48	11.60±1.48	0.8436
Maternal age at screening (years)	28.16±5.19	26.08±5.54	28.40±5.09	<.0001**
Prepregnancy BMI (kg/m^2)	25.59±5.62	25.95±5.68	25.55±5.61	0.1204
Percentage of federal poverty level (%)	493.05±301.14	353.48±283.28	507.52±299.26	<.0001**
Social support score	75.50±13.56	69.72±14.26	76.16±13.32	<.0001**
Variables	n (%)	n (%)	n (%)	p-value
Maternal age at screening (years)				0.0014**
13-17	59 (1.14)	13 (2.45)	46 (0.99)	
18-34	4562 (88.33)	480 (90.40)	4082 (88.09)	
35-39	470 (9.10)	33 (6.21)	437 (9.47)	
40 or higher	74 (1.43)	5 (0.94)	69 (1.49)	
Race ethnicity				<.0001**
Non-Hispanic white	3692 (71.48)	335 (63.09)	3357 (72.44)	
Non-Hispanic black	327 (6.33)	52 (9.79)	275 (5.93)	
Hispanic	681 (13.18)	98 (18.46)	583 (12.58)	
Asian	242 (4.69)	29 (5.46)	213 (4.60)	
Other [a]	223 (4.32)	17 (3.20)	206 (4.45)	
Prepregnancy BMI (kg/m2)				0.0144*
<18.5 (Underweight)	105 (2.06)	17 (3.22)	88 (1.92)	
18.5-<25 (Normal weight)	2839 (55.60)	260 (49.24)	2579 (56.33)	
25-<30 (Overweight)	1262 (24.72)	144 (27.27)	1118 (24.42)	
30-<35 (Obese)	523 (10.24)	65 (12.31)	458 (10.00)	
35 or higher (Morbidly obese)	377 (7.38)	42 (7.95)	335 (7.32)	
Educational level				<.0001**
Less than high school graduate	181 (3.51)	41 (7.72)	140 (3.02)	
High school graduated or GED	377 (7.30)	65 (12.24)	312 (6.73)	
Associate/Tech degree	470 (9.10)	59 (11.11)	411 (8.87)	
Some college	820 (15.88)	149 (28.06)	671 (14.48)	
College degree	1773 (34.33)	120 (22.60)	1653 (35.68)	
Degree beyond college	1543 (29.88)	97 (18.27)	1446 (31.21)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

*p<0.05; **p<0.01

Table 10. Aim 2 demographic characteristics of the study sample- Overall and by baseline EPDS status (cont.)

	Overall (n=5,165)	Baseline EPDS ≥10 (n=531)	Baseline EPDS <10 (n=4634)	
Variables	n (%)	n (%)	n (%)	p-value
Gravidity				0.4626
1	3969 (76.84)	415 (78.15)	3554 (76.69)	
2	931 (18.03)	86 (16.20)	845 (18.23)	
3 or more	265 (5.13)	30 (5.65)	235 (5.07)	
Ever used tobacco				<.0001**
Yes	2149 (41.61)	272 (51.22)	1877 (40.50)	
No	3016 (58.39)	259 (48.78)	2757 (59.50)	
Smoked tobacco within 3 months prior to pregnancy				<.0001**
Yes	720 (13.94)	144 (27.12)	576 (12.43)	
No	4444 (86.06)	387 (72.88)	4057 (87.57)	
Exercise within the last 4 weeks				
Yes	3887 (75.26)	351 (66.10)	3536 (76.31)	<.0001**
No	1278 (24.74)	180 (33.90)	1098 (23.69)	
Insurance type [b]				
Governmental	869 (16.94)	144 (27.53)	725 (15.70)	<.0001**
Military	41 (0.80)	3 (0.57)	38 (0.82)	0.5433
Commerical	4115 (80.06)	357 (68.26)	3758 (81.39)	<.0001**
Personal	1079 (20.99)	91 (17.40)	988 (21.40)	0.0333*
Other	58 (1.13)	16 (3.06)	42 (0.91)	<.0001**
Percentage of federal poverty level (%)				<.0001**
<100	397 (8.73)	83 (19.44)	314 (7.63)	
100-200	556 (12.23)	88 (20.61)	4685 (11.36)	
>200	3592 (79.03)	256 (59.95)	3336 (81.01)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

*p<0.05; **p<0.01

Table 11. Aim 2 Prenatal Depression Status in Early and Mid-pregnancy

	Continuous scoring			Categorized EPDS status	
	n	mean	SD	EPDS >=10	EPDS<10
Early pregnancy	5165	4.90	3.51	531 (10.28)	4634 (89.72)
Mid-pregnancy	5165	4.71	3.47	463 (8.96)	4702 (91.04)

Table 12. Aim 2 Sleep Health in Early and Mid-pregnancy

Sleep dimensions	Early pregnancy	Mid-pregnancy
Uncategorized sleep dimensions	Mean ± SD	Mean ± SD
Duration (hr)	8.03±1.05	7.88±1.08
Epworth Sleepiness Scale (ESS) Score	7.62±3.93	6.41±3.88
Wake after sleep onset (WASO, min)	19.39±18.91	23.56±20.17
Midpoint sleep (a.m.) [a]	3:08 (1:13)	3:07 (1:14)
Weekend-weekday difference in bedtime (hr)	0.82±0.65	0.73±0.65
Weekend-weekday difference in waketime (hr)	1.63±1.14	1.50±1.08
Weekend-weekday difference in midpoint sleep (hr)	1.20±0.76	1.08±0.73
Categorized by specified cutoffs [b]	n (%)	n (%)
Good sleep satisfaction, n (%)	2231 (43.19)	1957 (37.89)
Sufficient duration, n (%)	3643 (70.53)	3561 (68.94)
No excessive daytime sleepiness, n (%)	3632 (70.32)	4099 (79.36)
Good sleep continuity, n (%)	4484 (86.82)	4223 (81.76)
Appropriate sleep timing , n (%)	3770 (72.99)	3753 (72.66)
Regular bedtime, n (%)	4680 (90.61)	4765 (92.26)
Regular waketime, n (%)	2969 (57.48)	3219 (62.32)
Regular midpoint, n (%)	4243 (82.15)	4428 (85.73)
Composite sleep health score, Mean ± SD	5.31±0.56	5.28±0.58

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Table 13. Bivariable Estimates of the Cross-sctional Associations Between Prenatal Depression and Multidimensional Sleep Health

	Cross-sectional- Early pregnancy					Cross-sectional- Mid-pregnancy				
Sleep dimensions	EPDS ≥10[a]		EPDS <10[a]			EPDS ≥10[a]		EPDS <10[a]		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	888	7.96±1.60	6435	8.03±1.28	0.2653	868	7.66±1.73	6697	7.90±1.32	<.0001**
Epworth Sleepiness Scale (ESS) Score	966	8.92±4.30	6631	7.63±4.01	<.0001**	959	8.12±4.44	7032	6.39±3.97	<.0001**
Wake after sleep onset (WASO, min)	1086	26.84±34.49	7184	19.93±24.81	<.0001**	996	31.73±37.36	7254	25.41±28.71	<.0001**
Midpoint sleep (a.m.) [b]	888	3:37 (1:54)	6435	3:11 (1:22)	<.0001**	868	3:39 (1:55)	6697	3:12 (1:26)	<.0001**
Weekend-weekday difference in bedtime (hr)	776	0.95±1.24	5918	1.01±1.36	0.2651	729	0.99±1.57	6074	0.88±1.27	0.0753
Weekend-weekday difference in waketime (hr)	774	1.58±1.42	5923	1.75±1.42	0.0011**	730	1.60±1.67	6073	1.58±1.35	0.8451
Weekend-weekday difference in midpoint sleep (hr)	771	1.21±1.10	5905	1.35±1.24	0.0010**	725	1.24±1.45	6054	1.20±1.47	0.4132
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	970	207 (21.34)	6673	2848 (42.68)	<.0001**	966	168 (17.39)	7035	2691 (38.25)	<.0001**
Sufficient duration, n (%)	888	483 (54.39)	6435	4240 (65.89)	<.0001**	868	439 (50.58)	6697	4318 (64.48)	<.0001**
No excessive daytime sleepiness, n (%)	966	562 (58.18)	6631	4636 (69.91)	<.0001**	959	615 (64.13)	7032	5579 (79.34)	<.0001**
Good sleep continuity, n (%)	1086	859 (79.10)	7184	6192 (86.19)	<.0001**	996	732 (73.49)	7254	5859 (80.77)	<.0001**
Good sleep timing , n (%)	888	497 (55.97)	6435	4401 (68.39)	<.0001**	868	471 (54.26)	6697	4493 (67.09)	<.0001**
Regular bedtime, n (%)	776	654 (84.28)	5918	5182 (87.56)	0.0101*	729	626 (85.87)	6074	5444 (89.63)	0.0020**
Regular waketime, n (%)	774	461 (59.56)	5923	3316 (55.99)	0.0592	730	436 (59.73)	6073	3754 (61.81)	0.2730
Regular midpoint, n (%)	771	611 (79.25)	5905	4699 (79.58)	0.8314	725	582 (80.28)	6054	5074 (83.81)	0.0155*
Composite sleep health score, Mean ± SD	531	5.08±0.56	4364	5.34±0.55	<.0001**	644	5.00±0.64	4521	5.31±0.56	<.0001**

[a] EPDS score excluded one question in the EPDS that is associated with sleep.
[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression
*p<0.05; **p<0.01

Table 14. Adjusted Coefficient Estimates in the Cross-sectional Association Between Prenatal Depression and Sleep Health in Pregnancy

	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Cross-sectional- Early pregnancy								
Adjusted β [b]	-0.08	0.31	8.37	12.75	-0.09	-0.16	-0.14	-0.34
SE	0.05	0.04	1.05	4.96	0.06	0.06	0.05	0.05
p-value	0.0893	<.0001**	<.0001**	0.0112*	0.1289	0.0089*	0.0098*	<.0001**
Cross-sectional- Mid-pregnancy								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.29	0.38	6.44	18.93	0.05	0.07	0.05	-0.47
SE	0.05	0.04	1.19	5.00	0.06	0.06	0.06	0.05
p-value	<.0001**	<.0001**	<.0001**	0.0002**	0.4127	0.2902	0.3769	<.0001**

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; Composite sleep health score is the standardized sleep health score from sample mean

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, prepregnancy BMI, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

Table 15. Adjusted Odds Ratios in the Cross-sectional Association Between Prenatal Depression and Sleep Dimensions Categorized by Specified Cutoffs in Pregnancy

Cross-sectional- Early pregnancy								
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.53	0.79	0.60	0.59	0.81	0.99	1.11	1.15
95% CI	(0.46, 0.62)	(0.67, 0.95)	(0.51, 0.70)	(0.48, 0.71)	(0.68, 0.97)	(0.77, 1.28)	(0.93, 1.32)	(0.92, 1.43)
Cross-sectional- Mid-pregnancy								
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.43	0.66	0.50	0.61	0.79	0.84	0.85	0.82
95% CI	(0.36, 0.52)	(0.55, 0.79)	(0.41, 0.59)	(0.51, 0.73)	(0.66, 0.95)	(0.63, 1.12)	(0.71, 1.03)	(0.65, 1.03)

[a] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, prepregnancy BMI, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

Table 16. Bivariable Estimates of the Longitudinal Associations Between Prenatal Depression and Multidimensional Sleep Health

	Longitudinal- Early to mid-pregnancy				
Sleep dimensions	EPDS ≥10 [a]		EPDS <10 [a]		p-value
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	963	7.77±1.70	6618	7.89±1.32	0.0455*
Epworth Sleepiness Scale (ESS) Score	1057	7.82±4.44	6951	6.39±3.97	<.0001**
Wake after sleep onset (WASO, min)	1086	31.37±36.70	7184	25.28±28.27	<.0001**
Midpoint sleep (a.m.) [b]	963	3:38 (1:56)	6618	3:12 (1:26)	<.0001**
Weekend-weekday difference in bedtime (hr)	812	0.90±1.38	6004	0.89±1.30	0.8367
Weekend-weekday difference in waketime (hr)	808	1.48±1.47	6009	1.60±1.38	0.0229*
Weekend-weekday difference in midpoint sleep (hr)	807	1.13±1.23	5985	1.21±1.20	0.0610
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	1061	255 (24.03)	6957	2623 (37.70)	<.0001**
Sufficient duration, n (%)	963	494 (51.30)	6618	4279 (64.66)	<.0001**
No excessive daytime sleepiness, n (%)	1057	694 (65.66)	6951	5525 (79.48)	<.0001**
Good sleep continuity, n (%)	1086	803 (73.94)	7184	5808 (80.85)	<.0001**
Good sleep timing, n (%)	963	517 (53.69)	6618	4466 (67.48)	<.0001**
Regular bedtime, n (%)	812	715 (88.05)	6004	5372 (89.47)	0.2193
Regular waketime, n (%)	808	512 (63.37)	6009	3686 (61.34)	0.2665
Regular midpoint, n (%)	807	676 (83.77)	5985	4992 (83.41)	0.7970
Composite sleep health score, Mean ± SD	531	5.11±0.59	4634	5.30±0.57	<.0001**

[a] EPDS score excluded one question in the EPDS that is associated with sleep.

[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

*p<0.05; **p<0.01

Table 17. Adjusted Coefficient Estimates in the Longitudinal Association Between Prenatal Depression in Early Pregnancy and Sleep Health in Mid-Pregnancy

	Longitudinal- Early pregnancy prenatal depression and mid-pregnancy sleep							
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score
Adjusted β [b]	-0.18	0.36	6.31	10.00	-0.02	-0.08	-0.06	-0.24
SE	0.05	0.04	1.15	4.83	0.06	0.06	0.05	0.05
p-value	0.0003**	<.0001**	<.0001**	0.0384*	0.7625	0.1723	0.2562	<.0001**

[a] Sleep duration is in hour; Daytime sleepiness is the ESS score; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, and midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, prepregnancy BMI, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

Table 18. Adjusted Odds Ratios in the Longitudinal Association Between Prenatal Depression in Early Pregnancy and Sleep Dimensions Categorized by Specified Cutoffs in Mid-pregnancy

Longitudinal- Early pregnancy prenatal depression and mid-pregnancy sleep								
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.66	0.73	0.46	0.65	0.74	1.09	1.07	1.11
95% CI	(0.58, 0.76)	(0.62, 0.87)	(0.38, 0.55)	(0.55, 0.79)	(0.62, 0.89)	(0.82, 1.46)	(0.89, 1.29)	(0.88, 1.44)

[a] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, prepregnancy BMI, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

8.0 Aim 3. The Association Between Racial Discrimination and Multidimensional Sleep Health in Nulliparous Pregnancy

8.1 Abstract

Background

Poor sleep health in pregnancy increases the inflammatory responses, affects metabolism, and results in adverse maternal health outcomes. While research has identified racial differences in sleep health, such differences tend to attenuate after controlling for racism, suggesting that racism may be a potential social factor for poor sleep health in pregnancy. Furthermore, racism is a chronic stressor and may magnify sleep health. However, the findings regarding the impacts of racial discrimination experiences on individual sleep dimensions and multidimensional in pregnancy are limited.

Methods

We used the experiences of discrimination scale (EOD) in mid-pregnancy and self-reported sleep data from the Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-Be (nuMoM2b) in early and mid-pregnancy to investigate the associations between the experiences of racial discrimination and sleep health during pregnancy. There was complete EOD and sleep data from both timepoints for 5,190 participants. The EOD scale included experiences of racial discrimination under 9 situations. The sum of situations experienced ranged from 0 to 9. Participants with 3 or more situation experiences were identified as having high exposure to racial discrimination. We measured satisfaction, daytime sleepiness, timing, continuity, duration, and bedtime, waketime regularity, and used composite sleep health score to measure multidimensional

sleep health. We assessed the associations between the experiences of racial discrimination and sleep health in early and mid-pregnancy among all participants, and a subgroup that included Black, Hispanic, Asian, and other race people.

Results

Among the overall sample, the experiences of racial discrimination were associated with lower odds of characterized as "good" sleep health in daytime sleepiness, timing, bedtime regularity and composite score in early pregnancy; the experiences of racial discrimination were associated with lower odds of characterized as "good" sleep health in duration, daytime sleepiness, timing, and bedtime regularity. Among non-Hispanic Black , Hispanic, Asian, and other racial groups (American Indian, Native Hawaiian, Multiracial), the experiences of racial discrimination were associated with lower odds of characterized as "good" sleep health in sleep satisfaction (Early: OR=0.84, 95%CI: 0.70-0.99; Mid: OR=0.80, 95%CI: 0.66-0.97), daytime sleepiness (Early: OR=0.59, 95%CI: 0.45-0.77; Mid: OR=0.72, 95%CI: 0.53-0.93), and composite score (Early: β=-0.14, p=0.0024; Mid: β=-0.17, p=0.0004) in both early pregnancy and mid-pregnancy

Conclusion

The experiences of racial discrimination may be critical in affecting sleep health during pregnancy. Our results provided some understanding of the particular experiences of specific racial groups in racial discrimination and sleep health during pregnancy. More findings on the relationships between the experiences of racial discrimination and multidimensional sleep health are warranted to better understand how social factor affects individual sleep dimensions and overall multidimensional sleep health during pregnancy, which can further reduce adverse maternal health outcomes attributed to poor sleep health.

8.2 Background

Poor sleep health in pregnancy, including poor sleep quality and short sleep duration, are highly prevalent in pregnancy and is associated with poor maternal health outcomes (Cai et al., 2017; Champagne et al., 2009; Conlon et al., 2020; Facco et al., 2010; Facco et al., 2017; Hedman et al., 2002; Hutchinson et al., 2012; Lopes et al., 2004; Mindell et al., 2015; Okada et al., 2019; Okun et al., 2007; Reutrakul et al., 2011; Roca et al., 2020). Furthermore, poor sleep health in pregnancy is associated with poor maternal health outcomes. For example, a cross-sectional study of 364 high risk pregnant people in their second and third trimesters found 96.4% reported poor sleep quality in association with pregnancy complications (i.e., gestational hypertension and gestational diabetes) (Saadati et al., 2018). A study of 686 Asian pregnant people (Chinese, Malay, and Indian) in their second trimester reporting poor sleep quality had 1.75 times higher odds of gestational diabetes compared to people with good sleep quality (95%CI: 1.11-2.76). Pregnant people with short sleep duration (less than 6 hours) had 1.96 times higher odds of gestational diabetes than people with sleep duration of 6 hours or more (95%CI: 1.05-3.66) (Cai et al., 2017). Since poor sleep health is common during pregnancy and increases risk for poor maternal health, it is crucial to examine factors contributed to poor sleep health in pregnancy.

There are multiple factors contributed to poor sleep health during pregnancy including overweight/obese, sleep hygiene, race ethnicity, poverty, and residing in disadvantaged neighborhood (Duncan & Kawachi, 2018; Ferraro et al., 2014; Gay et al., 2017; Guinhouya et al., 2019; Hutchinson et al., 2012; Maasilta et al., 2001; Nodine & Matthews, 2013; Okun et al., 2014). Additionally, prior studies have also observed racial differences in sleep health during pregnancy. For example, a cross-sectional study in Metro Detroit, US with 267 pregnant people found 38.4% reported short sleep duration among African Americans, which is significantly higher than whites

(17.4%) (Kalmbach et al., 2019) A longitudinal study with biracial sample (Black, white people) has observed poorer subjective sleep quality, more sleep disturbances, and poorer sleep efficiency during pregnancy among Black people compared to white people (Christian et al., 2019) A study using data from the National Health Interview Survey (2004-2017) also found that African American pregnant people have a significantly higher prevalence of short sleep duration than white pregnant people (Prevalence ratio=1.35, 95%CI: 1.08-1.67) (Feinstein et al., 2020). A secondary analysis of the National Health and Nutrition Examination Survey 2005–2010 examining sleep health among women of childbearing age has found significantly less Mexican American and Black women reported sleep duration of 7 to 8 hours during pregnancy compared to white people (Amyx et al., 2017).

In non-pregnant populations, such racial differences were attenuated after adjusting racism, suggesting that there are impacts of racism on sleep health (Hicken et al., 2013). A cross-sectional survey of 3,105 adults aged 18 years or higher who lived in Chicago, US, found that racism-related vigilance (i.e., the anticipation of racial discrimination) is similarly associated with poor sleep health (i.e., sleep difficulty) among all racial groups in the sample (white, Black, Hispanic people) (Hicken et al., 2013). A longitudinal study of 274 Hispanic college students indicated that the anticipation and experience of racial discrimination were associated with poor sleep quality (Gordon et al., 2020). A study with a biracial sample of Black and white American adults with objective sleep assessment found shorter total sleep time and shorter deep sleep stage among Black people compared to white people. The study also supported the concept of racism as the mediator of racial differences in sleep health (Tomfohr et al., 2012). A secondary analysis using data from the 2006 Behavioral Risk Factor Surveillance System has observed racial discrimination associated with increased risks of sleep disturbance ($p < .0001$) and daytime fatigue ($p < .0001$)

(Grandner et al., 2012). Racism is a system that is structured to assign value and opportunity based on race. This can manifest as certain racial groups being seen as superior (e.g.., white supremacy) or inferior (Jones, 2000). It leads to negative beliefs (i.e., prejudice) and differential treatment (i.e., discrimination) towards groups by other individuals and social institutions (Bonilla-Silva, 1996; Grosfoguel, 2011; Grosfoguel, 2016; Williams, 1997). Racial discrimination is a product of the concept of racism that often refers to one's interpersonal experiences of differential treatment based on race ethnicity (Williams, 1997; Ahmed et al., 2007; Bailey et al., 2017; McLemore et al., 2018). It occurs during daily life events of different attitude received from receiving services and respect, suspicion toward criminal acts, and devaluating the achievement (Jones, 2000) The impact of racism on sleep health is also supported by the underlying biological mechanisms. There is a linkage between neurological and hormonal responses to stress that manifest in adverse health (Ganzel et al., 2010). The effects of stress have also been linked to preservative cognition, leading to worriedness and associated with physiological activation (Brosschot et al., 2005). Such stress-related thoughts and worriedness may also magnify poorsleep health (Hicken et al., 2013).

While previous studies have observed racial differences in poor sleep health during pregnancy, the findings on the impact of racism on poor sleep health during pregnancy were limited. The understanding of the particular experiences of specific racial groups in racial discrimination and sleep health during pregnancy was little. Specifically, the hormonal and physical changes in pregnancy often lead to poor sleep health and adverse maternal health. Exploring the psychosocial impacts on sleep health is critical for including social factors in strategies for improving sleep health during pregnancy and further improve maternal health outcomes attributed to poor sleep health.

Furthermore, prior studies predominantly measured poor sleep quality and short sleep duration to assess sleep health. However, sleep health includes multiple dimensions and can be assessed under sleep regularity, satisfaction, alertness, timing, efficiency, and duration (Buysse, 2014). Sleep quality and duration alone do not account for overall sleep health. For example, a recent study from Facco et al. found that later sleep timing was associated with increased risks of gestational diabetes (Facco et al., 2017). Therefore, including multiple sleep dimensions as sleep outcomes is necessary to identify the impacts of racial discrimination on one or multiple sleep dimensions.

While poor sleep health in pregnancy is partially explained by physical and hormonal changes occurring during pregnancy, social factors (i.e., the attitudes or beliefs that exist in the social contexts that potential influence one's concepts to other individuals or groups of people in the society) such as racism are critical in understanding sleep health and the current racial disparities. The goal of this study was to specifically investigates the relationship between racial discrimination and individual sleep dimensions and overall multidimensional sleep health during pregnancy. We specifically will investigate the association between individual's experiences of racial discrimination and how it relates to sleep health in early and mid-pregnancy. We hypothesized that individuals within each racial group who reported more lifetime experiences of racial discrimination were less likely to have good sleep health during pregnancy than those with low to no racial discrimination experiences. The results of this study will provide potential evidence of social impacts of racism on specific sleep dimensions or multidimensional sleep health in pregnancy.

8.3 Methods

Study design and settings

We used the Nulliparous Pregnancy Outcome Study data: Monitoring Mothers-to-Be (nuMom2b). The nuMom2b study is a multi-site prospective cohort study conducted from 2010 to 2013 to assess the relationship between maternal genetic and physiologic factors and adverse pregnancy and birth outcomes. There were 8 research sites, including Case Western University, Columbia University, Indiana University; University of Pittsburgh; Northwestern University; the University of California at Irvine, the University of Pennsylvania, and the University of Utah. There were 3 timepoints of data collection during pregnancy. The first visit was completed between 6 weeks+0 days and 13 weeks+6 days of gestation, the second visit was conducted between 16 weeks+0 days and 21 weeks+6 days of gestation, and the third study visit was between 22 weeks+0 days and 29 weeks+6 days of gestation. The second and the third visits occurred at least 4 weeks apart from the last study visit. Participants signed the informed consent before the first study visits. Haas et al.'s protocol paper described additional details on study procedures (Haas et al., 2015).

Study sample

The inclusion and exclusion criteria details were listed in the Haas et al. protocol paper (Haas et al., 2015) Pregnant people who planned to deliver at the hospitals affiliated with the study sites were screened for eligibility. Women with a viable, singleton pregnancy between 6 weeks+0 days to 13 weeks+6 days of gestation based on the ultrasound assessment, no previous pregnancy that lasted 20 weeks based on self-reported data and verified through medical records, if available, were included. Pregnant people with age under 13, or with a previous history of 3 or more spontaneous abortions and known fetal complications were excluded. The study has been approved by the institutional review boards with the protection of human subjects. There were 10,037 participants in the overall nuMom2b cohort. Within the cohort, 8204 had some data on the experiences of racial discrimination and sleep health, 5,190 have complete data on the experiences of racial discrimination from the second prenatal visit and sleep questionnaire data at the first and the third visits, the sample was used for the final analysis. (Figure 15) We further describe racial discrimination experiences, sleep health and the crude associations among sample with some but incomplete sleep data in the appendix.

Exposure- Experiences of racial discrimination

In the nuMom2b study, the experiences of racial discrimination were assessed using the experiences of discrimination scale (EOD) (Krieger et al., 2005) The data were collected once at the second study visit during the prenatal period asking about lifetime experiences of racial discrimination. The EOD Scale has acceptable internal consistency (Cronbach's alpha=0.74) in assessing one's experiences of racial discrimination under the study sample among Black, Hispanic, and white populations. (Krieger et al., 2005).

There were 9 questions asked in the EOD subscale. The questions asked whether the individuals encounter racial discrimination under nine situations: "Have you ever experienced discrimination, been prevented from doing something, or been hassled or made to feel inferior because of your race, ethnicity, or color" including at school, getting hired, at work, housing, medical care, getting service in a store or restaurant, getting credit, under public settings and from the police (Krieger et al., 2005) It is worth noting that while racial discrimination exists from legal systems to daily interpersonal interactions, the scale is to assess interpersonal racial discrimination while some situations, including school, work, healthcare, and police settings, may have involved the concept of institutional racism.

The nuMom2b study collected the binary responses to the listed situations (i.e., Yes or No). We summed up the binary response (Yes=1/No=0) for each condition. The score ranges from 0 to 9, with the higher score indicating a higher level of experience in racial discrimination. Based on the exploration of specified cutoffs under the association between racial discrimination and sleep health during pregnancy in our sample, we are unable to detect a good cutoff for the association between counts of situation experiencing racial discrimination and each sleep dimension. (Appendix Table 11) Therefore, we weighed in the cutoffs applied in prior study that validate the scale and used the same parent study data, we defined participants with high exposure of racial discrimination if they reported 3 or more situations of racial discrimination (Grobman et al., 2016; Krieger et al., 2005).

Outcome- Sleep health in pregnancy

We used self-reported sleep questionnaires data collected at the parent study's first and third prenatal visits. Based on the multidimensional sleep health framework from Buysse, we assessed sleep health through the following dimensions: regularity, satisfaction, sleepiness, timing, wake after sleep onset (WASO), and duration (Buysse, 2014). We also described the percentages of pregnant people good sleep health in each dimension that was dichotomized through specified cutoffs. We assessed sleep regularity through weekend-weekday differences in bedtime, waketime, and midpoint sleep (Roepke & Duffy, 2010). A weekend-weekday difference of less than 2 hours was defined as good bedtime, waketime, and midpoint sleep regularity (Beauvalet et al., 2017). Sleep satisfaction was assessed through a self-rated question: "Overall, was your typical night's sleep during the last 4 weeks: very good, good, fair, poor, very poor". We defined good sleep satisfaction if the responses were "very good" or "good". To measure daytime sleepiness, a measure of alertness, we used the Epworth Sleepiness Scale (ESS). The ESS is an 8-item scale with each item scores from 0 to 3 and an overall ESS score ranging from 0 to 24. The higher ESS score indicates a higher level of daytime sleepiness (i.e., poorer alertness) (Johns, 1991). The ESS has acceptable internal consistency (Cronbach's alpha=0.77) among pregnant populations and is a validated tool to assess daytime sleepiness (93.5% sensitivity and 100% specificity) (Johns, 2000; Johns, 1992; Tsai et al., 2016). In this domain, we define good sleep health as an ESS score of 10 or lower (i.e., no excessive daytime sleepiness) (Johns et al., 1991). Sleep timing was defined through midpoint sleep. Midpoint sleep is the halfway point between sleep onset and the final time waking up to start the day. It was calculated through: bedtime + (wake time - bedtime) (Facco et al., 2017). Midpoint sleep between 2 to 4 am was considered appropriate sleep timing (Dong et al., 2019) Wake after sleep onset (WASO) is a measure of sleep continuity, part of the construct as sleep efficiency. WASO was estimated by the sum of time spent awake between first falling asleep and fully awake through nighttime sleep (Ohayon et al., 2017). We considered individuals with WASO of less than 40 minutes WASO through nighttime sleep as having good sleep continuity (Ohayon et al., 2017). Sleep duration was assessed through a weekly average sleep duration weighted by workdays and weekends: ([weekday/workday duration × 5] + [weekend duration × 2]) / 7 (Facco et al., 2018). Since the recommendation of sufficient sleep duration differs between adolescents and adults, we applied different cutoffs to define good sleep duration based on participants' age. Weighted sleep duration between 8 to 10 hours was considered a good sleep duration among adolescents aged 13-17; and weighted sleep duration between 7 to 9 hours was considered a good sleep duration among individuals aged 18 or more (Hirshkowitz et al., 2015). (Table 4)

After describing each sleep dimension, we created a composite sleep health score to assess the overall multidimensional sleep health by summing the calculated z scores of each dimension centering from our identified empirical cutoffs (Brindle et al., 2019). We removed individuals with outliers (i.e., lower or higher than Q1±3×IQR) in each sleep dimension. Next, we recorded the z score of each dimension to reflect a higher score indicates better sleep health. Then, we scaled each recoded z score into a range of 0 to 1, with 1 being the closest to specified cutoff in the specific sleep dimension and 0 being the furthest. Finally, we summed the scaled sleep health score and created a composite sleep health score for each individual. To calculate the composite sleep health score, we included bedtime and waketime regularity instead of the midpoint sleep regularity. The composite sleep health score ranges from 0 to 7, with the higher score indicating better sleep health.

Covariates

We identified covariates based on the previous studies with similar areas of interest and studies using data from the same parent study (Grobman et al., 2016; Facco et al., 2018). Demographic characteristics were collected through self-reported questionnaires at the baseline visit. We described maternal age in the following categories: 13-17, 18-34, 35-39 and 40+ years. Five categories for race ethnicity: non-Hispanic white, non-Hispanic Black, Hispanic, Asian, and Other race ethnicity including American Indian, Native Hawaiian, and multiracial individuals. It is worth noting that differences in racial discrimination and sleep health by race should be described but not controlled for as a confounder because race is highly related to the experiences of racial discrimination. Instead of controlling for race, we examined the association between racial discrimination and sleep health by subcategory of pregnant people identified as Black, Hispanic, Asian, and other racial groups. Educational level was categorized as less than high school graduate, high school graduated/GED, associate or tech degree, some college, college graduated, and degree beyond college. Pregnancy-related covariates include gestational age at enrollment, prepregnancy

BMI, gravidity, and tobacco use. Gestational age was identified through ultrasound assessment, prepregnancy BMI was self-reported and gravidity was self-reported and further verified through medical records, if available. Subjects were overweight if prepregnancy BMI was between 18.5-25 kg/m^2 and obese if prepregnancy BMI was between 30-35 kg/m^2. Individuals with prepregnancy BMI of 35 kg/m^2 or higher were considered morbidly obese. Tobacco use was measured in two domains, ever used tobacco and 3 months prior to pregnancy. We also included social support as a psychosocial covariate. Social support was assessed through the Multidimensional Scale of Perceived Social Support (MSPSS). The MSPSS is a self-reported, 12-item, 7-point scale that assesses one's social support level through family, friends, and significant other. The score ranges from 12 to 84, with the higher score indicating better social support (Ziment et al., 1990). The MSPSS is a valid instrument to assess social support level in pregnancy, with a reported Cronbach's alpha of 0.93 in a pregnant sample from Pakistan (n=1,154) (Mirabzadeh et al., 2013).

We applied directed acyclic graphs (DAG) to identify the confounding effects of covariates and make decision on what confounders to be included in the adjusted model. DAGs allow researchers to identify causal relationships between variables through background knowledge, empirical literature findings, theories, and assumptions (Greenland et al., 1999; Tennant et al., 2021) Sleep health during pregnancy is associated with advanced maternal age, overweight/obese, sleep hygiene, exercise, and smoking. There are also differences in race ethnicity on sleep health during pregnancy. SES factors for sleep health include educational level and income level. Furthermore, the stressors such as lacking social support may impact sleep health during pregnancy.

Racial discrimination is highly associated with one’s race ethnicity. Age, income level, and social support. Racial discrimination could also be a stressor to overweight or obese. The identified minimal sufficient set from the DAG includes maternal age, educational level, poverty level, and smoking status. (Figure 16) To identify multicollinearity issues, we applied Spearman correlation to identify the correlation across variables. Maternal age, educational level, and poverty level had correlation over 0.5. (Appendix Table 3) We further explored the variance inflation factor (VIF) and all variables had VIF less than 2.5. (Appendix d) The multicollinearity issue was minor and all confounders in the minimum sufficient set were included for model adjustment.

Statistical analysis

We first presented the demographic characteristics of our study sample. We further described demographic characteristics, racial discrimination, sleep health, and the crude association between racial discrimination and sleep health among samples with incomplete data. Then, we observed the crude association between covariates and exposure (racial discrimination experiences) and outcomes (multidimensional sleep health in pregnancy). We applied bivariable analysis to assess the crude association between the experiences of discrimination and individual sleep dimensions and multidimensional sleep health. We used student's t-tests for the normally distributed continuous variables, Mann-Whitney tests for non-normally distributed continuous variables and chi-square tests for the categorical variables. For the adjusted model estimates, we presented the adjusted coefficients through linear regression models for continuous sleep outcomes. To help interpret the difference between exposure groups for ESS and composite sleep health scores between depressed non-depressed pregnant people, we standardized the scores. This allows us to interpret as how many standard deviations higher or lower in ESS and composite sleep health score among pregnant people reported 3+ situations of racial discrimination compared to pregnant people reported <3 situations of racial discrimination. We also applied logistic regression analyses to assess the association between racial discrimination experiences and each sleep dimension after dichotomizing them into "good" and "poor" dimensions. Based on our ancillary analysis on the prevalence of racial discrimination and its association with sleep outcomes by each racial group, we found Black, Hispanic, Asian, and other racial groups had substantially higher prevalence of racial discrimination compared to white people. Furthermore, Black, Hispanic, Asian, and other racial groups had similar associations between racial discrimination and sleep outcomes including satisfaction, duration, timing, and sleepiness. (Appendix Table 12, 13) Therefore, we combined all racial groups (Black, Hispanic, Asian, and other race) in the subgroup analysis to examine the association between racial discrimination and sleep health in pregnancy.

We accepted a type 1 error (α=0.05) for determining the significance level of the statistical testing. We used SAS version 9.4 for data management and analyses (SAS Institute, Cary, NC).

8.4 Results

Demographic characteristics

Among 8,221 study participants with data on the experiences of racial discrimination and sleep health in early and mid-pregnancy, 5,190 had complete data on racial discrimination and sleep data in early and mid-pregnancy, 3031 had some but incomplete data. Among all participants with complete racial discrimination and sleep data (n=5190), 277 (5.34%) had reported 3 or more situations of racial discrimination experiences. Participants reported 3 or more situations of racial discrimination experiences were older (29.09±6.01 vs. 28.13±5.12 years, p=0.0099), had higher prepregnancy BMI (26.90±6.26 vs. 25.50±5.58 kg/m^2, p=0.0004), a lower percentage of the federal poverty level (433.92±305.94 vs. 496.92±300.05%, p=0.0016), and lower social support score (72.77±13.83 vs. 75.70±13.45, p=0.0004) than participants reported less than 3 situations of racial discrimination experiences. Furthermore, participants reporting 3 or more situations of racial discrimination experiences were at higher percentages of tobacco use (51.62% vs. 41.07%, p<.0001), a higher percentage of using governmental health insurance (25.63% vs. 16.28%, p<.0001), and a lower percentage of commercial health insurance use (67.87% vs. 80.85%, p<.0001). Racial differences were significant in the experiences of racial discrimination. Among participants with 3 or more situations of racial discrimination experiences, only 10.83% were white, 27.44% were Black, 25.27% were Hispanic, and 25.99% were Asian. (Table19)

For the demographic characteristics among participants with some but incomplete sleep data, we observed younger age and a lower percentage of federal poverty level than the complete case sample. The differences in demographic characteristics between participants with 3 or more versus less than 3 situations of racial discrimination experiences were similar to the complete case sample, except maternal age was no different from the incomplete sample. The sample with some but incomplete data also had younger maternal age, higher prepregnancy BMI, higher educational level, higher percentages of smoking and lower income level than the sample with complete data. (Appendix Table 14)

Racial discrimination

We described the number of situations of racial discrimination among our study sample who has complete data on sleep and racial discrimination. Asians had the lowest percentage of 0 situations of racial discrimination experiences (52.48%), followed by non-Hispanic Black people (55.08%), other racial groups (61.88%), and Hispanics (64.77%). Non-Hispanic Black peoples reported the highest percentage of 3 or more situations of racial discrimination experiences among all racial groups (21.54%), followed by Asians (12.40%), other racial groups (13.00%), and Hispanics (11.11%). (Table 20)

We also described the distribution of racial discrimination experiences among the overall sample and sample with some but incomplete data. (Appendix Table 15) The distributions were similar where Asian people had the lowest percentage of reported 0 situation of racial discrimination (Overall sample: 52.65%; Sample with incomplete data: 53.06%). Non-Hispanic Black people had the highest percentage of reported 3+ situations of racial discrimination in the overall sample (15.93%) and Asian people had the highest percentage of reported 3+ situations of racial discrimination in the sample with some but incomplete data (21.43%).

Sleep health

We described sleep health in this study sample during early and mid-pregnancy. Sleep duration declined from 8.03±1.05 hours in early pregnancy to 7.87±1.08 hours in mid-pregnancy. The average ESS score decreased from 7.61±3.93 in early pregnancy to 6.42±3.88 in mid-pregnancy. WASO increased from 19.45±18.98 minutes in early pregnancy to 23.59±20.19 minutes in mid-pregnancy. The midpoint sleep was similar between 2 timepoints. There were slight decreases in weekend-weekday differences in bedtime, waketime, and midpoint sleep from early to mid-pregnancy. When we looked at the sleep health after dichotomized by specified cutoffs for each dimension, we saw decreased percentages of good sleep health in satisfaction and sleep continuity. The percentages of no excessive daytime sleepiness increased from 70.40% in early pregnancy to 79.29% in mid-pregnancy. There was also a 1.6 to 4.9% increase in the percentages of a regular bedtime, waketime, and midpoint sleep from early to mid-pregnancy. The percentages of sufficient sleep duration and appropriate sleep timing were similar between the two timepoints. (Table 21)

The sample with incomplete sleep data also had lower sleep duration and higher ESS scores in early pregnancy. These dimensions were similar between two samples in mid-pregnancy. The incomplete case sample had higher WASO, later midpoint sleep, and larger weekend-weekday differences in bedtime, waketime, and midpoint sleep during both early and mid-pregnancy compared to the complete case sample. The percentages of satisfied sleep were lower in both early and mid-pregnancy than in the complete case sample. (Appendix Table 16)

The association between racial discrimination and sleep health in pregnancy-all samples

In the crude association between racial discrimination and sleep health in early pregnancy among study participants across all races, pregnant people who experienced 3 or more situations of racial discrimination had lower average sleep duration (7.81±1.49 vs. 8.03±1.31 hours, p=0.0024), higher ESS score (8.66±4.10 vs. 7.73±4.06, p<.0001), longer WASO (24.75±32.22 vs. 20.68±26.00 minutes, p=0.0055), and later midpoint sleep (3:38 vs. 3:13 am, p<.0001) than pregnant people with <3 situations of racial discrimination. There were no statistically significant differences in weekend-weekday differences in bedtime, waketime, and midpoint sleep between participants with 3+ situations of racial discrimination and <3 situations of racial discrimination. When we dichotomized sleep dimensions by specified cutoffs, pregnant people with 3+ situations of racial discrimination had lower percentages of satisfied sleep (32.69% vs. 40.41%, p=0.0010), sufficient duration (57.57% vs. 64.91$, p=0.0019), no excessive daytime sleepiness (58.41% vs. 69.17%, p<.0001), appropriate sleep timing (57.34% vs. 67.41%, p<.0001), and regular bedtime (80.99% vs. 87.50%, p=0.0002). For the multidimensional sleep health, pregnant people with 3+ situations of racial discrimination had statistically significant lower composite sleep health score (5.20±0.59) compared to pregnant people with <3 situations of racial discrimination (5.32±0.55, p=0.0005). (Table 22)

In the crude association between racial discrimination and sleep health in mid-pregnancy among all study samples, pregnant people who experienced 3+ situations of racial discrimination had lower sleep duration (7.62±1.50 vs. 7.89±1.35 hours, $p=0.0002$), higher ESS score (7.40±4.34 vs. 6.54±4.04, $p<.0001$), and later sleep timing (3:34 vs. 3:13 am, $p<.0001$) than pregnant people with <3 situations of racial discrimination experiences. WASO increased from early to mid-pregnancy, and WASO in mid-pregnancy between 2 groups were not statistically significant ($p=0.1223$). After dichotomizing the sleep dimensions into specified cutoffs, pregnant people with 3+ situations of racial discrimination had statistically significant lower percentages of sufficient sleep duration (55.04% vs. 63.71%, $p=0.0002$), no excessive daytime sleepiness (69.75% vs. 78.09%, $p<.0001$), appropriate sleep timing (56.58% vs. 66.32%, $p<.0001$), and regular bedtime (83.33% vs. 89.70%, $p<.0001$) compared to pregnant people with <3 situations of racial discrimination. For the multidimensional sleep health, pregnant people with 3+ situations of racial discrimination had lower composite sleep health score in mid-pregnancy (5.17±0.62) compared to pregnant people who reported <3 situations of racial discrimination (5.29±0.57, $p=0.0012$). (Table 22)

We also examined the crude association between racial discrimination and sleep health in pregnancy among samples with some incomplete sleep data (3031 out of 8221 participants who had some data in racial discrimination and sleep health, 37%). Similar to the sample with complete sleep data, pregnant people with 3+ situations of racial discrimination had shorter sleep duration, higher ESS score, longer WASO, and. later midpoint sleep during early pregnancy than pregnant people with <3 situations of racial discrimination. Specifically, the median midpoint sleep was later than our specified cutoff (4 am) among people with 3+ situations of racial discrimination (4:03 am). After dichotomizing sleep health by specified cutoffs, pregnant people with 3+

situations of racial discrimination had lower percentages of satisfying sleep, sufficient duration, no excessive daytime sleepiness, and appropriate sleep timing compared to pregnant people with <3 situations of racial discrimination. In mid-pregnancy, the differences in sleep health between pregnant people reported 3+ and <3 situations of racial discrimination were similar to the sample with complete sleep data. There were statistically significant differences in sleep duration, ESS score, and midpoint sleep. After dichotomizing sleep dimensions by specified cutoffs, pregnant people with 3+ situations of racial discrimination had lower percentages of satisfying sleep, sufficient duration, no excessive daytime sleepiness, and appropriate sleep timing in mid-pregnancy than pregnant people with <3 situations of racial discrimination. (Appendix Table 17)

In multivariable analyses, we controlled for maternal age, poverty in percentage, social support score, and educational level to assess the association between racial discrimination experiences and pregnancy sleep health. The adjusted association between racial discrimination and early pregnancy sleep duration was no longer statistically significant (p=0.0847). Pregnant people had 3+ situations of racial discrimination had 0.19 standard deviations higher ESS score (p=0.0002) and 18.42 minutes later in midpoint sleep (p=0.0053) in early pregnancy than pregnant people who reported <3 situations of racial discrimination. Pregnant people reported 3+ situations of racial discrimination also had 0.20 standard deviations lower of composite sleep health score in early pregnancy than pregnant people reported <3 situations of racial discrimination (p=0.0023). For sleep outcomes in mid-pregnancy, pregnant people with 3+ situations of racial discrimination had 0.22 hours less in sleep duration (p=0.0010), 0.18 standard deviations higher in ESS score (p=0.0061), 27.67 minutes later in midpoint sleep (p<.0001), and 0.17 hours more in weekend-weekday difference in bedtime than pregnant people reported <3 situations of racial discrimination (p=0.0266). Pregnant people with 3+ situations of racial discrimination also had 0.18 standard deviations lower of composite sleep health score in mid-pregnancy than pregnant people reported <3 situations of racial discrimination (p=0.0077). (Table 23)

For the adjusted associations between racial discrimination experiences and early pregnancy sleep dimensions dichotomized by specified cutoffs, pregnant people who reported 3+ situations of racial discrimination had 33% lower odds of no excessive daytime sleepiness (OR=0.67, 95% CI: 0.54-0.83), 33% lower odds of good sleep timing (OR=0.67, 95% CI: 0.53-0.84), and 44% lower odds of regular bedtime (OR=0.56, 95% CI: 0.41-0.75) than pregnant people reported <3 situations of racial discrimination. In mid-pregnancy, pregnant people with 3+ situations of racial discrimination had 29% lower odds of sufficient sleep duration (OR=0.71, 95% CI: 0.57-0.89), 30% lower odds of no excessive daytime sleepiness (OR=0.70, 95% CI: 0.55-0.89), 33% lower odds of good sleep timing (OR=0.67, 95% CI: 0.53, 0.85), and 47% lower odds of regular bedtime (OR=0.53, 95% CI: 0.38-0.74) than pregnant people with <3 situations of racial discrimination. (Table 24)

<u>The association between racial discrimination and sleep health in pregnancy-among Black, Hispanic, Asian, and other racial groups</u>

Since the proportion of racial discrimination were lower in white people compared to Black, Hispanic, Asian and other race people. We further examined the association between racial discrimination and sleep health among Black, Hispanic, Asian, and other race (American Indian, Native Hawaiian, Multiracial) populations. We explored the associations for each racial/ethnic group represented in the study, and in our sample, we found similar associations in racial discrimination and sleep dimensions in satisfaction, duration, ESS score, WASO, and composite sleep health score. Therefore, we examined the associations between racial discrimination and sleep health among Black , Hispanic, Asian and other racial groups altogether.

For the crude associations between racial discrimination experiences and early pregnancy sleep health, pregnant people with 3+ situations of racial discrimination had lower sleep duration, higher ESS score, and longer WASO than pregnant people with < 3 situations of racial discrimination. After dichotomizing sleep dimensions by specified cutoffs, pregnant people with 3+ situations of racial discrimination had lower percentages of satisfied sleep (33.70% vs. 41.10%, p=0.0078), no excessive daytime sleepiness (56.15% vs. 67.35%, p<.0001), and efficient sleep (84.54% vs. 88.41%, p=0.0271). There was no longer a significant crude association between racial discrimination and early pregnancy sleep duration after dichotomizing by specified cutoffs (p=0.1878). There was a crude association between racial discrimination experiences and composite sleep health scores in early pregnancy (5.19±0.59 vs. 5.30±0.58, p=0.0099). (Table25)

For sleep outcomes in mid-pregnancy, pregnant people reported with 3+ situations of racial discrimination had lower sleep duration (7.56±1.58 vs. 8.08±1.66 hours, p<.0001), higher ESS score (7.49±4.33 vs. 6.77±4.38, p=0.0027), longer WASO (27.46±30.89 vs. 22.22±31.31 minutes, p=0.0018) than pregnant people with <3 situations of racial discrimination. Among all dichotomized sleep dimensions, pregnant people experienced 3+ situations of racial discrimination had lower percentages of satisfied sleep (32.98% vs. 39.63%, p=0.0130), no excessive daytime sleepiness (68.67% vs. 74.92%, p=0.0093), and efficient sleep (79.30% vs. 84.72%, p=0.0059) than pregnant people reported <3 situations of racial discrimination. Pregnant people with 3+ situations of racial discrimination also had statistically significant lower mid-pregnancy composite sleep health scores than pregnant people with <3 situations of racial discrimination (5.15±0.64 vs. 5.31±0.57, p=0.0010). (Table 25)

In a sample with some but incomplete sleep data, the statistically significant results of the associations between racial discrimination and sleep health were similar to the sample with complete sleep data. Only sufficient sleep duration was no longer statistically significantly different in early pregnancy by racial discrimination groups (p=0.6498). In mid-pregnancy sleep, sleepiness was not different by racial discrimination experiences, both ESS score (p=0.1617) and dichotomized by ESS<10 (p=0.2937). There were crude associations between racial discrimination experiences and mid-pregnancy sufficient duration (p=0.0114) and efficient sleep (p=0.0046) among the dichotomized sleep dimensions. (Appendix Table 18)

We further examined the adjusted associations between racial discrimination experiences and pregnancy sleep health. In early pregnancy, pregnant people who reported 3+ situations of racial discrimination had 0.20 hours shorter in sleep duration (p=0.0381), 0.23 standard deviations higher in ESS score (p=0.0003) and 3.49 minutes more in WASO (p=0.0422) than pregnant people who reported <3 situations of racial discrimination experiences. Pregnant people reported 3+ situations of racial discrimination also had 0.26 standard deviations lower in composite sleep health score in early pregnancy than pregnant people reported <3 situations of racial discrimination (p=0.0012). In mid-pregnancy, pregnant people reported 3+ situations of racial had 0.31 hours shorter in sleep duration (p=0.0014), 0.18 standard deviations higher in ESS score (p=0.0048), 19.99 minutes later in midpoint sleep (p=0.0164) compared to pregnant people reported <3 dimensions of racial discrimination. Pregnant people with 3+ situations of racial discrimination also had 0.31 standard deviations lower in composite sleep health score in mid-pregnancy than pregnant people reported <3 dimensions of racial discrimination (p=0.0002). (Table 26)

In the adjusted models with sleep dimensions dichotomized by specified cutoffs, pregnant people with 3+ situations of racial discrimination had 17% lower odds of having a satisfying sleep (OR=0.83, 95% CI: 0.69-0.98), and 40% lower odds of no excessive daytime sleepiness (OR=0.60, 95% CI: 0.46-0.78) in early pregnancy compared to pregnant people reported <3 situations of racial discrimination. Pregnant people with 3+ situations of racial discrimination had 20% lower odds of satisfying sleep (OR=0.80, 95% CI: 0.66-0.97) and 31% lower odds of no excessive daytime sleepiness (OR=0.69, 95% CI: 0.52-0.93) in mid-pregnancy compared to pregnant people with <3 situations of racial discrimination experiences. (Table 27)

8.5 Discussion

Based on our findings, the experiences of racial discrimination were associated with some sleep dimensions and multidimensional sleep health in early and mid-pregnancy. Specifically, among overall study samples, racial discrimination experiences were associated with higher ESS score and later midpoint sleep in both early and mid-pregnancy after adjusting for potential confounders. The experiences of racial discrimination were associated with short duration and larger weekend-weekday differences in bedtime in mid-pregnancy. After dichotomizing by specified cutoffs, pregnant people with 3+ situations of racial discrimination had lower odds of no excessive daytime sleepiness, good sleep timing, and regular bedtime in both early and mid-pregnancy, lower odds of sufficient sleep duration and regular midpoint sleep in mid-pregnancy. Among Black, Hispanic, Asian and other racial groups, we found the experiences of racial discrimination were associated with shorter sleep duration and higher ESS score in both early and mid-pregnancy. The experiences of racial discrimination were associated with higher WASO in early pregnancy and later midpoint sleep in mid-pregnancy. After dichotomizing by specified cutoffs, pregnant people with 3+ situations of racial discrimination had lower odds of satisfying sleep and no excessive daytime sleepiness. There were associations between the experiences of racial discrimination and composite sleep health score in both overall and Black, Hispanic, Asian, and other race combined samples and at both early and mid-pregnancy

This study identified racial discrimination experiences as a potential risk factor for poor sleep health in pregnancy. We explored specified cutoffs in the association between racial discrimination and sleep health, but based on our sample, the cutoff was not feasible (cutoff at 0) to identify higher and lower exposure groups. Therefore, we utilized a cutoff at 3 situations or more as high exposure to racial discrimination based on previous validity study for the scale and studies that apply racial discrimination data from the same parent study (Grobman et al., 2016; Kreiger, 2005). We further focused on Black, Hispanic, Asian, and other racial groups, who are at higher prevalence of experiencing racial discrimination in the US (Abramson et al., 2015; Lee et al., 2019). After the ancillary analysis of our sample indicating similar associations between racial discrimination and sleep health outcomes observed across these racial groups, we combined Black, Hispanic, Asian, and other racial groups as a subgroup for analysis.

Our findings support that racial discrimination experiences as a risk factor contributing to poor sleep health in pregnancy under some specific dimensions (satisfaction, daytime sleepiness, sleep timing) and multidimensional sleep health (composite sleep health score). Previous studies have also examined the relationship between racial discrimination and sleep in some dimensions, under both pregnant and non-pregnant populations. A study of 640 pregnant people from prenatal registry data has found a cross-sectional association between everyday experiences of discrimination and poor sleep quality. Increased experiences of discrimination were associated with poor sleep initiation, maintenance, and daytime functioning (Francis et al., 2017). The study results were consistent with our findings under similar study populations (i.e., pregnant population) and outcomes (sleep quality and daytime functioning). The relationship between racial discrimination and sleep health were also assessed among non-pregnant populations. Previous studies have examined the effects of racial discrimination on sleep health among Hispanics and African American college students Rumination, the anticipation and experiences of racial discrimination negatively impact sleep quality among Hispanic and African American college students in their freshman year (Gordon et al., 2020; Hoggard & Hill, 2018).

Our results and previous findings support the mechanisms between racial discrimination as a potential stressor and its impact on sleep health. The experiences of racial discrimination are chronic psychosocial stressors that contribute to health disparities (Brondolo et al., 2011; Clark et al., 1999). A chronic stressor may affect endocrine response and physiological changes and physiological adapt to the stress and decrease in arousal during the stress. Stress may lead to organ and tissue damages, which will further impact health (Burchfield, 1979). There is a linkage between neurological and hormonal responses to stress that manifest individual health (Ganzel et al., 2010). The effects of stress have also been linked to preservative cognition, leading to worriedness and associated with physiological activation (Brosschot et al., 2005). Such stress-related thoughts and worriedness may also magnify sleep health (Hicken et al., 2013).

Our study further considered sleep health under a multidimensional concept and incorporates multiple sleep dimensions together as an outcome. In both overall sample and the subgroup sample including Black, Hispanic, Asian and other race pregnant people, we found that pregnant people reported 3+ situations of racial discrimination had lower composite sleep health score (poorer multidimensional sleep health) in both early and mid-pregnancy compared to those reported <3 situations of racial discrimination. While we observed statistically significant associations in racial discrimination and sleep health, we are unable to confirm that the statistically significant findings were indicative of clinically meaningful differences in sleep health by racial discrimination experiences. However, our results suggested the consideration of racial discrimination experiences as psychosocial factors that have an impact on individual sleep dimensions and multidimensional sleep health during pregnancy. Identifying racial discrimination associated with specific sleep dimensions and multidimensional sleep health in pregnancy will support evidence of considering racial discrimination experiences in promoting sleep health in pregnancy, which can further reduce adverse maternal health outcomes attributed to poor sleep health in pregnancy (Hutchinson et al., 2012; Lee et al., 2000).

There are a few strengths in our study. First, to our knowledge, this is the first study in examining the effects of racial discrimination on sleep health among pregnant people with the consideration of multidimensional sleep health. We considered racial discrimination as a potential social factor that may attribute to sleep health during pregnancy. Furthermore, we are able to include multiple sleep outcomes and the overall multidimensional sleep health to examine the sleep dimensions that racial discrimination experiences may associated with. Second, we are able to observe the association between racial discrimination experiences and sleep health at more than one timepoint in pregnancy. Since sleep health changes dynamically in pregnancy, having sleep assessment in different trimesters will provides us information on when social factors may contribute more to sleep health during the prenatal period (Lee, 1998). However, due to the nature of secondary analysis, we only have early and mid-pregnancy sleep assessment. Future studies should consider sleep outcomes in late pregnancy for a more comprehensive view on how social factor associated with sleep health throughout pregnancy.

There are also some limitations in our study. First, this is secondary analysis from an observational study, there are residual confounders that we are unable to adjust for, including the information about residing in disadvantaged neighborhoods and other neighborhood-level factors that may contribute to racial discrimination experiences and sleep health. We are also limited to the assessment of racial discrimination experiences. There are other important factors such as the frequency and coping strategies of racial discrimination was not available. Second, we used self-reported sleep data for our study outcome. NuMom2b study has a substudy that assessed sleep objectively during second trimester of pregnancy. However, the substudy has a different target sample than the overall study. Furthermore, sleep satisfaction and sleepiness are better captured through subjective assessment (Zhang & Zhao, 2007) Third, the empirical cutoffs we used for dichotomizing sleep dimensions were based on general populations but not specifically for pregnant populations. More studies on exploring thresholds for each sleep dimension is necessary to establish thresholds for good sleep health in pregnant populations. Lastly, our study sample may not be representative enough for overall pregnant populations. Our study sample was limited to nulliparous pregnant people and were recruited under hospital settings. Therefore, our sample have healthcare access and reported higher educational level and less poverty. We are unable to apply the findings to multiparous women while parity is also an important factor for sleep health in pregnancy (Christian et al., 2019; Lee et al., 2000) We are also unable to conclude the findings on underserved pregnant populations. Future studies will need to consider a more diverse pregnant population to better assess the effects of social factors on sleep health in pregnancy.

8.6 Conclusion

Pregnant people's experiences of racial discrimination were associated with specific sleep dimensions, including sleep satisfaction, daytime sleepiness, sleep timing, and multidimensional sleep health in pregnancy. This study suggested that racial discrimination is an important psychosocial stressor for poor sleep health in early and mid-pregnancy. Our findings supported that reducing racial discrimination experiences may improve pregnant people's sleep health and further reduce adverse maternal health outcomes attributed to poor sleep health during pregnancy. Our results also provided some understanding of the particular experiences of specific racial groups in understanding the relationship between racial discrimination and sleep health during pregnancy. Future studies should further examine the effects of racial discrimination experiences on sleep health under different and diverse pregnant populations (multiparous, low-income etc.) to better understand the impact of racial discrimination on sleep health in pregnancy. Future studies should also examine the clinical meaningfulness of changes in individual sleep dimensions and multidimensional sleep health between pregnant people with high and low to no experiences of racial discrimination.

8.7 Aim 3 Tables and Figures

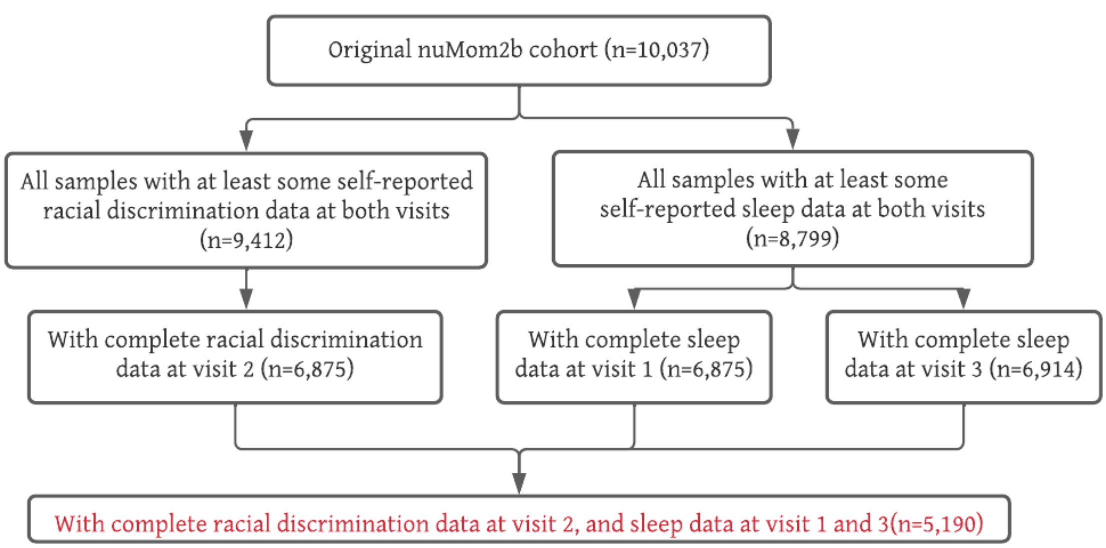

Figure 15. Figure 15. Aim 3 Participant Flowchart

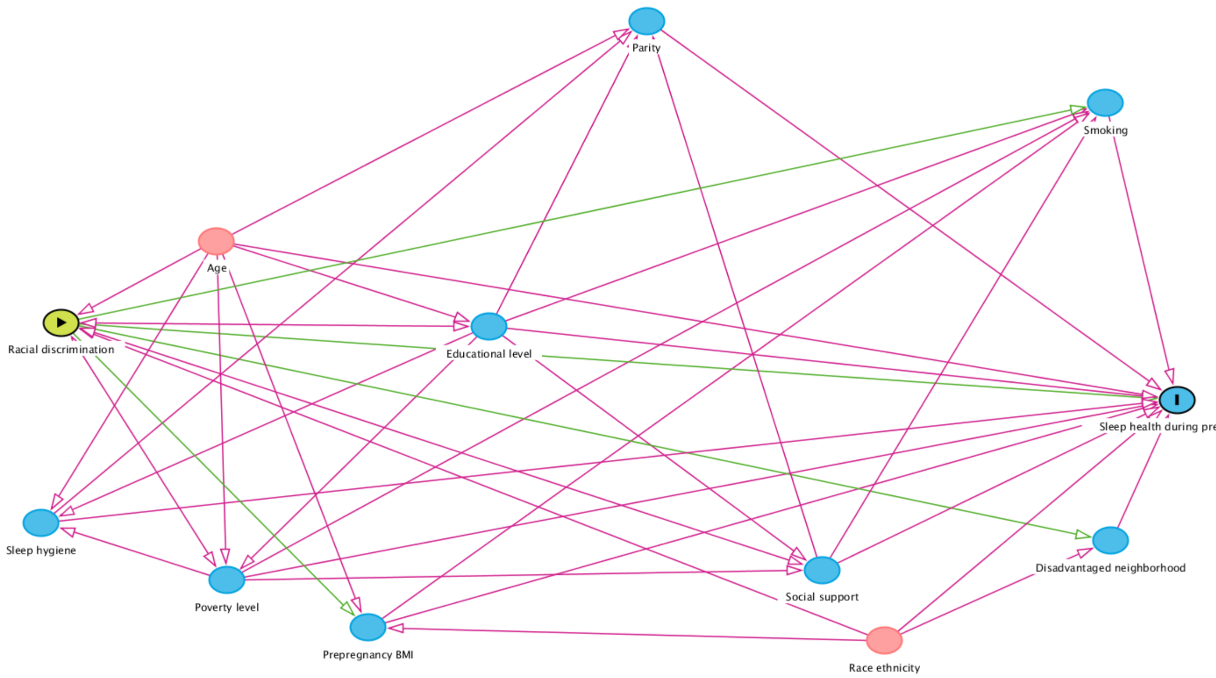

Figure 16. DAG for Racial Discrimination, Sleep Health, and Covariates

Table 19. Aim 3 Demographic Characteristics of the Study Sample- Overall and by the Experiences of Racial Discrimination

	Overall (n=5190)	<3 situations of racial discrimination (n=4913)	3+ situations of racial discrimination (n=277)	
Variables	Mean ± SD	Mean ± SD	Mean ± SD	p-value
Gestational age at screening (weeks)	11.60±1.48	11.59±1.47	11.69±1.48	0.3074
Maternal age at screening (years)	28.18±5.18	28.13±5.12	29.09±6.01	0.0099**
Prepregnancy BMI (kg/m^2)	25.58±5.63	25.50±5.58	26.90±6.26	0.0004**
Percentage of federal poverty level (%)	493.65±300.65	496.92±300.05	433.92±305.94	0.0016**
Social support score	75.55±13.49	75.70±13.45	72.77±13.83	0.0004**
Variables	n (%)	n (%)	n (%)	p-value
Maternal age at screening (years)				<.0001**
13-17	59 (1.14)	57 (1.16)	2 (0.72)	
18-34	4582 (88.29)	4364 (88.83)	218 (78.70)	
35-39	475 (9.15)	429 (8.73)	46 (16.61)	
40 or higher	74 (1.43)	63 (1.28)	11 (3.97)	
Race ethnicity				<.0001**
Non-Hispanic white	3716 (71.60)	3644 (74.17)	30 (10.83)	
Non-Hispanic Black	325 (6.26)	255 (5.19)	76 (27.44)	
Hispanic	684 (13.18)	608 (12.38)	70 (25.27)	
Asian	242 (4.66)	212 (4.32)	72 (25.99)	
Other [a]	223 (4.30)	194 (3.95)	29 (10.47)	
Prepregnancy BMI (kg/m2)				<.0001**
<18.5 (Underweight)	105 (2.05)	95 (1.96)	10 (3.62)	
18.5-<25 (Normal weight)	2859 (55.71)	2742 (56.47)	117 (42.39)	
25-<30 (Overweight)	1267 (24.69)	1191 (24.53)	76 (27.54)	
30-<35 (Obese)	526 (10.25)	485 (9.99)	41 (14.86)	
35 or higher (Morbidly obese)	375 (7.31)	343 (7.06)	32 (11.59)	
Educational level				0.1278
Less than high school graduate	181 (3.49)	169 (3.44)	12 (4.33)	
High school graduated or GED	370 (7.13)	346 (7.04)	24 (8.66)	
Associate/Tech degree	471 (9.08)	451 (9.18)	20 (7.22)	
Some college	825 (115.90)	772 (15.71)	53 (19.13)	
College degree	1787 (34.43)	1709 (34.79)	78 (28.16)	
Degree beyond college	1556 (29.98)	1466 (29.84)	90 (32.49)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other
[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size
*p<0.05; **p<0.01

Table 19. Aim 3 Demographic Characteristics of the Study Sample- Overall and by the Experiences of Racial Discrimination (cont.)

	Overall (n=5190)	<3 situations of racial discrimination (n=4913)	3+ situations of racial discrimination (n=277)	
Variables	n (%)	n (%)	n (%)	p-value
Gravidity				<.0001**
1	3985 (76.78)	3804 (77.43)	181 (65.34)	
2	939 (18.09)	872 (17.75)	67 (24.19)	
3 or more	266 (5.13)	237 (4.82)	29 (10.47)	
Ever used tobacco				0.0005**
Yes	2161 (41.64)	2018 (41.07)	143 (51.62)	
No	3029 (58.36)	2895 (58.93)	134 (48.38)	
Smoked tobacco within 3 months prior to pregnancy				0.0031**
Yes	720 (13.88)	665 (13.54)	55 (19.86)	
No	4469 (86.12)	4247 (86.46)	222 (80.14)	
Insurance type (can be more than one) [b]				
Governmental	867 (163.78)	796 (16.28)	71 (25.63)	<.0001**
Military	40 (0.77)	36 (0.74)	4 (1.44)	0.1911
Commercial	4141 (80.16)	3953 (80.85)	188 (67.87)	<.0001**
Personal	1085 (21.00)	1014 (20.74)	71 (25.63)	0.0519
Other	59 (1.14)	55 (1.12)	4 (1.44)	0.6268
Percentage of federal poverty level (%)				<.0001**
<100	393 (8.58)	355 (8.18)	38 (15.97)	
100-200	564 (12.32)	532 (12.26)	32 (13.45)	
>200	3622 (79.10)	3454 (79.57)	168 (70.59)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

*p<0.05; **p<0.01

Table 20. Aim 3 Descriptive Statistics of the Experiences of Racial Discrimination by Racial Groups

Number of situations experiencing racial discrimination, n (%)	Non-Hispanic white (n=3716)	Non-Hispanic Black (n=325)	Hispanic (n=684)	Asian (n=242)	Other (n=223)
0	3251 (87.49)	179 (55.08)	443 (64.77)	127 (52.48)	138 (61.88)
1	289 (7.78)	39 (12.00)	109 (15.94)	46 (19.01)	39 (17.49)
2	104 (2.80)	37 (11.38)	56 (8.19)	39 (16.12)	17 (7.62)
3	44 (1.18)	30 (9.23)	32 (4.68)	18 (7.44)	17 (7.62)
4	17 (0.46)	21 (6.46)	25 (3.65)	9 (3.72)	6 (2.69)
5	7 (0.19)	9 (2.77)	12 (1.75)	2 (0.83)	1 (0.45)
6	0 (0.00)	5 (1.54)	7 (1.02)	1 (0.41)	3 (1.35)
7	1 (0.03)	4 (1.23)	0 (0.00)	0 (0.00)	1 (0.45)
8	0 (0.00)	1 (0.31)	0 (0.00)	0 (0.00)	1 (0.45)
9	3 (0.08)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Less than 3 domains	3644 (98.06)	255 (78.46)	608 (88.89)	212 (87.60)	194 (87.00)
3 or more domains	72 (1.94)	70 (21.54)	76 (11.11)	30 (12.40)	29 (13.00)

Table 21. Aim 3 Sleep Health in Early and Mid-pregnancy

Sleep dimensions	Early pregnancy	Mid-pregnancy
Uncategorized sleep dimensions	Mean ± SD	Mean ± SD
Duration (hr)	8.03±1.05	7.87±1.08
Epworth Sleepiness Scale (ESS) Score	7.61±3.93	6.42±3.88
Wake after sleep onset (WASO, min)	19.45±18.98	23.59±20.19
Midpoint sleep (a.m.) [a]	3:09 (1:13)	3:07 (1:14)
Weekend-weekday difference in bedtime (hr)	0.82±0.66	0.73±0.65
Weekend-weekday difference in waketime (hr)	1.63±1.15	1.50±1.08
Weekend-weekday difference in midpoint sleep (hr)	1.20±0.76	1.09±0.73
Categorized by specified cutoffs [b]	n (%)	n (%)
Good sleep satisfaction, n (%)	2249 (43.33)	1962 (37.80)
Sufficient duration, n (%)	3656 (70.44)	3590 (69.17)
No excessive daytime sleepiness, n (%)	3654 (70.40)	4115 (79.29)
Good sleep continuity, n (%)	4500 (86.71)	4244 (81.77)
Appropriate sleep timing , n (%)	3783 (72.89)	3769 (72.62)
Regular bedtime, n (%)	4703 (90.62)	4788 (92.25)
Regular waketime, n (%)	2982 (57.46)	3238 (62.39)
Regular midpoint, n (%)	4261 (82.10)	4447 (85.68)
Composite sleep health score, Mean ± SD	5.31±0.56	5.28±0.58

[a] Midpoint is presented in median with interquartile range

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Table 22. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health- Overall Sample

	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	3+ situations of racial discrimination		<3 situations of racial discrimination			3+ situations of racial discrimination		<3 situations of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	436	7.81±1.49	6871	8.03±1.31	0.0024**	456	7.62±1.50	7090	7.89±1.35	0.0002**
Epworth Sleepiness Scale (ESS) Score	464	8.66±4.10	7110	7.73±4.06	<.0001**	486	7.40±4.34	7486	6.54±4.04	<.0001**
Wake after sleep onset (WASO, min)	508	24.75±32.22	7713	20.68±26.00	0.0055**	508	28.18±30.72	7713	26.06±29.83	0.1223
Midpoint sleep (a.m.) [a]	508	3:38 (1:36)	7713	3:13(1:25)	<.0001**	456	3:34 (1:41)	7090	3:13 (1:27)	<.0001**
Weekend-weekday difference in bedtime (hr)	384	1.08±1.32	6302	1.00±1.34	0.2779	396	0.97±1.37	6401	0.88±1.30	0.1945
Weekend-weekday difference in waketime (hr)	383	1.65±1.40	6306	1.74±1.42	0.2603	397	1.56±1.44	6398	1.59±1.38	0.6825
Weekend-weekday difference in midpoint sleep (hr)	382	1.32±1.15	6286	1.34±1.23	0.7338	396	1.20±1.27	6377	1.20±1.20	0.9841
Categorized by specified cutoffs [b]	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	465	152 (32.69)	7154	2891 (40.41)	0.0010**	487	155 (31.83)	7493	2698 (36.01)	0.0622
Sufficient duration, n (%)	436	251 (57.57)	6871	4460 (64.91)	0.0019**	456	251 (55.04)	7090	4517 (63.71)	0.0002**
No excessive daytime sleepiness, n (%)	464	271 (58.41)	77110	4918 (69.17)	<.0001**	486	339 (69.75)	7486	5846 (78.09)	<.0001**
Efficient sleep, n (%)	508	417 (82.09)	7713	6586 (85.39)	0.0425*	508	397 (78.15)	7713	6171 (80.01)	0.3115
Appropriate sleep timing, n (%)	436	250 (57.34)	6871	4632 (67.41)	<.0001**	456	258 (56.58)	7090	4702 (66.32)	<.0001**
Regular bedtime, n (%)	384	311 (80.99)	6302	5514 (87.50)	0.0002**	396	330 (83.33)	6401	5742 (89.70)	<.0001**
Regular waketime, n (%)	383	229 (59.79)	6306	3542 (56.17)	0.1651	397	245 (61.71)	6398	3946 (61.63)	0.9733
Regular midpoint, n (%)	382	294 (76.96)	6286	5008 (79.67)	0.2033	396	313 (79.04)	6377	5340 (83.74)	0.0146*
Composite sleep health score, Mean ± SD	277	5.20±0.59	4913	5.32±0.55	0.0005**	277	5.17±0.62	4913	5.29±0.57	0.0012**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Table 23. Adjusted Coefficient Estimates in the Associations Between Racial Discrimination Experiences and Sleep Health in Pregnancy- Overall Sample

	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Early pregnancy								
Adjusted β [b]	-0.11	0.19	2.73	18.42	0.09	-0.02	0.02	-0.20
SE	0.06	0.05	1.40	6.60	0.08	0.08	0.07	0.06
p-value	0.0847	0.0002**	0.0503	0.0053**	0.2290	0.8170	0.7972	0.0023**
Mid-pregnancy								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.22	0.18	0.89	27.67	0.17	0.02	0.07	-0.18
SE	0.07	0.05	1.53	6.33	0.08	0.08	0.07	0.07
p-value	0.0010**	0.0010**	0.5592	<.0001*	0.0266*	0.7979	0.3005	0.0077*

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score centering from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; composite sleep health score is the standardized composite sleep health score centering from sample mean

[b] Adjusted for: maternal age, educational level, percentage of federal poverty level, and social support score.

*p<0.05; **p<0.01

Table 24. Adjusted Odds Ratios in the Associations Between Racial Discrimination Experiences and Sleep Dimensions Categorized by Specified Cutoffs in Pregnancy- Overall Sample

	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
Early pregnancy								
3+ situations Odds ratios [b]	0.87	0.81	0.67	0.85	0.67	0.56	1.15	0.83
95% CI	(0.75, 1.01)	(0.65, 1.02)	(0.54, 0.83)	(0.65, 1.12)	(0.53, 0.85)	(0.41, 0.75)	(0.91, 1.45)	(0.63, 1.09)
Mid-pregnancy								
3+ situations Odds ratios [b]	0.89	0.71	0.70	0.97	0.67	0.53	1.01	0.71
95% CI	(0.76, 1.04)	(0.57, 0.89)	(0.55, 0.89)	(0.75, 1.25)	(0.53, 0.85)	(0.38, 0.74)	(0.79, 1.28)	(0.53, 0.95)

[a] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] Adjusted for: maternal age, educational level, percentage of federal poverty level, and social support score.

*p<0.05; **p<0.01

Table 25. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health- Non-Hispanic Black, Hispanics, Asians, and Other Races (American Indian, Native Hawaiian, Multiracial)

	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	3+ situations of racial discrimination		<3 situations of racial discrimination			3+ situations of racial discrimination		<3 situations of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	N	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	334	7.76±1.53	2123	8.20±1.64	<.0001**	355	7.56±1.58	2251	8.08±1.66	<.0001**
Epworth Sleepiness Scale (ESS) Score	358	8.85±4.08	2288	7.92±4.38	0.0002**	383	7.49±4.33	2520	6.77±4.38	0.0027**
Wake after sleep onset (WASO, min)	401	22.88±30.45	2605	17.86±26.11	0.0005**	401	27.46±30.89	2605	22.22±31.31	0.0018**
Midpoint sleep (a.m.) [a]	334	3:43 (1:32)	2123	3:38 (1:50)	0.9132	355	3:41 (1:41)	2251	3:41 (1:50)	0.7124
Weekend-weekday difference in bedtime (hr)	292	1.06±1.18	1811	1.02±1.43	0.5915	303	0.97±1.24	1875	0.91±1.29	0.4900
Weekend-weekday difference in waketime (hr)	291	1.61±1.34	1812	1.69±1.58	0.3635	304	1.58±1.41	1873	1.55±1.49	0.7076
Weekend-weekday difference in midpoint sleep (hr)	290	1.28±1.01	1803	1.32±1.33	0.5793	303	1.20±1.18	1865	1.16±1.22	0.6184
Categorized by specified cutoffs [b]	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	359	121 (33.70)	2299	945 (41.10)	0.0078**	382	126 (32.98)	2521	999 (39.63)	0.0130*
Sufficient duration, n (%)	334	191 (57.19)	2123	1132 (53.32)	0.1878	355	188 (52.96)	2251	1240 (55.09)	0.4538
No excessive daytime sleepiness, n (%)	358	201 (56.15)	2288	1541 (67.35)	<.0001**	383	263 (68.67)	2520	1888 (74.92)	0.0093**
Efficient sleep, n (%)	401	339 (84.54)	2605	2303 (88.41)	0.0271*	401	318 (79.30)	2605	2207 (84.72)	0.0059**
Appropriate sleep timing , n (%)	334	192 (57.49)	2123	1142 (53.79)	0.2079	355	196 (55.21)	2251	1210 (53.75)	0.6086
Regular bedtime, n (%)	292	236 (80.82)	1811	1511 (83.43)	0.2693	303	251 (82.84)	1875	1606 (85.65)	0.1996
Regular waketime, n (%)	291	177 (60.82)	1812	1048 (57.84)	0.3373	304	184 (60.53)	1873	1157 (61.77)	0.6786
Regular midpoint, n (%)	290	223 (76.90)	1803	1411 (78.26)	0.6029	303	238 (78.55)	1865	1518 (81.39)	0.2415
Composite sleep health score, Mean ± SD	205	5.19±0.59	1269	5.30±0.58	0.0099**	205	5.15±0.64	1269	5.31±0.57	0.0010**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Table 26. Adjusted Coefficient Estimates in the Associations Between Racial Discrimination Experiences and Sleep Health in Pregnancy- Non-Hispanic Black, Hispanics, Asians, and Other Races (American Indian, Native Hawaiian, Multiracial)

	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Cross-sectional- Early pregnancy								
Adjusted β [b]	-0.20	0.23	3.49	2.35	0.05	-0.05	-0.02	-0.26
SE	0.10	0.06	1.72	8.56	0.10	0.11	0.09	0.08
p-value	0.0381*	0.0003**	0.0422*	0.7835	0.5918	0.6219	0.8020	0.0012**
Cross-sectional- Mid-pregnancy								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.31	0.18	3.22	19.99	0.14	0.05	0.07	-0.31
SE	0.10	0.06	1.85	8.33	0.10	0.11	0.09	0.08
p-value	0.0014**	0.0048**	0.0821	0.0164*	0.1700	0.6326	0.4215	0.0002**

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score centering from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; composite sleep health score is the standardized composite sleep health score centering from sample mean

[b] Adjusted for: maternal age, educational level, percentage of federal poverty level, and social support score.

*p<0.05; **p<0.01

Table 27. Adjusted Odds Ratios in the Associations Between Racial Discrimination Experiences and Sleep Dimensions Categorized by Specified Cutoffs in Pregnancy- Non-Hispanic Black, Hispanics, Asians, and Other Races (American Indian, Native Hawaiian, Multiracial)

	Early pregnancy							
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
3+ situations Odds ratios [b]	0.83	1.03	0.60	0.82	0.92	0.68	1.23	0.81
95% CI	(0.69, 0.98)	(0.76, 1.32)	(0.46, 0.78)	(0.58, 1.16)	(0.70, 1.22)	(0.47, 0.99)	(0.92, 1.63)	(0.58, 1.13)
	Mid-pregnancy							
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
3+ situations Odds ratios [b]	0.80	0.76	0.69	0.84	0.84	0.69	0.99	0.78
95% CI	(0.66, 0.97)	(0.58, 1.00)	(0.52, 0.93)	(0.61, 1.15)	(0.63, 1.11)	(0.46, 1.03)	(0.74, 1.32)	(0.55, 1.12)

[a] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] Adjusted for: maternal age, educational level, percentage of federal poverty level, and social support score.

*p<0.05; **p<0.01

9.0 Discussion

This section summarizes the study objectives and discusses the findings from three aims. First, we discussed the sleep characteristics of individual sleep dimensions and multidimensional sleep health during pregnancy. Second, we expanded our discussion to the findings on individual and psychosocial factors associated with sleep health during pregnancy. We compared our results to previous studies describing sleep health and identifying factors associated with poor sleep health during pregnancy. We also listed the strengths and limitations of our research. Finally, based on the discussion, we discussed public health implications and future research direction on describing and improving sleep health during pregnancy.

9.1 Summary of Research Objectives

Sleep health is fundamental for one's health and well-being. Specifically, since there are drastic physical and hormonal changes during pregnancy, declined sleep health is common among pregnant people. While sleep health has been defined as a multidimensional behavior, and prior studies had observed other sleep dimension such as late sleep timing associated with adverse obstetric outcomes, it is important to expand the view of multidimensional sleep health among pregnant people. Characterizing multiple sleep dimensions individually and the multidimensional sleep health provide fundamental knowledge on sleep health in pregnancy. We described sleep health in individual dimensions and multidimensional sleep health during pregnancy in the first aim. We characterized multiple sleep dimensions during early and mid-pregnancy, including sleep satisfaction, duration, daytime sleepiness, continuity, timing, regularity in bedtime, waketime, and midpoint sleep. We created a composite sleep health score by quantifying the distance from specified cutoffs for each sleep dimension and sum for a composite sleep health score. We further described sleep by maternal age groups and race ethnicity to characterize sleep health within each subcategory.

Since poor sleep health affects pregnant people's health and well-being, researchers have been identifying risk factors associated with poor sleep health in pregnancy. Understanding these factors will support evidence for considering these factors for sleep health improvement and further reduces the risks of adverse maternal health outcomes attributed to poor sleep health in pregnancy. In the second and third aim, our goal was to identify mental health and psychosocial factors associated with poor sleep health during pregnancy.

Prior studies have observed a close relationship between depression and poor sleep. Prenatal depression is a depressive episode that occurs explicitly in pregnancy. With previous studies supporting the association between mental health in sleep health, it is worth considering prenatal depression as a potential factor of poor sleep health in pregnancy. The management of prenatal health could potentially improve sleep health in pregnancy. The second aim examined the relationship between prenatal depression and sleep health in pregnancy. We assessed the cross-sectional associations in early and mid-pregnancy and the longitudinal association between prenatal depression in early pregnancy and sleep health in mid-pregnancy.

Racial disparities in sleep health have been characterized in previous studies where non-white races are more likely to experience poor sleep health than whites. However, based on previous findings, racial differences no longer existed once controlled for racial discrimination and racism-related factors. These racial disparities are more likely a social factor that induces stressors from one's experiences in racial discrimination and negatively affect sleep health. Furthermore, racial discrimination experiences are chronic stressors that lead to neurological and hormonal responses to stress that manifest individual health. In the third aim, we identified whether lifetime racial discrimination experiences were psychosocial stressors that increased poorer sleep health in early and mid-pregnancy. We further investigated non-white races specifically in the association between racial discrimination experiences and sleep health in pregnancy.

In the next section, we will summarize the findings from each aim and discuss our findings with the comparison of prior studies.

9.2 Summary of Research Findings

There are changes in individual sleep dimensions from early to mid-pregnancy

There are changes in specific sleep dimensions between two timepoints. Specifically, we found declined sleep health in dimensions such as satisfaction, duration, and continuity (i.e., increased WASO). The findings on these sleep dimensions aligned with prior studies describing sleep health during pregnancy. For example, a cross-sectional study collected sleep data from 2,427 women across all gestational ages through an online survey has found that pregnant people in their 8 months of pregnancy had 0.7 hours shorter sleep than participants at 2 months pregnancy. Furthermore, the duration of waking at night also increased by 19.7 minutes from 2 to 8 months of pregnancy (Mindell et al., 2015). Similar results were found in a longitudinal study from Finland that described sleep health throughout pregnancy. Among all 325 women who reported sleep at all timepoints, sleep duration decreased by 0.3 hours from the first to second trimester (First trimester:

8.7 hours, Second trimester: 8.4 hours). The percentage of pregnant people reported restless sleep increased from 15.4% in the first trimester to 20.3% in the second trimester.

The findings on sleep timing and regularity during pregnancy are limited. The study results showed that 90% of pregnant people maintain regular bedtime while only 60% could maintain regular waketime during pregnancy. Specifically, weekend waketimes were later than weekdays at early and mid-pregnancy. It is likely that individuals have later waketime during non-workdays to reach sufficient sleep (i.e., social jetlag) (Wittmann et al., 2006).

<u>The differences in composite sleep health scores were small between early and mid-pregnancy</u>

Although the composite sleep health score in the overall sample showed a statistically significant decrease from early to mid-pregnancy, the differences in the composite sleep health score were small. Specifically, the composite sleep health score decline is less than 0.1 points. The overall sleep health likely deteriorates starting in early pregnancy and with the dynamic changes throughout pregnancy. Lee's review on the alteration of sleep during pregnancy indicated poor sleepiness in early pregnancy was likely due to morning sickness and hormonal changes. Enlarged uterus in later pregnancy limited sleep position and frequent urination that caused increases in awakenings and shorter sleep duration in late pregnancy (Lee, 1998). Our results reflect Lee's finding where we observed small differences in overall sleep health but there were improvements in less daytime sleepiness and declines in sleep satisfaction, duration, and sleep continuity from early pregnancy to mid-pregnancy.

<u>The younger maternal age group had better sleep satisfaction and duration but more sleepiness, later sleep timing, and more irregular sleep than other age groups</u>

Based on our findings, the youngest age group (i.e., age 13 to 17) showed better sleep satisfaction and longer duration than other age groups (i.e., 18-24 and 25+ years). Specifically, pregnant people aged 13-17 had increases in the percentages of satisfying sleep and average duration as the pregnancy progressed. Prior studies have identified advanced maternal age as a potential risk factor for poor sleep health in pregnancy. For example, Sedov et al.'s meta-analysis on sleep quality during pregnancy reported that older samples had a higher prevalence of poor sleep quality (Sedov et al., 2018). A longitudinal study from Finland collected self-reported sleep data from 325 pregnant people has found that women over 30 years of age were more likely to report decreased sleep duration throughout pregnancy (Hedman et al., 2002). Our findings aligned with previous findings on the association between advanced age and poor sleep quality and short sleep duration in pregnancy.

However, we also observed that pregnant people aged 13-17 years experienced more sleepiness, later sleep timing, and irregular sleep than other age groups. Though we did not see much information on sleep health among teenage pregnancies, prior studies have observed that longer screen time before bedtime and hormonal differences between adolescents and adults are potential factors for more sleepiness and irregular sleep among adolescents (Carskadon et al., 1997; Carskadon et al., 1999).

<u>In contrast with prior findings, non-Hispanic whites in our sample performed worse sleep health</u>

When we characterized sleep health by racial groups, we found non-Hispanic whites in our sample had the largest decline in the proportion of good sleep satisfaction, and the largest increase in WASO among all racial groups from early to mid-pregnancy. Previous studies generally found poorer sleep quality and duration among non-Hispanic Black people than white people. For example, a longitudinal study with a biracial sample of 133 pregnant people has found poorer sleep quality (i.e., PSQI score) among Black women compared to white women (Christian et al., 2019). Another nationally representative sample in the U.S. with 2,349 pregnant people has found a higher prevalence of self-reported short sleep duration among non-Hispanic Black participants than whites (Feinstein et al., 2020) Such differences in the results may be related to the different sample characteristics and measurements of sleep health. Our assessment of sleep satisfaction was not the same as sleep quality assessed through PSQI. Our sample was also limited to nulliparous women with better education and income levels.

Furthermore, while previous findings have identified racial differences in sleep health, the differences were attenuated after controlling for racism-related factors (Hicken et al., 2013). Racial disparities in sleep health are not merely racial differences. Specifically, racial discrimination may be an underlying factor for poor sleep health (Hicken et al., 2013; William & Mohammed, 2009). These findings lead us to explore racial discrimination experiences as potential factors of poor sleep health in pregnancy.

<u>There is a close pathological association between depression and sleep during pregnancy</u>

Sleep deficiency both increase inflammation responses and neurotransmitters level (Irwin & Cole, 2011; Irwin et al., 2018). Previous studies have found the increase in cellular inflammation is common among patients with depression and more often in females (Gimeno et al., 2009; Miller et al., 2009). Abnormal REM sleep circles and depression share the same type of monoamine neurotransmitters (Irwin et al., 2018) Patients with depression are more likely to experience reduced REM sleep and disturbed sleep (low sleep continuity) (Steiger & Pawlowski, 2019).

Deficient sleep is also a major symptom among people with depression. Common symptoms include difficulties in initiating or maintaining sleep due to the stress and depressive moods (Hamilton, 1989; Yates et al., 2007). These findings support our study targeting pregnant people who are already at a higher inflammatory state (i.e, C-reactive protein and interleukin-6)

(Carroll et al., 2019). Our results aligned with the theory and examined the relationship between prenatal depression and poor sleep health in pregnancy.

<u>There are cross-sectional and longitudinal associations between prenatal depression and some but not all sleep dimensions</u>

Our study findings from aim 2 supported that prenatal depression is associated with poor sleep health in some sleep dimensions. Specifically, we found individuals with prenatal depression were less likely to have a satisfying sleep and sufficient sleep duration. The associations exist cross-sectionally and longitudinally in early and mid-pregnancy. Previous findings suggested that there are effects of depression on sleep health (Field et al., 2007; Swanson et al., 2011; Yu et al., 2017). However, the results were mainly based on non-pregnant populations. A prospective populational study with 24,715 adults has seen a nearly 7-fold increase in risks of developing insomnia (measured as the inability to get back to sleep after nighttime awakenings) among depressed individuals (OR=6.7, 95%CI; 5.46-8.26) (Sivertsen et al., 2012). Another Chinese sample of 10704 adults aged 45 and older has found that depressed individuals are more likely to experience short sleep duration than non-depressed individuals (RR=1.20, 95%CI: 1.02-1.43) (Sun et al., 2018). Our findings on pregnant sleep health aligned with these findings.

<u>Large sleep timing and weekend-weekday differences in sleep are more prevalent in pregnant people with probable prenatal depression, but the results were only found in early pregnancy and no longer exist after dichotomizing sleep regularity</u>

For some less observed sleep dimensions, such as sleep timing and regularity, we observed later sleep timing and larger weekend-weekday differences in waketime and midpoint sleep during early pregnancy among pregnant people with EPDS ≥10. However, we did not see the differences after dichotomizing weekend-weekday differences in bedtime, waketime, and midpoint sleep by specified cutoffs, either cross-sectionally or longitudinally. The discrepancies in results before and after dichotomizing by specified cutoffs suggest the need to consider the most appropriate assessment of sleep regularity in pregnancy.

Prenatal depression was associated with a lower composite sleep health score in early and mid-pregnancy

There were cross-sectional and longitudinal associations between prenatal depression and composite sleep health scores. However, the differences of the sleep health score were small, from 0.26 points in early pregnancy to 0.31 points in mid-pregnancy. Based on previous findings, there is no information on clinically meaningful differences in multidimensional sleep health in pregnancy. Our results support the statistically significant differences in composite sleep health scores, but more studies are needed to investigate the clinical meaningfulness of differences in multidimensional sleep health in pregnancy.

Racial discrimination is a stressor that explains the intergroup differences in sleep health

Racial discrimination is a chronic stressor. A chronic stressor may affect endocrine response and physiological changes and physiological adapt to the stress and decrease in arousal during the stress. Stress may lead to organism to tissue damage and impact health (Burchfield, 1979) There is a linkage between neurological and hormonal responses to stress that manifest individual health (Ganzel et al., 2010) The effects of stress have also been linked to preservative cognition, leading to worriedness and associated with physiological activation (Brosschot et al., 2005) Such stress-related thoughts and worriedness may also magnify sleep health (Hicken et al., 2013).

Racial discrimination experiences are associated with lower sleep satisfaction, more sleepiness, and later sleep timing

Our findings support that racial discrimination experiences as a significant factor contributing to poor sleep health in pregnancy under some specific dimensions (satisfaction, daytime sleepiness, sleep timing). Our findings aligned with a previous study targeting both pregnant and non-pregnant populations. For example, previous studies have examined the effects of racial discrimination on sleep health among Hispanics and African American college students (Gordon et al., 2020; Hoggard & Hill, 2018). Similar findings from a study targeting pregnant populations. A study of 640 pregnant people on the cross-sectional association between the experiences of racial discrimination and pregnancy sleep health. Pregnant people with everyday experiences of discrimination were more likely to experience poor sleep quality than those with low exposure to racial discrimination (Francis et al., 2017). These results reflect findings from previous studies that stated that racial discrimination experiences are chronic psychosocial stressors that contribute to health disparities (Brondolo et al., 2011).

<u>Pregnant people with higher exposure to racial discrimination performed lower composite sleep health score than those experiencing less racial discrimination</u>

We explored specified cutoffs in the association between racial discrimination and sleep health, but based on our sample, the cutoff was not feasible (cutoff at 0). Therefore, we utilized a cutoff at 3 situations or more as high exposure to racial discrimination based on previous validity study for the scale and studies that apply racial discrimination data from the same parent study (Grobman et al., 2016; Kreiger, 2005). Based on our findings, pregnant people with 3 or more racial discrimination experiences had lower composite sleep health scores than those who had less than 3 situations of racial discrimination in mid-pregnancy among overall sample. When we limited to only non-white samples, there are statistically significant associations between racial discrimination experiences and composite sleep health scores in both early and mid-pregnancy.

Even though we observed statistically significant differences in composite sleep health scores by the exposure of racial discrimination experiences, the differences were by 0.09 to 0.17 points. The differences were small, and we do not know whether these differences were clinically meaningful. Our findings suggest that there are potentials to observe the differences by overall sleep health, but more findings on appropriate measurements for all sleep dimensions and explore clinical meaningfulness for individual and overall sleep health changes are warranted to better assess multidimensional sleep health in pregnancy.

9.3 Strengths and Limitations

There are some strengths to our studies. First, this is the first study that describes sleep health in pregnancy with multiple dimensions and composite scoring. While sleep quality and duration have been widely examined in understanding sleep pattern in pregnancy, we characterized sleep through other domains that prior findings had less information on, such as sleep timing and regularity. Second, we created a composite sleep health score to assess multidimensional sleep health. The score calculation was based on the distance from specified cutoffs for each dimension. Although the scoring requires more information on selecting the best cutoffs for pregnant samples and further validity testing, we can quantify and describe multidimensional sleep health in pregnancy. Third, we used the concept of multidimensional sleep health as the outcome to identify factors for poor sleep health in pregnancy. Our findings supported the importance of mental health (prenatal depression) and psychosocial stressors (racial discrimination experiences) in sleep health improvement during pregnancy. The successful improvement of sleep health may further reduce the adverse maternal health outcomes attributed to poor sleep health during pregnancy.

There are also some limitations to our study. First, our study is based on data from an observational study. We acknowledged that there are residual confounders (e.g., neighborhood factors) that we were unable to capture and adjust for these factors in the assessment of associations between prenatal depression/racial discrimination experiences and sleep health. Since this is a secondary analysis, we only have sleep data in early and mid-pregnancy. There was no data on sleep health for prepregnancy or late pregnancy. Therefore, while previous studies indicated sleep deteriorates in late pregnancy with significant body discomfort, we cannot capture sleep health in later pregnancy (Hedman et al., 2002; Hutchison et al., 2012). However, we still have a longitudinal assessment of sleep to indicate the changes from early to mid-pregnancy and understand how each sleep dimension differs between the first and second trimesters. Based on data availability, the experiences of racial discrimination were only measured through dichotomized (Yes/No) responses in 9 situations. We did not have information such as frequency and everyday exposure to racial discrimination. Second, the specified cutoffs for each sleep dimension that we applied were based on general populations but not specifically on pregnant populations. More studies on multidimensional sleep health in pregnancy is warranted to observe clinically meaningful cutoffs for pregnant populations. Third, our data were limited to self-reported sleep data. While nuMom2b study had a substudy that collected actigraphy data on sleep health in pregnancy, the substudy has different subsample and it did not overlap the self-reported assessment. Furthermore, self-reported data offers a better assessment of sleep satisfaction and sleepiness (Zhang & Zhao, 2007) Future studies may include both subjective and objective assessment in describing multidimensional sleep health during pregnancy. Fourth, our study sample was limited to nulliparous pregnancies. We are unable to assess the effects of parity, which has been identified as an important factor for poor sleep health in pregnancy (Christian et al., 2019; Lee et al., 2000).

9.4 Public Health Implications and Future Directions

In this dissertation, we focused on the significant research question of how sleep health could be improved in pregnancy and the improvement may potentially reduce adverse maternal health outcomes attributed to poor sleep health in pregnancy. The completion of our three aims provided the characteristics of individual sleep dimensions and multidimensional sleep health in pregnancy and identified potential factors that can be further considered in the development of sleep health intervention. Our findings introduced multidimensional sleep health in characterizing sleep health during pregnancy. The refinement of the specified cutoffs for good sleep health targeting pregnant people is needed to better assess individual sleep dimensions and multidimensional sleep health during pregnancy. Furthermore, the refinement of the composite sleep health score is also necessary to consider different levels of contributions from each sleep dimension to the multidimensional sleep health among pregnant people.

Our results from the second aim supported the importance of prenatal depression on sleep health during pregnancy. There are potential impacts of prenatal depression that manifest some sleep dimensions and multidimensional sleep health during pregnancy, suggesting that prenatal mental health management is critical for sleep health improvement during pregnancy. Future studies should examine the associations under different pregnant population and include measurement on sleep health during late pregnancy to better understand the association.

Our findings from the third aim also supported the evidence that the exposure to the experiences of racial discrimination manifests sleep health during pregnancy. The results suggested that there are social impacts on sleep health among pregnant people and may explain poor characteristics of sleep health during pregnancy. Future studies should refine the measurement of racial discrimination and include other measurement (everyday exposure, frequency, coping experiences) and under different pregnant populations. With close relationship between depression and sleep by shared biological pathways and symptoms, future studies should examine the bidirectional nature of prenatal depression and sleep health in pregnancy to better understand the influences of mental health and sleep health among pregnancy people." The examination of bidirectional relationship between depression and sleep in pregnancy could be potentially included in the manuscript by applying the structural equation modeling. Future studies should also further observe the interaction effect between stressor (racial discrimination) and mental health (prenatal depression) on sleep health during pregnancy. The integration of the effects of stressors and mental health on sleep health will be beneficial for developing strategies for sleep health management during pregnancy.

The completion of these aims is fundamental to further incorporating prenatal depression and racial discrimination experiences into sleep health intervention in pregnancy and potentially reduces the risks of adverse maternal health outcomes attributed to poor sleep health during pregnancy. Future studies should further identify the associations under different pregnant populations, incorporating psychological and social factors in the interventions of sleep health improvement during pregnancy. (Figure 17)

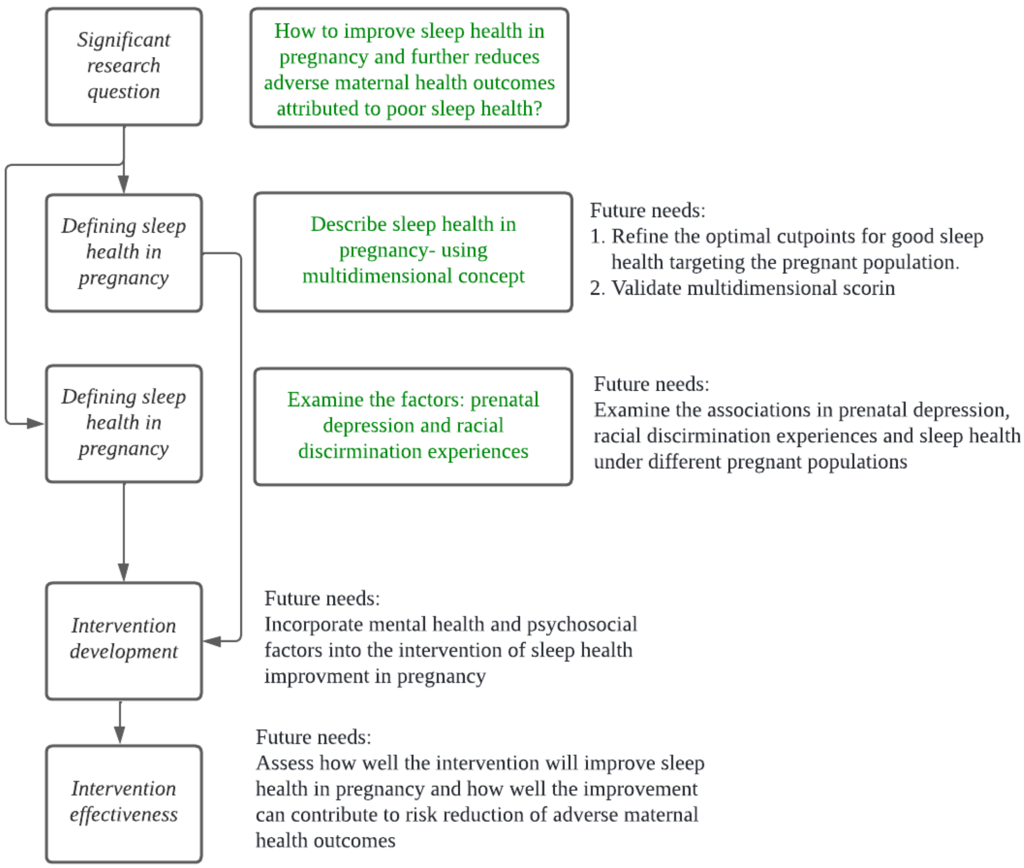

Figure 17. Public Health Implications and Future Directions for Sleep Health Improvement in Pregnancy

10.0 Conclusion

While the composite sleep health scores were consistent from early to mid-pregnancy, there were changes in specific sleep dimensions. Sleep satisfaction, duration, and continuity declined while sleep timing was consistent and regularity improved from early to mid-pregnancy. There were cross-sectional and longitudinal associations between prenatal depression and sleep satisfaction, duration, sleepiness, sleep timing, and overall multidimensional sleep health. There were cross-sectional associations between prenatal depression and nighttime awakening in early and mid-pregnancy, but no longitudinal association was found. There was no association found between prenatal depression and sleep regularity. Pregnant people's lifetime experiences of racial discrimination are associated with specific sleep dimensions, including sleep satisfaction, daytime sleepiness, sleep timing, and overall multidimensional sleep health in pregnancy.

In summary, there are changes in specific sleep dimensions from early to mid-pregnancy. Prenatal depression and the experiences of racial discrimination may be potential factor of poor sleep health in pregnancy, suggesting the importance of considering mental health and psychosocial factors in sleep health improvements in pregnant population. More studies on refining the assessment of multidimensional sleep health are warranted to better understand multidimensional sleep pattern in pregnancy and identify potential factor for sleep health improvement during pregnancy.

11.0 Acknowledgement

Throughout the writing of this dissertation, I have received great support and assistance. I would first like to thank my advisor, Professor Dara Mendez, for providing me guidance on developing the research questions and help throughout the writing. I would like to thank Professor Marquis Hawkins who brought me into the world of sleep research. I would also like to thank Professor Michele Levine and Professor Meredith Wallace for providing insightful feedback on this dissertation. Thank you to the whole committee for the guidance and pushing me to sharpen my thinking. Additionally, I would like to acknowledge the work from the NuMOM2b participants and study team. The invaluable knowledge from the study provides great support in accomplishing the study goals.

I would like to thank my parents, Tsung-Chi Hsiao and Li-Fang Huang, and all my friends for their great support and encouragement throughout the process. I would also like to thank my husband, Trevor Hickey, for always being there for me since the beginning of this journey. Final thanks to my cat, Taffy, for her loving companionship during the process.

12.0 Appendices

Appendix Table 1. Aim 1 Demographic of Samples with Some Sleep Data and Complete Case Samples

	Some sleep data (n=8,799)	Complete case (n=5,717)	
Variables	Mean ± SD	Mean ± SD	p-values [c]
Gestational age at enrollment (weeks)	11.55±1.51	11.59±1.49	0.0007
Maternal age at enrollment (years)	27.03±5.60	28.08±5.23	<.0001
Variables	N (%)	N (%)	p-values [c]
Race ethnicity			<.0001**
Non-Hispanic White	5438 (61.80)	4054 (70.91)	
Non-Hispanic Black	1124 (12.77)	394 (6.89)	
Hispanic	1443 (16.40)	760 (13.29)	
Asian	361 (4.10)	262 (4.58)	
Other [a]	433 (4.92)	247 (4.32)	
Prepregnancy BMI categories			<.0001**
<18.5 kg/m^2 (Underweight)	201 (2.32)	114 (2.02)	
18.5-<25 kg/m^2 (Normal weight)	4514 (52.15)	3096 (54.77)	
25-<30 kg/m^2 (Overweight)	2167 (25.03)	1419 (25.10)	
30-<35 kg/m^2 (Obese)	1015 (11.73)	593 (10.49)	
35+ kg/m^2 (Morbidly obese)	759 (8.77)	431 (7.62)	
Educational level			<.0001**
Less than high school degree	660 (7.50)	218 (3.81)	
High school graduated or GED	992 (11.28)	440 (7.70)	
Some college	1653 (18.79)	922 (16.13)	
Assoc/Tech college	897 (10.20)	541 (9.46)	
Completed college	2500 (28.42)	1946 (34.04)	
Beyond college degree	2095 (23.81)	1649 (28.85)	
Missing	2	1	
Gravidity			<.0001**
1	6570 (74.67)	4368 (76.40)	
2	1677 (19.06)	1043 (18.24)	
3+	552 (6.27)	306 (5.35)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

[c] p-values were comparing between samples with complete sleep data (n=5,717) and without (n=3,082); *p<0.05; **p<0.01

Appendix Table 1. Aim 1 Demographic of Samples with Some Sleep Data and Complete Case Samples (cont).

	Some sleep data (n=8,799)	Complete case (n=5,717)	
Variables	N (%)	N (%)	p-values [c]
Insurance type (May be more than one type) [b]			
Governmental	2336 (26.72)	1004 (17.64)	<.0001**
Military	59 (0.67)	43 (0.76)	0.2081
Commercial	6117 (69.96)	4519 (79.39)	<.0001**
Personal income	1556 (17.80)	1165 (20.47)	<.0001**
Other	123 (1.41)	64 (1.12)	0.0022**
Income in percentage of federal poverty level (%)			<.0001**
>200%	5120 (70.80)	3933 (78.53)	
100-200%	1102 (15.24)	613 (12.24)	
<100%	1010 (13.97)	462 (9.23)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

[c] p-values were comparing between samples with complete sleep data (n=5,717) and without (n=3,082); *p<0.05; **p<0.01

Appendix Table 2. Aim 1 Description of Each Sleep Dimension in Samples with Some Sleep Data and the Complete-case Sample

	Visit 1			Visit 3		
Variables	Some sleep data (n=8,799)	Complete case (n=5,717)	p-values [a]	Some sleep data (n=8,799)	Complete case (n=5,717)	p-values [a]
	n (%)	n (%)		n (%)	n (%)	
Sleep satisfaction, n (%)			<.0001**			<.0001**
Very good	1030 (12.88)	729 (12.75)		919 (11.12)	565 (9.88)	
Good	2154 (26.93)	1647 (28.81)		2048 (24.77)	1513 (26.46)	
Fair	3311 (41.39)	2344 (41.00)		3484 (42.14)	2426 (42.43)	
Poor	1308 (16.35)	875 (15.31)		1568 (18.97)	1078 (18.86)	
Very poor	196 (2.45)	122 (2.13)		248 (3.00)	135 (2.36)	
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
Duration (hr)	8.03±1.34	7.96±1.19	<.0001**	7.88±1.39	7.79±1.22	<.0001**
Epworth Sleepiness Scale (ESS) Score	7.81±4.08	7.68±3.98	<.0001**	6.60±4.07	6.49±3.95	0.0002**
Wake after sleep onset (WASO, min)	20.57±26.44	22.71±26.12	<.0001**	25.32±29.76	27.34±28.43	<.0001**
Midpoint sleep (a.m.)	3:39±2:07	3:30±1:59	<.0001**	3:40 ±2.04	3:24±1:55	<.0001**
Weekend-weekday difference in bedtime (hr)	1.00±1.34	0.97±1.29	<.0001**	0.89±1.30	0.86±1.21	<.0001**
Weekend-weekday difference in waketime (hr)	1.73±1.42	1.73±1.38	0.0016**	1.58±1.39	1.59±1.33	0.0009**
Weekend-weekday difference in midpoint sleep (hr)	1.40±1.70	1.39±1.64	0.7410	1.23±1.47	1.22±1.40	0.5333

[a] p-values were comparing between samples with complete sleep data (n=5,717) and without (n=3,082)

*p<0.05; **p<0.01

Appendix Table 3. Spearman Correlation Between Covariates

	Maternal age	Prepregnancy BMI	Poverty level	Educational level	Smoking status	Social support score	Exercise	Race ethnicity
Maternal age	1.000	-0.005	**0.656**	**0.628**	-0.140	0.184	0.199	-0.273
Prepregnancy BMI		1.000	-0.140	-0.078	0.085	-0.044	-0.064	0.072
% Poverty			1.000	**0.605**	-0.186	0.185	0.225	-0.280
Educational level				1.000	-0.239	0.232	0.221	-0.327
Smoking status					1.000	-0.110	-0.071	0.023
Social support score						1.000	0.107	-0.141
Exercise							1.000	-0.183
Race ethnicity								1.000

Appendix Table 4. Variance Inflation Factor (VIF) across Covariates

	Aim 2								
	Prenatal depression	Maternal age	Prepregnancy BMI	Poverty level	Educational level	Smoking status	Social support score	Exercise	Race ethnicity
VIF	1.06	1.64	1.05	1.65	1.55	1.08	1.05	1.05	1.08
	Aim 3								
	Racial discrimination	Maternal age	Poverty level	Education al level	Social support score				
VIF	1.02	1.60	1.59	1.41	1.03				

Appendix Table 5. Aim 2 Sensitivity Analysis for the Adjusted Estimates of the Associations Between Prenatal Depression and Sleep Health During Pregnancy- Removed Prepregnancy BMI

Cross-sectional- Early pregnancy								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.09	0.31	8.67	12.66	-0.09	-0.17	-0.14	-0.33
SE	0.05	0.04	1.04	4.94	0.06	0.06	0.05	0.05
p-value	0.0695	<.0001**	<.0001**	0.0104*	0.1354	0.0054**	0.0071**	<.0001**

Cross-sectional- Early pregnancy								
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.54	0.79	0.60	0.58	0.81	0.97	1.13	1.16
95% CI	(0.46, 0.62)	(0.66, 0.93)	(0.51, 0.71)	(0.48, 0.70)	(0.68, 0.96)	(0.76, 1.25)	(0.95, 1.35)	(0.94, 1.45)

Cross-sectional- Mid-pregnancy								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.28	0.38	6.50	18.76	0.05	0.07	0.05	-0.46
SE	0.05	0.04	1.19	4.97	0.06	0.06	0.06	0.05
p-value	<.0001**	<.0001**	<.0001**	0.0002**	0.3921	0.2901	0.3878	<.0001**

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; Composite sleep health score is the standardized sleep health score from sample mean. Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.; *p<0.05; **p<0.01

Appendix Table 5. Aim 2 Sensitivity Analysis for the Adjusted Estimates of the Associations Between Prenatal Depression and Sleep Health During Pregnancy- Removed Prepregnancy BMI (cont.)

Cross-sectional- Mid-pregnancy								
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.43	0.66	0.50	0.61	0.78	0.84	0.85	0.82
95% CI	(0.36, 0.52)	(0.55, 0.78)	(0.41, 0.59)	(0.51, 0.74)	(0.65, 0.94)	(0.63, 1.11)	(0.71, 1.03)	(0.65, 1.04)
Longitudinal- Early pregnancy prenatal depression and mid-pregnancy sleep								
	Duration [a]	Daytime sleepiness [a]	WASO [a]	Midpoint sleep [a]	Bedtime regularity [a]	Waketime regularity [a]	Midpoint regularity [a]	Composite sleep health score [a]
Adjusted β [b]	-0.17	0.36	6.29	10.11	-0.02	-0.09	-0.06	-0.23
SE	0.05	0.04	1.15	4.80	0.06	0.06	0.05	0.05
p-value	0.0006**	<.0001**	<.0001**	0.0352*	0.7949	0.1408	0.2421	<.0001**

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; Composite sleep health score is the standardized sleep health score from sample mean. Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

Appendix Table 5. Aim 2 Sensitivity Analysis for the Adjusted Estimates of the Associations Between Prenatal Depression and Sleep Health During Pregnancy- Removed Prepregnancy BMI (cont.)

	Longitudinal- Early pregnancy prenatal depression and mid-pregnancy sleep							
	Satisfied sleep [a]	Sufficient sleep duration [a]	No excessive daytime sleepiness [a]	Good sleep continuity [a]	Good sleep timing [a]	Regular bedtime [a]	Regular waketime [a]	Regular midpoint sleep [a]
EPDS ≥10 Odds ratios [b]	0.66	0.73	0.46	0.66	0.73	1.07	1.09	1.13
95% CI	(0.57, 0.76)	(0.61, 0.86)	(0.38, 0.54)	(0.55, 0.79)	(0.62, 0.88)	(0.80, 1.42)	(0.90, 1.31)	(0.89, 1.45)

[a] Sleep duration is in hour; Daytime sleepiness is the standardized ESS score from sample mean; Wake after sleep onset (WASO) is the amount of time awake between sleep time and waketime, WASO is presented in minutes; Bedtime, waketime, midpoint regularity are calculated by weekend-weekday differences in hour in bedtime, waketime, and midpoint sleep; Composite sleep health score is the standardized sleep health score from sample mean. Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

[b] EPDS score excluded one question in the EPDS that is associated with sleep. Adjusted for: maternal age, race ethnicity, educational level, percentage of federal poverty level, social support score, exercise within the last 4 weeks in early pregnancy, and smoking status within 3 months prior to pregnancy.

*p<0.05; **p<0.01

Appendix Table 6. Aim 2 Demographic Characteristics of the Overall Sample and the Sample with some but Incomplete Data

	Overall sample with some sleep and EPDS data, including the complete case sample (n=8270)			Overall sample with some sleep and EPDS data, excluding the complete case sample (n=3105) [a]		
	EPDS≥10 in early pregnancy (n=1086)	EPDS<10 in early pregnancy (n=7184)		EPDS≥10 in early pregnancy (n=555)	EPDS<10 in early pregnancy (n=2550)	
Variables	Mean ± SD	Mean ± SD	p-values	Mean ± SD	Mean ± SD	p-values
Gestational age at screening (weeks)	11.50±1.55	11.57±1.50	0.1441	11.41±1.60	11.51±1.55	0.1661
Maternal age at screening (years)	25.03±5.62	27.39±5.49	<.0001**	24.01±5.52	25.56±5.69	<.0001**
Prepregnancy BMI (kg/m^2)	26.59±6.35	25.89±5.91	0.0008**	27.21±6.88	26.53±6.36	0.0340*
Percentage of federal poverty level (%)	299.91±276.14	462.88±308.93	<.0001**	241.85±256.15	367.09±307.65	<.0001**
Social support score	68.30±14.96	75.51±13.45	<.0001**	66.63±15.59	74.10±13.64	<.0001**
Variables	n (%)	n (%)	p-values	n (%)	n (%)	p-values
Maternal age at screening (years)			<.0001**			0.1459
13-17	42 (3.87)	141 (1.96)		29 (5.23)	95 (3.73)	
18-34	978 (90.06)	6362 (88.56)		498 (89.73)	2280 (89.41)	
35-39	58 (5.34)	583 (8.12)		25 (4.50)	146 (5.73)	
40 or higher	8 (0.74)	98 (1.36)		3 (0.54)	29 (1.14)	
Race ethnicity			<.0001**			0.0149*
Non-Hispanic White	581 (53.50)	4644 (64.64)		246 (44.32)	1287 (50.47)	
Non-Hispanic Black	188 (17.31)	801 (11.15)		136 (24.50)	526 (20.63)	
Hispanic	219 (20.17)	1089 (15.16)		121 (21.80)	506 (19.84)	
Asian	41 (3.78)	303 (4.22)		12 (2.16)	90 (.53)	
Other [b]	57 (5.25)	347 (4.83)		40 (7.21)	141 (5.53)	
Prepregnancy BMI categories			0.0010**			0.3906
<18.5 kg/m^2 (Underweight)	33 (3.08)	158 (2.23)		16 (2.94)	70 (2.80)	
18.5-<25 kg/m^2 (Normal weight)	508 (47.39)	3770 (53.26)		248 (45.59)	1191 (47.64)	
25-<30 kg/m^2 (Overweight)	273 (25.47)	1763 (24.91)		129 (23.71)	645 (25.80)	
30-<35 kg/m^2 (Obese)	150 (13.99)	794 (11.22)		85 (15.63)	336 (13.44)	
35+ kg/m^2 (Morbidly obese)	108 (10.07)	593 (8.38)		66 (12.13)	258 (10.32)	
Educational level			<.0001**			<.0001**
Less than high school degree	151 (13.90)	452 (6.29)		110 (19.82)	312 (12.24)	
High school graduated or GED	177 (16.30)	743 (10.34)		112 (20.18)	431 (16.90)	
Some college	282 (25.97)	1253 (17.44)		133 (23.96)	582 (22.82)	
Assoc/Tech college	137 (12.62)	712 (9.91)		78 (14.05)	301 (11.850)	
Completed college	195 (17.96)	2192 (30.52)		75 (13.51)	539 (21.14)	
Beyond college degree	144 (13.26)	1831 (25.49)		47 (8.47)	385 (15.10)	

[a] The samples are those with data from the overall sample (n=8270), excluding the complete case sample (n=5165) (8,270-5,165=3,105)

[b] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[c] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size; *p<0.05; **p<0.01

Appendix Table 6. Aim 2 Demographic Characteristics of the Overall Sample and the Sample with some but Incomplete Data (cont.)

	Overall sample with some sleep and EPDS data, including the complete case sample (n=8270)			Overall sample with some sleep and EPDS data, excluding the complete case sample (n=3105) [a]		
	EPDS≥10 in early pregnancy (n=1086)	EPDS<10 in early pregnancy (n=7184)		EPDS≥10 in early pregnancy (n=555)	EPDS<10 in early pregnancy (n=2550)	
Variables	n (%)	n (%)	p-values	n (%)	n (%)	p-values
Gravidity			0.1506			0.4179
1	815 (75.05)	5405 (75.24)		400 (72.07)	1851 (72.59)	
2	193 (17.77)	1363 (18.97)		107 (19.28)	518 (20.31)\	
3+	78 (7.18)	416 (5.79)		48 (8.65)	181 (7.10)	
Ever used tobacco			<.0001**			<.0001**
Yes	553 (50.92)	2903 (40.02)		281 (50.63)	1026 (40.27)	
No	533 (49308)	4279 (59.58)		274 (49.37)	1522 (59.73)	
Smoked tobacco within 3 months prior to pregnancy			<.0001**			<.0001**
Yes	337 (31.03)	1087 (15.14)		193 (34.77)	511 (20.05)	
No	749 (68.97)	6094 (84.86)		362 (65.23)	2037 (79.95)	
Exercise within the last 4 weeks			<.0001**			0.0097**
Yes	223 (32.99)	2344 (45.29)		89 (27.13)	570 (34.50)	
No	453 (67.01)	2832 (54.71)		239 (72.87)	1082 (65.50)	
Insurance type (May be more than one type) [c]						
Governmental	448 (41.79)	1682 (23.53)	<.0001**	304 (55.37)	957 (37.81)	<.0001**
Military	5 (0.47)	51 (0.71)	0.3591	2 (0.36)	13 (0.51)	0.6487
Commercial	585 (54.57)	5227 (73.13)	<.0001**	228 (41.53)	1469 (58.04)	<.0001**
Personal income	149 (13.90)	1352 (18.91)	<.0001**	58 (10.56)	364 (14.38)	0.0184*
Other	25 (2.33)	90 (1.26)	0.0053**	9 (1.64)	48 (1.90)	0.6853
Income in percentage of federal poverty level (%)			<.0001**			<.0001**
>200%	241 (29.35_	785 (13.00)		158 (40.10)	471 (24.54)	
100-200%	175 (21.32)	777 (12.87)		87 (22.08)	309 (16.10)	
<100%	405 (49.33)	4475 (74.13)		149 (37.82)	1139 (59.35)	

[a] The samples are those with data from the overall sample (n=8270), excluding the complete case sample (n=5165) (8,270-5,165=3,105)

[b] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[c] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

*p<0.05; **p<0.01

Appendix Table 7. Aim 2 EPDS Status of the Overall Sample and the Sample with some but Incomplete Data

	Continuous scoring			Categorized EPDS status	
Overall Sample	n	mean	SD	EPDS >=10	EPDS<10
Early pregnancy	8270	5.29	3.73	1086 (13.13)	7184 (86.87)
Mid-pregnancy	8250	5.08	3.71	996 (12.07)	7254 (87.93)
Complete case sample	n	mean	SD	EPDS >=10	EPDS<10
Early pregnancy	5165	4.9	3.51	531 (10.28)	4634 (89.72)
Mid-pregnancy	5165	4.71	3.47	463 (8.96)	4702 (91.04)
Overall excluding the complete sample	n	mean	SD	EPDS >=10	EPDS<10
Early pregnancy	3105	5.95	3.99	555 (17.87)	2550 (82.13)
Mid-pregnancy	3085	5.69	4.00	533 (17.28)	2552 (82.72)

Appendix Table 8. Aim 2 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data

Overall sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	7364	8.02±1.32	7625	7.87±1.37
Epworth Sleepiness Scale (ESS) Score	7633	7.80±4.07	8055	6.59±4.07
Wake after sleep onset (WASO, min)	8317	20.85±26.40	8317	26.13±29.89
Midpoint sleep (a.m.) [b]	7364	3:14 (1:26)	7625	3:15 (1:29)
Weekend-weekday difference in bedtime (hr)	6729	1.00±1.34	6855	0.89±1.31
Weekend-weekday difference in waketime (hr)	6732	1.73±1.42	6856	1.58±1.39
Weekend-weekday difference in midpoint sleep (hr)	6711	1.34±1.23	6831	1.20±1.20
Categorized by specified cutoffs	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	7678	3066 (39.93)	8063	2887 (35.81)
Sufficient duration, n (%)	7364	4746 (64.45)	7625	4799 (62.94)
No excessive daytime sleepiness, n (%)	7633	5221 (68.40)	8055	6249 (77.58)
Good sleep continuity, n (%)	8317	7091 (85.26)	8317	6648 (79.93)
Appropriate sleep timing, n (%)	7364	4919 (66.80)	7625	5003 (65.61)
Regular bedtime, n (%)	6729	5867 (87.19)	6855	6119 (89.26)
Regular waketime, n (%)	6732	3795 (56.37)	6856	4225 (61.62)
Regular midpoint, n (%)	6711	5339 (79.56)	6831	5700 (83.44)

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 8. Aim 2 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data

(cont.)

Complete case sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	5165	8.03±1.05	5165	7.88±1.08
Epworth Sleepiness Scale (ESS) Score	5165	7.62±3.93	5165	6.41±3.88
Wake after sleep onset (WASO, min)	5165	19.39±18.91	5165	23.56±20.17
Midpoint sleep (a.m.) [b]	5165	3:08 (1:13)	5165	3:07 (1:14)
Weekend-weekday difference in bedtime (hr)	5165	0.82±0.65	5165	0.73±0.65
Weekend-weekday difference in waketime (hr)	5165	1.63±1.14	5165	1.50±1.08
Weekend-weekday difference in midpoint sleep (hr)	5165	1.20±0.76	5165	1.08±0.73
Categorized by specified cutoffs	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	5165	2231 (43.19)	5165	1957 (37.89)
Sufficient duration, n (%)	5165	3643 (70.53)	5165	3561 (68.94)
No excessive daytime sleepiness, n (%)	5165	3632 (70.32)	5165	4099 (79.36)
Good sleep continuity, n (%)	5165	4484 (86.82)	5165	4223 (81.76)
Appropriate sleep timing, n (%)	5165	3770 (72.99)	5165	3753 (72.66)
Regular bedtime, n (%)	5165	4680 (90.61)	5165	4765 (92.26)
Regular waketime, n (%)	5165	2969 (57.48)	5165	3219 (62.32)
Regular midpoint, n (%)	5165	4243 (82.15)	5165	4428 (85.73)

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 8. Aim 2 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data (cont.)

Overall excluding the complete sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	2199	7.99±1.80	2460	7.86±1.84
Epworth Sleepiness Scale (ESS) Score	2468	8.16±4.33	2890	6.91±4.37
Wake after sleep onset (WASO, min)	3152	23.23±35.28	3152	30.36±40.78
Midpoint sleep (a.m.) [b]	2199	3:35 (2:04)	2460	3:38 (2:12)
Weekend-weekday difference in bedtime (hr)	1564	1.60±2.43	1690	1.38±2.30
Weekend-weekday difference in waketime (hr)	1567	2.06±2.05	1691	1.85±2.04
Weekend-weekday difference in midpoint sleep (hr)	1546	1.79±2.08	1666	1.56±2.02
Categorized by specified cutoffs	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	2513	835 (33.23)	2898	930 (32.09)
Sufficient duration, n (%)	2199	1103 (50.16)	2460	1238 (50.33)
No excessive daytime sleepiness, n (%)	2468	1589 (64.38)	2890	2150 (74.39)
Good sleep continuity, n (%)	3152	2607 (82.71)	3152	2425 (76.94)
Appropriate sleep timing, n (%)	2199	1149 (52.25)	2460	1250 (50.81)
Regular bedtime, n (%)	1564	1187 (75.90)	1690	1354 (80.12)
Regular waketime, n (%)	1567	826 (52.71)	1691	1006 (59.49)
Regular midpoint, n (%)	1546	1096 (70.89)	1666	1272 (76.35)

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 9. Bivariable Estimates of the Cross-Sectional Associations Between Prenatal Depression and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimension, Excluding the Complete Case Sample [a]

Sleep dimensions	EPDS ≥10 [b]		EPDS <10 [b]			EPDS ≥10 [b]		EPDS <10 [b]		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	357	7.95±2.06	1801	7.99±1.76	0.754	405	7.70±2.12	1995	7.89±1.79	0.0903
Epworth Sleepiness Scale (ESS) Score	435	9.07±4.37	1997	7.96±4.31	<.0001**	496	8.52±4.58	2330	6.60±4.27	<.0001**
Wake after sleep onset (WASO, min)	555	29.55±43.36	2550	21.86±33.23	<.0001**	533	35.4±46.44	2552	29.54±39.81	0.0069**
Midpoint sleep (a.m.) [c]	357	3:45 (2:16)	1801	3:33 (2:02)	0.0012**	405	4:10 (2:24)	557	3:36 (2:08)	<.0001**
Weekend-weekday difference in bedtime (hr)	245	1.33±1.90	1284	1.68±2.54	0.0139*	266	1.41±2.36	1372	1.40±2.33	0.9446
Weekend-weekday difference in waketime (hr)	243	1.73±1.77	1289	2.14±2.11	0.0012**	267	1.85±2.26	1371	1.86±2.03	0.9519
Weekend-weekday difference in midpoint sleep (hr)	240	1.43±1.55	1271	1.87±2.18	0.0002**	262	1.59±2.12	1352	1.58±2.03	0.9106
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	439	84 (19.13)	2039	740 (36.29)	<.0001**	503	85 (16.90)	2333	817 (35.02)	<.0001**
Sufficient duration, n (%)	357	147 (41.18)	1801	933 (51.80)	0.0002**	405	172 (42.47)	1995	1024 (51.33)	0.0011**
No excessive daytime sleepiness, n (%)	435	250 (57.47)	1997	1316 (65.90)	0.0009**	496	303 (61.09)	2330	1792 (76.91)	<.0001**
Good sleep continuity, n (%)	555	430 (77.48)	2550	2137 (83.80)	0.0004**	533	380 (71.29)	2552	1988 (77.90)	0.0010**
Good sleep timing , n (%)	357	174 (48.74)	1801	954 (52.97)	0.1437	405	178 (43.95)	1995	1033 (51.78)	0.0041**
Regular bedtime, n (%)	245	181 (73.88)	1284	975 (75.93)	0.4921	266	211 (79.32)	1372	1094 (79.74)	0.8779
Regular waketime, n (%)	243	144 (59.26)	1289	664 (51.51)	0.0265*	267	158 (59.18)	1371	813 (59.30)	0.9700
Regular midpoint, n (%)	240	173 (72.08)	1271	894 (70.34)	0.5862	262	197 (75.19)	1352	1031 (76.26)	0.7111

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 7,643 had data on sleep satisfaction and 5,165 had complete sleep data. The table is showing the 2,478 participants who had sleep satisfaction data but did not have all sleep dimension data available (7,643-5,165=2,478)

[b] EPDS score excluded one question in the EPDS that is associated with sleep.

[c] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

*p<0.05; **p<0.01

Appendix Table 10. Bivariable Estimates of the Longitudinal Associations Between Prenatal Depression and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimension, Excluding the Complete Case Sample [a]

	Longitudinal- Early to mid-pregnancy				
Sleep dimensions	EPDS ≥10 [b]		EPDS <10 [b]		p-value
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	432	7.69±2.11	1984	7.90±1.79	0.0574
Epworth Sleepiness Scale (ESS) Score	526	7.97±4.66	2317	6.64±4.27	<.0001**
Wake after sleep onset (WASO, min)	555	37.34±46.42	2550	28.74±38.73	<.0001**
Midpoint sleep (a.m.) [c]	432	4:00 (2:11)	1984	3:35 (2:35)	0.0012**
Weekend-weekday difference in bedtime (hr)	281	1.26±2.10	1370	1.41±2.37	0.2818
Weekend-weekday difference in waketime (hr)	277	1.68±1.97	1375	1.90±2.07	0.1090
Weekend-weekday difference in midpoint sleep (hr)	276	1.40±1.80	1351	1.61±2.08	0.0960
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	530	112 (21.13)	2323	809 (34.83)	<.0001**
Sufficient duration, n (%)	432	189 (43.75)	1984	1023 (51.56)	0.0033**
No excessive daytime sleepiness, n (%)	526	336 (63.88	2317	1784 (77.00)	<.0001**
Good sleep continuity, n (%)	555	383 (69.01)	2550	2005 (78.63)	<.0001**
Good sleep timing, n (%)	432	199 (46.06)	1984	1031 (51.97)	0.0262*
Regular bedtime, n (%)	281	227 (80.78)	1370	1095 (79.33)	0.7435
Regular waketime, n (%)	277	167 (60.29)	1375	812 (59.05)	0.7029
Regular midpoint, n (%)	276	217 (78.62)	1351	1023 (75.72)	0.3022

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 7,643 had data on sleep satisfaction and 5,165 had complete sleep data. The table is showing the 2,478 participants who had sleep satisfaction data but did not have all sleep dimension data available (7,643-5,165=2,478)

[b] EPDS score excluded one question in the EPDS that is associated with sleep.

[c] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without prenatal depression

*p<0.05; **p<0.01

Appendix Table 11. The Exploratory Analysis on Specified Cutoff for Racial Discrimination Experiences on Sleep Health Outcomes – Using Sample with Complete Data

Sleep dimensions	Area under curve	Optimal cutoff [a]	Youden Index	Distance to (0,1)
Early pregnancy				
Satisfaction	0.54	0	0.07	0.68
Duration	0.51	1	0.02	0.71
Sleepiness	0.54	0	0.06	0.68
Continuity	0.55	0	0.04	0.77
Timing	0.51	0	0.02	0.79
Bedtime regularity	0.50	0	0.06	0.77
Waketime regularity	0.51	1	0.04	0.79
Midpoint regularity	0.49	1	0.01	0.81
Mid-pregnancy				
Sleep dimensions	Area under curve	Optimal cutoff [a]	Youden Index	Distance to (0,1)
Satisfaction	0.52	0	0.04	0.78
Duration	0.53	0	0.05	0.77
Sleepiness	0.52	0	0.04	0.78
Continuity	0.52	0	0.04	0.78
Timing	0.53	0	0.06	0.77
Bedtime regularity	0.52	0	0.03	0.79
Waketime regularity	0.52	1	0.04	0.79
Midpoint regularity	0.50	0	-0.01	0.82

[a] Optimal cutoff is decided by the shortest distance to the (0,1) the optimal point

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group

Overall sample	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	436	7.81±1.49	6871	8.03±1.31	0.0024**	456	7.62±1.50	7090	7.89±1.35	0.0002**
Epworth Sleepiness Scale (ESS) Score	464	8.66±4.10	7110	7.73±4.06	<.0001**	486	7.40±4.34	7486	6.54±4.04	<.0001**
Wake after sleep onset (WASO, min)	508	24.75±32.22	7713	20.68±26.00	0.0055**	508	28.18±30.72	7713	26.06±29.83	0.1223
Midpoint sleep (a.m.) [a]	508	3:38 (31:36	7713	3:13 (1:13)	<.0001**	456	3:34 (1:41)	7090	3:13 (1:27)	<.0001**
Weekend-weekday difference in bedtime (hr)	384	1.08±1.32	6302	1.00±1.34	0.2779	396	0.97±1.37	6401	0.88±1.30	0.1945
Weekend-weekday difference in waketime (hr)	383	1.65±1.40	6306	1.74±1.42	0.2603	397	1.56±1.44	6398	1.59±1.38	0.6825
Weekend-weekday difference in midpoint sleep (hr)	382	1.32±1.15	6286	1.34±1.23	0.7338	396	1.20±1.27	6377	1.20±1.20	0.9841
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	465	152 (32.69)	7154	2891 (40.41)	0.0010**	487	155 (31.83)	7493	2698 (36.01)	0.0622
Sufficient duration, n (%)	436	251 (57.57)	6871	4460 (64.91)	0.0019**	456	251 (55.04)	7090	4517 (63.71)	0.0002**
Daytime wakefulness, n (%)	464	271 (58.41)	77110	4918 (69.17)	<.0001**	486	339 (69.75)	7486	5846 (78.09)	<.0001**
Efficient sleep, n (%)	508	417 (82.09)	7713	6586 (85.39)	0.0425*	508	397 (78.15)	7713	6171 (80.01)	0.3115
Appropriate sleep timing , n (%)	436	250 (57.34)	6871	4632 (67.41)	<.0001**	456	258 (56.58)	7090	4702 (66.32)	<.0001**
Regular bedtime, n (%)	384	311 (80.99)	6302	5514 (87.50)	0.0002**	396	330 (83.33)	6401	5742 (89.70)	<.0001**
Regular waketime, n (%)	383	229 (59.79)	6306	3542 (56.17)	0.1651	397	245 (61.71)	6398	3946 (61.63)	0.9733
Regular midpoint, n (%)	382	294 (76.96)	6286	5008 (79.67)	0.2033	396	313 (79.04)	6377	5340 (83.74)	0.0146*
Composite sleep health score, Mean ± SD	277	5.20±0.59	4913	5.32±0.55	0.0005**	277	5.17±0.62	4913	5.29±0.57	0.0012**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Non-Hispanic white	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	102	7.97±1.38	4748	7.96±1.12	0.9249	101	7.83±1.16	4839	7.79±1.16	0.7439
Epworth Sleepiness Scale (ESS) Score	106	8.00±4.13	4822	7.65±3.90	0.3554	103	7.07±4.39	4966	6.41±3.85	0.0888
Wake after sleep onset (WASO, min)	107	31.77±37.48	5108	22.12±25.83	0.0002**	107	30.84±30.10	5108	28.02±28.85	0.3171
Midpoint sleep (a.m.) [a]	102	3:17 (1:48)	4748	3:04 (1:13)	0.0029**	101	3:13 (1:32)	4839	3:03 (1:13)	0.1448
Weekend-weekday difference in bedtime (hr)	92	1.14±1.68	4491	0.99±1.32	0.4161	93	0.98±1.73	4526	0.87±1.31	0.5300
Weekend-weekday difference in waketime (hr)	92	1.78±1.57	4494	1.76±1.35	0.8826	93	1.49±1.54	4525	1.61±1.34	0.4651
Weekend-weekday difference in midpoint sleep (hr)	92	1.44±1.51	4483	1.35±1.19	0.5614	93	1.21±1.53	4512	1.22±1.19	0.9663
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	106	31 (29.25)	4855	1946 (40.08)	0.0242*	105	29 (27.62)	4972	1699 (34.17)	0.1608
Sufficient duration, n (%)	102	60 (58.82)	4748	3328 (70.09)	0.0141*	101	63 (62.38)	4839	3277 (67.72)	0.256
Daytime wakefulness, n (%)	106	70 (66.04)	4822	3377 (70.03)	0.3748	103	76 (73.79)	4966	3958 (79.70)	0.1404
Efficient sleep, n (%)	107	78 (72.90)	5108	4283 (83.85)	0.0024**	107	79 (73.83)	5108	3964 (77.60)	0.3549
Appropriate sleep timing , n (%)	102	58 (56.86)	4748	3490 (73.50)	0.0002**	101	62 (61.39)	4839	3492 (72.16)	0.0170*
Regular bedtime, n (%)	92	75 (81.52)	4491	4003 (89.13)	0.0210*	93	79 (84.95)	4526	4136 (91.38)	0.0296*
Regular waketime, n (%)	92	52 (56.52)	4494	2494 (55.50)	0.8447	93	61 (65.59)	4525	2786 (61.57)	0.4297
Regular midpoint, n (%)	92	71 (77.17)	4483	3597 (80.24)	0.4658	93	75 (80.65)	4512	3822 (84.71)	0.2824
Composite sleep health score, Mean ± SD	72	5.24±0.59	3644	5.33±0.55	0.1633	72	5.42±0.55	3644	5.28±0.58	0.5634

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Non-Hispanic Black	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	127	7.55±1.52	575	8.17±1.91	0.0007**	133	7.44±1.58	667	8.12±2.07	<.0001**
Epworth Sleepiness Scale (ESS) Score	141	9.21±4.13	657	8.97±4.77	0.5574	150	8.11±4.51	795	7.85±4.74	0.5360
Wake after sleep onset (WASO, min)	156	24.36±32.70	823	18.42±29.40	0.0234*	156	27.04±27.48	823	23.17±33.26	0.1207
Midpoint sleep (a.m.) [a]	127	3:31 (1:41)	575	3:53 (2:04)	0.0575	133	3:34 (1:45)	667	3:56 (2:11)	0.1304
Weekend-weekday difference in bedtime (hr)	112	1.05±1.26	446	1.14±1.40	0.5638	109	1.07±1.53	501	1.09±1.51	0.9025
Weekend-weekday difference in waketime (hr)	112	1.53±1.51	442	1.68±1.75	0.3950	109	1.49±1.38	502	1.53±1.76	0.8122
Weekend-weekday difference in midpoint sleep (hr)	111	1.23±1.16	440	1.36±1.410	0.2970	109	1.17±1.30	498	1.22±1.45	0.7568
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	141	45 (31.91)	661	249 (37.67)	0.1979	149	55 (36.91)	794	331 (41.69)	0.2767
Sufficient duration, n (%)	127	64 (50.39)	575	266 (46.26)	0.3984	133	63 (47.37)	667	313 (46.93)	0.9257
Daytime wakefulness, n (%)	141	70 (49.65)	657	382 (58.14)	0.0647	150	97 (64.67)	795	517 (65.03)	0.9315
Efficient sleep, n (%)	156	132 (84.62)	823	717 (87.12)	0.3979	156	125 (80.13)	823	681 (82.75)	0.4319
Appropriate sleep timing , n (%)	127	75 (59.06)	575	265 (46.09)	0.0081**	133	78 (58.65)	667	314 (47.08)	0.0148*
Regular bedtime, n (%)	112	89 (79.46)	446	341 (76.46)	0.4986	109	87 (79.82)	501	391 (78.04)	0.6838
Regular waketime, n (%)	112	69 (61.61)	442	261 (59.05)	0.6223	109	69 (63.30)	502	318 (63.35)	0.9931
Regular midpoint, n (%)	111	85 (76.58)	440	331 (75.23)	0.7677	109	86 (78.90)	498	389 (78.11)	0.8569
Composite sleep health score, Mean ± SD	70	5.24±0.53	255	5.15±0.60	0.2190	70	5.18±0.63	255	5.18±0.59	0.9693

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Hispanics	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	120	7.94±1.58	987	8.41±1.60	0.0027**	121	7.69±1.61	1014	8.21±1.49	0.0003**
Epworth Sleepiness Scale (ESS) Score	122	8.77±4.22	1056	7.43±4.20	0.0009**	127	7.24±4.55	1116	6.19±4.24	0.0087**
Wake after sleep onset (WASO, min)	136	23.21±32.20	1152	17.27±23.04	0.0381*	136	27.30±35.09	1152	21.34±31.29	0.0385*
Midpoint sleep (a.m.) [a]	120	3:50 (1:37)	987	3:41 (1:51)	0.4388	121	3:44 (1:39)	1014	3:42 (1:46)	0.8341
Weekend-weekday difference in bedtime (hr)	101	1.14±1.32	849	1.01±1.41	0.3799	106	0.92±0.87	854	0.89±1.25	0.7410
Weekend-weekday difference in waketime (hr)	101	1.78±1.35	851	1.73±1.57	0.7897	106	1.67±1.55	851	1.58±1.44	0.5548
Weekend-weekday difference in midpoint sleep (hr)	101	1.40±1.01	847	1.33±1.31	0.5122	106	1.24±1.08	848	1.17±1.13	0.5394
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	124	41 (33.06	1058	428 (40.45)	0.1116	127	35 (27.56)	1118	419 (37.48)	0.0278*
Sufficient duration, n (%)	120	66 (55.00)	987	522 (52.89)	0.6615	121	63 (52.07)	1014	568 (56.02)	0.4085
Daytime wakefulness, n (%)	122	72 (59.02)	1056	760 (71.97)	0.0029**	127	86 (67.72)	1116	883 (79.12)	0.0033**
Efficient sleep, n (%)	136	114 (83.82)	1152	1027 (89.15)	0.0647	136	107 (78.68)	1152	991 (86.02)	0.0223*
Appropriate sleep timing , n (%)	120	63 (52.50)	987	535 (54.20)	0.7235	121	63 (52.07)	1014	548 (54.04)	0.6801
Regular bedtime, n (%)	101	79 (78.22)	849	721 (84.92)	0.0806	106	84 (81.13)	854	744 (87.12)	0.0893
Regular waketime, n (%)	101	58 (57.43)	851	480 (56.40)	0.8448	106	59 (55.66)	851	505 (59.34(	0.4675
Regular midpoint, n (%)	101	73 (72.28)	847	652 (76.98)	0.2925	106	78 (73.58)	848	685 (80.78)	0.0810
Composite sleep health score, Mean ± SD	76	5.05±0.66	608	5.29±0.57	0.0026**	76	5.03±0.71	608	5.30±0.57	0.0023**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Asians	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	44	7.75±1.35	267	7.83±1.14	0.6846	49	7.39±1.57	269	7.75±1.11	0.1273
Epworth Sleepiness Scale (ESS) Score	46	7.80±3.27	267	7.70±4.10	0.8705	50	5.88±3.22	281	6.22±3.89	0.5631
Wake after sleep onset (WASO, min)	51	20.20±23.26	289	15.15±21.33	0.1253	51	25.63±25.98	289	18.59±22.51	0.0453*
Midpoint sleep (a.m.) [a]	44	3:28 (1:26)	267	3:21 (1:22)	0.3731	49	3:41 (1:21)	269	3:32 (1:24)	0.1317
Weekend-weekday difference in bedtime (hr)	40	0.88±0.98	254	0.97±1.68	0.6240	44	0.69±0.55	258	0.78±1.29	0.4341
Weekend-weekday difference in waketime (hr)	40	1.50±1.02	256	1.69±1.52	0.3096	45	1.47±1.13	257	1.50±1.35	0.8882
Weekend-weekday difference in midpoint sleep (hr)	40	1.17±0.76	254	1.32±1.50	0.3497	44	1.01±0.74	257	1.11±1.29	0.4544
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	46	20 (43.48)	272	146 (53.68)	0.2003	50	17 (34.00)	281	127 (45.20)	0.1412
Sufficient duration, n (%)	44	35 (79.55)	267	177 (66.29)	0.0804	49	34 (69.39)	269	182 (67.66)	0.8114
Daytime wakefulness, n (%)	46	33 (71.74)	267	184 (68.91)	0.7011	50	43 (86.00)	281	234 (83.27)	0.6308
Efficient sleep, n (%)	51	45 (88.24)	289	267 (92.39)	<u>0.4034</u>	51	41 (80.39)	289	257 (88.93)	0.0877
Appropriate sleep timing , n (%)	44	27 (61.36)	267	176 (65.92)	0.5566	49	30 (61.22)	269	171 (63.57)	0.7543
Regular bedtime, n (%)	40	35 (87.50)	254	223 (87.80)	<u>1.0000</u>	44	42 (95345)	258	243 (94.19)	<u>1.0000</u>
Regular waketime, n (%)	40	25 (62.50)	256	154 (60.16)	0.7780	45	28 (62.22)	257	172 (66.93)	0.5382
Regular midpoint, n (%)	40	34 (85.00)	254	213 (83.86)	0.8547	44	38 (86.36)	257	226 (87.96)	0.7689
Composite sleep health score, Mean ± SD	30	5.47±0.44	212	5.48±0.52	0.9241	30	5.38±0.52	212	5.47±0.51	0.3602

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01; The underlined p-values are from Fisher's Exact test

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Other race (American Indian, Native Hawaiian, Multiracial)	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	43	7.88±1.55	294	7.92±1.52	0.8774	52	7.70±1.50	301	7.87±1.56	0.4537
Epworth Sleepiness Scale (ESS) Score	49	9.02±4.24	308	7.53±3.96	0.0159*	56	7.84±3.86	328	6.61±3.85	0.0278*
Wake after sleep onset (WASO, min)	58	20.52±25.48	341	20.85±30.51	0.9374	58	30.59±33.49	341	25.94±32.55	0.3180
Midpoint sleep (a.m.) [a]	43	3:42 (1:26)	294	3:20 (1:47)	0.1292	52	3:53 (1:43)	301	3:29 (1:40)	0.0747
Weekend-weekday difference in bedtime (hr)	39	1.04±0.73	262	0.88±1.20	0.2396	44	1.11±1.63	262	0.79±0.90	0.2042
Weekend-weekday difference in waketime (hr)	38	1.56±1.03	263	1.59±1.35	0.9020	44	1.70±1.44	263	1.51±1.16	0.3535
Weekend-weekday difference in midpoint sleep (hr)	38	1.21±0.75	262	1.20±1.06	0.9280	44	1.38±1.45	262	1.10±0.86	0.2210
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	48	15 (31.25)	308	122 (39.61)	0.2682	56	19 (33.93)	328	122 (37.20)	0.6393
Sufficient duration, n (%)	43	26 (60.47)	294	167 (56.80)	0.6502	52	28 (53.85)	301	177 (58.80)	0.5035
Daytime wakefulness, n (%)	49	26 (53.06)	308	215 (69.81)	0.0201*	56	37 (66.07)	328	254 (77.44)	0.0665
Efficient sleep, n (%)	58	48 (82.76)	341	292 (85.63)	0.5689	58	45 (77.59)	341	278 (81.52)	0.4801
Appropriate sleep timing , n (%)	43	27 (62.79)	294	166 (56.46)	0.4333	52	25 (48.08)	301	177 (58.80)	0.1488
Regular bedtime, n (%)	39	33 (84.62)	262	226 (86.26)	0.7822	44	36 (81.82)	262	228 (87.02)	0.3532
Regular waketime, n (%)	38	25 (65.79)	263	153 (58.17)	0.3721	44	28 (63.64)	263	162 (61.60)	0.7966
Regular midpoint, n (%)	38	31 (81.58)	262	215 (82.06)	0.9424	44	36 (81.82)	262	218 (83.21)	0.8206
Composite sleep health score, Mean ± SD	29	5.14±0.56	194	5.34±0.57	0.0846	29	5.13±0.55	194	5.32±0.55	0.0975

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Excluding non-Hispanic white	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	334	7.76±1.53	2123	8.20±1.64	<.0001**	355	7.56±1.58	2251	8.08±1.66	<.0001**
Epworth Sleepiness Scale (ESS) Score	358	8.85±4.08	2288	7.92±4.38	0.0002**	383	7.49±4.33	2520	6.77±4.38	0.0027**
Wake after sleep onset (WASO, min)	401	22.88±30.45	2605	17.86±26.11	0.0005**	401	27.46±30.89	2605	22.22±31.31	0.0018**
Midpoint sleep (a.m.) [a]	334	3:43 (1:32)	2123	3:38 (1:50)	0.9132	355	3:41 (1:41)	2251	3:41 (1:50)	0.7124
Weekend-weekday difference in bedtime (hr)	292	1.06±1.18	1811	1.02±1.43	0.5915	303	0.97±1.24	1875	0.91±1.29	0.4900
Weekend-weekday difference in waketime (hr)	291	1.61±1.34	1812	1.69±1.58	0.3635	304	1.58±1.41	1873	1.55±1.49	0.7076
Weekend-weekday difference in midpoint sleep (hr)	290	1.28±1.01	1803	1.32±1.33	0.5793	303	1.20±1.18	1865	1.16±1.22	0.6184
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	359	121 (33.70)	2299	945 (41.10)	0.0078**	382	126 (32.98)	2521	999 (39.63)	0.0130*
Sufficient duration, n (%)	334	191 (57.19)	2123	1132 (53.32)	0.1878	355	188 (52.96)	2251	1240 (55.09)	0.4538
Daytime wakefulness, n (%)	358	201 (56.15)	2288	1541 (67.35)	<.0001**	383	263 (68.67)	2520	1888 (74.92)	0.0093**
Efficient sleep, n (%)	401	339 (84.54)	2605	2303 (88.41)	0.0271*	401	318 (79.30)	2605	2207 (84.72)	0.0059**
Appropriate sleep timing, n (%)	334	192 (57.49)	2123	1142 (53.79)	0.2079	355	196 (55.21)	2251	1210 (53.75)	0.6086
Regular bedtime, n (%)	292	236 (80.82)	1811	1511 (83.43)	0.2693	303	251 (82.84)	1875	1606 (85.65)	0.1996
Regular waketime, n (%)	291	177 (60.82)	1812	1048 (57.84)	0.3373	304	184 (60.53)	1873	1157 (61.77)	0.6786
Regular midpoint, n (%)	290	223 (76.90)	1803	1411 (78.26)	0.6029	303	238 (78.55)	1865	1518 (81.39)	0.2415
Composite sleep health score, Mean ± SD	205	5.19±0.59	1269	5.30±0.58	0.0099**	205	5.15±0.64	1269	5.31±0.57	0.0010**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 12. Bivariable Estimates of the Association Between the Experiences of Racial Discrimination and Multidimensional Sleep Health by each Racial Group (cont.)

Non-Hispanic Black and Hispancis	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	High experiences of racial discrimination		Low to no experiences of racial discrimination			High experiences of racial discrimination		Low to no experiences of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	247	7.74±1.56	1562	8.32±1.72	<.0001**	254	7.56±1.60	1681	8.17±1.74	<.0001**
Epworth Sleepiness Scale (ESS) Score	263	9.00±4.17	1713	8.02±4.49	0.0009**	277	7.71±4.54	1911	6.88±4.53	0.0044**
Wake after sleep onset (WASO, min)	292	23.82±32.42	1975	17.75±25.88	0.0024**	292	27.16±31.20	1975	22.11±32.13	0.0118*
Midpoint sleep (a.m.) [a]	247	3:45 (1:56)	1562	3:44 (1:37)	0.4477	254	3:38 (1:46)	1681	3:47 (1:55)	0.4239
Weekend-weekday difference in bedtime (hr)	213	1.09±1.28	1295	1.05±1.41	0.6901	215	0.99±1.24	1355	0.96±1.35	0.7373
Weekend-weekday difference in waketime (hr)	213	1.65±1.44	1293	1.72±1.64	0.5212	215	1.58±1.46	1353	1.56±1.57	0.8705
Weekend-weekday difference in midpoint sleep (hr)	212	1.31±1.09	1287	1.34±1.34	0.7290	215	1.20±1.20	1346	1.19±1.26	0.8433
Categorized by specified cutoffs	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	265	86 (32.45)	1719	677 (39.38)	0.0309*	276	90 (32.61)	1912	750 (39.23)	0.0346*
Sufficient duration, n (%)	247	130 (52.63)	1562	788 (50.45)	0.5236	254	126 (49.61)	1681	881 (52.41)	0.4046
Daytime wakefulness, n (%)	263	142 (53.99)	1713	1142 (66.67)	<.0001**	277	183 (66.06)	1911	1400 (73.26)	0.0123*
Efficient sleep, n (%)	292	246 (84.25)	1975	1744 (88.30)	0.0482*	292	232 (79.45)	1975	1672 (84.66)	0.0236*
Appropriate sleep timing , n (%)	247	138 (55.87)	1562	800 (51.22)	0.1737	254	141 (55.51)	1681	862 (51.28)	0.2083
Regular bedtime, n (%)	213	168 (78.87)	1295	1062 (82.01)	0.2743	215	173 (80.47)	1355	1135 (83.76)	0.2282
Regular waketime, n (%)	213	127 (59.62)	1293	741 (57.31)	0.5262	215	128 (59.53)	1353	823 (60.83)	0.7185
Regular midpoint, n (%)	212	158 (74.53)	1287	983 (76.38)	0.5581	215	164 (76.28)	1346	1074 (79.79)	0.2377
Composite sleep health score, Mean ± SD	146	5.14±0.61	863	5.25±0.58	0.0381*	146	5.10±0.67	863	5.26±0.58	0.0071**

[a] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with and without the experiences of racial discrimination

*p<0.05; **p<0.01

Appendix Table 13. Descriptive Statistics of the Counts of Situations in Racial Discrimination Experiences at all Cutoffs – Using Sample with Complete Data

Cutoff	All races	Non-Hispanic white	Non-Hispanic Black	Hispanics	Asians	Other	Exclude Non-Hispanic white	Non-Hispanic Black and Hispanics
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
0	4138 (79.71)	3251 (87.49)	179 (55.08)	443 (64.77)	127 (52.48)	133 (61.88)	887 (60.18)	622 (61.65)
1 or more	1052 (20.27)	465 (12.51)	146 (44.92)	241 (35.23)	115 (47.52)	85 (38.12)	587 (39.82)	387 (38.35)
1 or less	4660 (89.79)	3540 (95.26)	218 (67.08)	552 (80.70)	173 (71.49)	177 (79.37)	1120 (75.98)	770 (76.31)
2 or more	530 (10.21)	176 (4.74)	107 (32.92)	132 (19.30)	69 (28.51)	46 (20.63)	354 (24.02)	239 (23.69)
2 or less	4913 (94.66)	3644 (98.06)	255 (78.46)	608 (88.89)	212 (87.60)	194 (87.00)	1269 (86.09)	863 (85.53)
3 or more	277 (5.34)	72 (1.94)	70 (21.54)	76 (11.11)	30 (12.40)	29 (13.00)	205 (13.91)	146 (14.47)
3 or less	5054 (97.38)	3688 (99.25)	285 (87.69)	640 (93.57)	230 (95.04)	211 (94.62)	1366 (92.67)	925 (91.67)
4 or more	136 (2.62)	28 (0.75)	40 (12.31)	44 (6.43)	12 (4.96)	12 (5.38)	108 (7.33)	84 (8.33)
4 or less	5132 (98.88)	3705 (99.70)	306 (94.15)	665 (97.22)	239 (98.76)	217 (97.31)	1427 (96.81)	971 (96.23)
5 or more	58 (1.12)	11 (0.30)	19 (5.85)	19 (2.78)	3 (1.24)	6 (2.69)	47 (3.19)	38 (3.77)
5 or less	5163 (99.48)	3712 (99.89)	315 (96.92)	677 (98.98)	241 (99.59)	218 (97.76)	1451 (98.44)	992 (98.32)
6 or more	27 (0.52)	4 (0.11)	10 (3.08)	7 (1.02)	1 (0.41)	5 (2.24)	23 (1.56)	17 (1.68)
6 or less	5179 (99.79)	3712 (99.89)	320 (98.46)	684 (100.00)	242 (100.00)	221 (99.10)	1467 (99.53)	1004 (99.50)
7 or more	11 (0.21)	4 (0.11)	5 (1.54)	0 (0.00)	0 (0.00)	2 (0.90)	7 (0.47)	5 (0.50)
7 or less	5185 (99.90)	3713 (99.92)	324 (99.69)	684 (100.00)	242 (100.00)	222 (99.55)	1472 (99.86)	1008 (99.90)
8 or more	5 (0.10)	3 (0.08)	1 (0.31)	0 (0.00)	0 (0.00)	1 (0.45)	2 (0.14)	1 (0.10)
8 or less	5187 (99.94)	3713 (99.92)	325 (100.00)	684 (100.00)	242 (100.00)	223 (100.00)	1474 (100.00)	1009 (100.00)
9	3 (0.06)	3 (0.08)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)

Appendix Table 14. Aim 3 Demographic Characteristics of the Study Sample – Overall and by the Experiences of Racial Discrimination

	Overall sample with some sleep and racial discrimination data, including the complete case sample (n=8221)			Overall sample with some sleep and racial discrimination data, excluding the complete case sample (n=3031) [a]		
	3+ situations (n=508)	<3 situations (n=7713)		3+ situations (n=231)	<3 situations (n=2800)	
Variables	Mean ± SD	Mean ± SD	p-values	Mean ± SD	Mean ± SD	p-values
Gestational age at screening (weeks)	11.64±1.49	11.56±1.51	0.1991	11.59±1.51	11.49±1.56	0.3275
Maternal age at screening (years)	27.53±6.14	27.08±5.51	0.1106	25.66±5.77	25.25±5.68	0.2845
Prepregnancy BMI (kg/m^2)	27.61±7.18	25.88±5.88	<.0001**	28.48±8.08	26.54±6.32	0.0005**
Percentage of federal poverty level (%)	367.96±300.54	449.00±309.12	<.0001**	278.25±268.95	348.81±303.82	0.0011**
Social support score	71.91±14.08	74.83±13.80	<.0001**	70.68±14.39	72.97±14.32	0.0336*
Variables	n (%)	n (%)	p-value	n (%)	n (%)	p-value
Maternal age at screening (years)			<.0001**			0.7176
13-17	10 (1.97)	172 (2.23)		8 (3.46)	115 (4.11)	
18-34	422 (83.07)	6870 (89.07)		204 (878.31)	2506 (89.50)	
35-39	62 (12.20)	580 (7.52)		16 (6.93)	151 (5.39)	
40 or higher	14 (2.76)	91 (1.18)		3 (1.30)	28 (1.00)	
Race ethnicity			<.0001**			<.0001**
Non-Hispanic white	5108 (66.23)	107 (21.06)		35 (15.15)	1464 (52.29)	
Non-Hispanic Black	823 (10.67)	156 (30.71)		86 (37.23)	568 (20.29)	
Hispanic	1152 (14.94)	136 (26.77)		60 (25.97)	544 (19.43)	
Asian	289 (3.75)	51 (10.04)		21 (9.09)	77 (2.75)	
Other [a]	341 (4.42)	58 (11.42)		29 (12.55)	147 (5.25)	
Prepregnancy BMI (kg/m2)			<.0001**			<.0001**
<18.5 (Underweight)	20 (3.97)	172 (2.26)		20 (4.00)	172 (2.27)	
18.5-<25 (Normal weight)	199 (39.48)	4053 (53.31)		199 (39.80)	4038 (53.29)	
25-<30 (Overweight)	133 (26.39)	1893 (24.90)		130 (26.00)	1889 (24.93)	
30-<35 (Obese)	76 (15.08)	859 (11.30)		75 (15.00)	856 (11.30)	
35 or higher (Morbidly obese)	76 (15.08)	625 (8.22)		76 (15.20)	623 (8.22)	
Educational level			0.0209*			0.6013
Less than high school graduate	41 (8.07)	544 (7.05)		29 (12.55)	375 (13.39)	
High school graduated or GED	61 (12.01)	842 (10.92)		37 (16.02)	496 (17.71)	
Associate/Tech degree	51 (10.04)	791 (10.26)		31 (13.42)	340 (12.14)	
Some college	116 (22.83)	1421 (18.42)		63 (27.27)	649 (23.18)	
College degree	116 (22.83)	2267 (29.39)		38 (16.45)	558 (19.93)	
Degree beyond college	123 (24.21)	1848 (23.96)		33 (14.29)	382 (13.64)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size; *p<0.05; **p<0.01

Appendix Table 14. Aim 3 Demographic Characteristics of the Study Sample – Overall and by the Experiences of Racial Discrimination (cont.)

	Overall sample with some sleep and racial discrimination data, including the complete case sample (n=8221)			Overall sample with some sleep and racial discrimination data, excluding the complete case sample (n=3031) [a]		
	3+ situations (n=508)	<3 situations (n=7713)		3+ situations (n=231)	<3 situations (n=2800)	
Variables	n (%)	n (%)	p-value	n (%)	n (%)	p-value
Gravidity			<.0001**			0.0283*
1	335 (65.94)	5852 (75.87)		154 (6.67)	2048 (73.14)	
2	118 (23.23)	1429 (18.53)		51 (22.08)	557 (19.89)	
3 or more	55 (10.83)	432 (5.60)		26 (11.26)	195 (6.96)	
Ever used tobacco			0.0002**			0.0820
Yes	252 (49.61)	3174 (41.16)		109 (47.19)	1156 (41.32)	
No	256 (50.39)	4537 (58.84)		122 (52.81)	109 (47.19)	
Smoked tobacco within 3 months prior to pregnancy			<.0001**			0.0005**
Yes	128 (25.20)	1271 (16.49)		73 (31.60)	606 (21.66)	
No	380 (74.80)	6439 (83.51)		158 (68.40)	2192 (78.34)	
Insurance type (can be more than one) [b]						
Governmental	179 (35.39)	1924 (25.09)	<.0001**	108 (46.96)	1128 (40.60)	0.0599
Military	5 (0.99)	51 (0.67)	0.3961	1 (0.43)	15 (0.54)	1.0000
Commercial	299 (58.67)	5497 (71.70)	<.0001**	111 (48.26)	1544 (55.58)	0.0320*
Personal	97 (19.13)	1401 (18.27)	0.6282	26 (11.30)	387 (13.93)	0.2660
Other	12 (2.37)	99 (1.29)	0.0427*	8 (3.48)	44 (1.58)	0.0568
Percentage of federal poverty level (%)			<.0001**			0.0159*
<100	102 (24.70)	905 (14.10)		64 (36.57)	550 (26.49)	
100-200	59 (14.29)	895 (13.95)		27 (15.43)	363 (17.49)	
>200	252 (61.02)	4617 (71.95)		84 (48.00)	1163 (56.02)	

[a] Other racial ethnicity groups include: American Indian, Native Hawaiian, Multiracial, and other

[b] Participants may select more than one insurance type, the sum of the overall number of all insurance types may exceed the sample size

*p<0.05; **p<0.01

Appendix Table 15. Aim 3 Descriptive Statistics of Racial Discrimination Experiences in Overall Sample and by Racial Groups-Sample with some but Incomplete Data

Overall Sample						
Number of situations experiencing racial discrimination, n (%)		Non-Hispanic White (n=5215)	Non-Hispanic Black (n=979)	Hispanic (n=1288)	Asian (n=340)	Other (n=399)
	0	4526 (86.79)	583 (59.55)	844 (65.53)	179 (52.65)	220 (55.14)
	1	428 (8.21)	127 (12.97)	203 (15.76)	62 (18.24)	75 (18.80)
	2	154 (2.95)	113 (11.54)	105 (8.15)	48 (14.12)	46 (11.53)
	3	66 (1.27)	74 (7.56)	64 (4.97)	27 (7.94)	33 (8.27)
	4	25 (0.48)	40 (4.09)	39 (3.03)	16 (4.71)	9 (2.26)
	5	9 (0.17)	17 (1.74)	17 (1.32)	4 (1.18)	6 (1.50)
	6	0 (0.00)	16 (1.63)	15 (1.16)	4 (1.18)	8 (2.01)
	7	1 (0.02)	5 (0.51)	1 (0.08)	0 (0.00)	1 (0.25)
	8	0 (0.00)	4 (0.41)	0 (0.00)	0 (0.00)	1 (0.25)
	9	6 (0.12)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Less than 3 domains		5108 (97.95)	823 (84.07)	1152 (89.44)	289 (85.00)	341 (85.46)
3 or more domains		107 (2.05)	156 (15.93)	136 (10.56)	51 (15.00)	58 (14.54)
Complete sample						
Number of situations experiencing racial discrimination, n (%)		Non-Hispanic White (n=3716)	Non-Hispanic Black (n=325)	Hispanic (n=684)	Asian (n=242)	Other (n=223)
	0	3251 (87.49)	179 (55.08)	443 (64.77)	127 (52.48)	138 (61.88)
	1	289 (7.78)	39 (12.00)	109 (15.94)	46 (19.01)	39 (17.49)
	2	104 (2.80)	37 (11.38)	56 (8.19)	39 (16.12)	17 (7.62)
	3	44 (1.18)	30 (9.23)	32 (4.68)	18 (7.44)	17 (7.62)
	4	17 (0.46)	21 (6.46)	25 (3.65)	9 (3.72)	6 (2.69)
	5	7 (0.19)	9 (2.77)	12 (1.75)	2 (0.83)	1 (0.45)
	6	0 (0.00)	5 (1.54)	7 (1.02)	1 (0.41)	3 (1.35)
	7	1 (0.03)	4 (1.23)	0 (0.00)	0 (0.00)	1 (0.45)
	8	0 (0.00)	1 (0.31)	0 (0.00)	0 (0.00)	1 (0.45)
	9	3 (0.08)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Less than 3 domains		3644 (98.06)	255 (78.46)	608 (88.89)	212 (87.60)	194 (87.00)
3 or more domains		72 (1.94)	70 (21.54)	76 (11.11)	30 (12.40)	29 (13.00)

Appendix Table 15. Aim 3 Descriptive Statistics of Racial Discrimination Experiences in Overall Sample and by Racial Groups-Sample with some but Incomplete Data (cont.)

		Overall excluding the complete sample				
Number of situations experiencing racial discrimination, n (%)		Non-Hispanic White (n=1499)	Non-Hispanic Black (n=654)	Hispanic (n=604)	Asian (n=98)	Other (n=176)
	0	1275 (85.06)	404 (61.77)	401 (66.39)	52 (53.06)	82 (46.59)
	1	139 (9.27)	88 (13.45)	94 (15.56)	16 (16.33)	36 (20.45)
	2	50 (3.34)	76 (11.62)	49 (8.11)	9 (9.18)	29 (16.48)
	3	22 (1.47)	44 (6.73)	32 (5.30)	9 (9.18)	116 (9.09)
	4	8 (0.53)	19 (2.91)	14 (2.32)	7 (7.14)	3 (1.70)
	5	2 (0.13)	8 (1.22)	15 (0.83)	2 (2.04)	5 (2.84)
	6	0 (0.00)	11 (1.68)	8 (1.32)	3 (3.06)	5 (2.84)
	7	0 (0.00)	1 (0.15)	1 (0.17)	0 (0.00)	0 (0.00)
	8	0 (0.00)	3 (0.46)	0 (0.00)	0 (0.00)	0 (0.00)
	9	3 (0.20)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Less than 3 domains		1464 (97.67)	568 (86.85)	544 (90.07)	77 (78.57)	147 (83.52)
3 or more domains		35 (2.33)	86 (13.15)	60 (9.93)	21 (21.43)	29 (16.48)

Appendix Table 16. Aim 3 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data

Overall sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	7307	8.02±1.32	7546	7.87±1.36
Epworth Sleepiness Scale (ESS) Score	7574	7.79±4.07	7972	6.59±4.06
Wake after sleep onset (WASO, min)	8221	20.93±26.44	8221	26.19±29.89
Midpoint sleep (a.m.) [a]	7307	3:14 (1:26)	7546	3:14 (1:29)
Weekend-weekday difference in bedtime (hr)	6686	1.00±1.35	6797	0.89±1.31
Weekend-weekday difference in waketime (hr)	6689	1.73±1.42	6795	1.59±1.39
Weekend-weekday difference in midpoint sleep (hr)	6668	1.34±1.23	6773	1.20±1.20
Categorized by specified cutoffs [b]	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	7619	3043 (39.94)	7980	2853 (35.75)
Sufficient duration, n (%)	7307	4711 (64.47)	7546	4768 (63.19)
No excessive daytime sleepiness, n (%)	7574	5189 (68.51)	7972	6185 (77.58)
Good sleep continuity, n (%)	8221	7003 (85.18)	8221	6568 (79.89)
Appropriate sleep timing, n (%)	7307	4882 (66.81)	7546	4960 (65.73)
Regular bedtime, n (%)	6686	5825 (87.12)	6797	6072 (89.33)
Regular waketime, n (%)	6689	3771 (56.38)	6795	4188 (61.63)
Regular midpoint, n (%)	6668	5302 (79.51)	6773	5653 (83.46)

[a] Midpoint is presented in median with interquartile range

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 16. Aim 3 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data (cont.)

Complete case sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	5190	8.03±1.05	5190	7.87±1.08
Epworth Sleepiness Scale (ESS) Score	5190	7.61±3.93	5190	6.42±3.88
Wake after sleep onset (WASO, min)	5190	19.45±18.98	5190	23.59±20.19
Midpoint sleep (a.m.) [a]	5190	3:09 (1:13)	5190	3:07 (1:14)
Weekend-weekday difference in bedtime (hr)	5190	0.82±0.66	5190	0.73±0.65
Weekend-weekday difference in waketime (hr)	5190	1.63±1.15	5190	1.50±1.08
Weekend-weekday difference in midpoint sleep (hr)	5190	1.20±0.76	5190	1.09±0.73
Categorized by specified cutoffs [b]	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	5190	2249 (43.33)	5190	1962 (37.80)
Sufficient duration, n (%)	5190	3656 (70.44)	5190	3590 (69.17)
No excessive daytime sleepiness, n (%)	5190	3654 (70.40)	5190	4115 (79.29)
Good sleep continuity, n (%)	5190	4500 (86.71)	5190	4244 (81.77)
Appropriate sleep timing, n (%)	5190	3783 (72.89)	5190	3769 (72.62)
Regular bedtime, n (%)	5190	4703 (90.62)	5190	4788 (92.25)
Regular waketime, n (%)	5190	2982 (57.46)	5190	3238 (62.39)
Regular midpoint, n (%)	5190	4261 (82.10)	5190	4447 (85.68)

[a] Midpoint is presented in median with interquartile range

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 16. Aim 3 Sleep Health of the Overall Sample and the Sample with some but Incomplete Data (cont.)

Overall excluding the complete sample				
Sleep dimensions	Early pregnancy		Mid-pregnancy	
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD
Duration (hr)	2117	7.99±1.82	2356	7.86±1.83
Epworth Sleepiness Scale (ESS) Score	2384	8.18±4.34	2782	6.90±4.37
Wake after sleep onset (WASO, min)	3031	23.48±35.64	3031	30.65±41.15
Midpoint sleep (a.m.) [a]	2117	3:36 (2:03)	2356	3:40 (2:14)
Weekend-weekday difference in bedtime (hr)	1496	1.64±2.47	1607	1.40±2.35
Weekend-weekday difference in waketime (hr)	1499	2.08±2.08	1605	1.87±2.06
Weekend-weekday difference in midpoint sleep (hr)	1478	1.81±2.11	1583	1.58±2.06
Categorized by specified cutoffs [b]	n	n (%)	n	n (%)
Good sleep satisfaction, n (%)	2429	794 (32.69)	2790	891 (31.94)
Sufficient duration, n (%)	2117	1055 (49.83)	2356	1178 (50.00)
No excessive daytime sleepiness, n (%)	2384	1535 (64.39)	2782	2070 (74.41)
Good sleep continuity, n (%)	3031	2503 (82.58)	3031	2324 (76.67)
Appropriate sleep timing, n (%)	2117	1099 (51.91)	2356	1191 (50.55)
Regular bedtime, n (%)	1496	1122 (75.00)	1607	1284 (79.90)
Regular waketime, n (%)	1499	789 (52.64)	1605	950 (59.19)
Regular midpoint, n (%)	1478	1041 (70.43)	1583	1206 (76.18)

[a] Midpoint is presented in median with interquartile range

[b] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

Appendix Table 17. Bivariable Estimates of Cross-Sectional Associations between Racial Discrimination Experiences and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimensions, Excluding the Complete Case Sample [a]

	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	3+ situations of racial discrimination		<3 situations of racial discrimination			3+ situations of racial discrimination		<3 situations of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	159	7.67±1.95	1958	8.01±1.81	0.0247*	179	7.55±1.88	2177	7.89±1.83	0.0178*
Epworth Sleepiness Scale (ESS) Score	187	9.30±4.09	2197	8.08±4.35	0.0002**	209	7.75±4.60	2573	6.83±4.35	0.0034**
Wake after sleep onset (WASO, min)	231	29.38±42.20	2800	23.00±35.00	0.0261*	231	32.73±39.59	2800	30.47±41.28	0.4229
Midpoint sleep (a.m.) [b]	159	4:03 (2:00)	1958	3:34 (2:04)	0.0285*	179	4:01 (2:10)	2177	3:38 (2:12)	0.0408*
Weekend-weekday difference in bedtime (hr)	107	1.65±2.09	1389	1.64±2.50	0.9872	119	1.38±2.19	1488	1.40±2.37	0.9191
Weekend-weekday difference in waketime (hr)	106	1.88±1.87	1393	2.09±2.09	0.3175	120	1.91±1.92	1485	1.87±2.08	0.8254
Weekend-weekday difference in midpoint sleep (hr)	105	1.70±2.14	1373	1.82±2.14	0.4780	119	1.57±1.92	1464	1.59±2.07	0.9195

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 7,619 had data on sleep satisfaction and 5,190 had complete sleep data. The table is showing the 2,429 participants who had sleep satisfaction data but did not have all sleep dimension data available (7,619-5,190=2,429)

[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[c] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Appendix Table 17. Bivariable Estimates of Cross-Sectional Associations between Racial Discrimination Experiences and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimensions, Excluding the Complete Case Sample [a] (cont.)

Categorized by specified cutoffs [c]	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	2429	49 (26.06)	2241	745 (33.24)	0.0438*	210	67 (31.90)	2580	824 (31.94)	0.9921
Sufficient duration, n (%)	159	63 (39.62)	1958	992 (50.66)	0.0074**	179	70 (39.11)	2177	1108 (50.90)	0.0024**
No excessive daytime sleepiness, n (%)	187	97 (51.87)	2197	1438 (65.45)	0.0002**	209	140 (66.99)	2573	1930 (75.01)	0.0106*
Efficient sleep, n (%)	231	184 (79.65)	2800	2319 (82.82)	0.2224	231	167 (72.29)	2800	2157 (77.04)	0.1015
Appropriate sleep timing , n (%)	159	70 (44.03)	1958	1029 (52.55)	0.0385*	179	76 (42.46)	2177	1115 (51.22)	0.0243*
Regular bedtime, n (%)	107	71 (66.36)	1389	1051 (75.67)	0.0321*	119	88 (73.95)	1488	1196 (80.38)	0.0923
Regular waketime, n (%)	106	62 (58.49)	1393	727 (52.19)	0.2104	120	68 (56.67)	1485	882 (59.39)	0.5587
Regular midpoint, n (%)	105	71 (67.62)	1373	970 (70.65)	0.5121	119	85 (71.43)	1464	1121 (76.57)	0.2053

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 7,619 had data on sleep satisfaction and 5,190 had complete sleep data. The table is showing the 2,429 participants who had sleep satisfaction data but did not have all sleep dimension data available (7,619-5,190=2,429)

[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[c] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Appendix Table 18. Bivariable Estimates of the Cross-Sectional Associations between Racial Discrimination Experiences and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimension, Excluding the Complete Case Sample [a] – Non-Hispanic Black, Hispanics, Asians, and other Races (American Indian, Native Hawaiian, Multiracial)

	Early pregnancy sleep health					Mid-pregnancy sleep health				
Sleep dimensions	3+ situations of racial discrimination		<3 situations of racial discrimination			3+ situations of racial discrimination		<3 situations of racial discrimination		
Uncategorized sleep dimensions	n	Mean ± SD	n	Mean ± SD	p-value	n	Mean ± SD	n	Mean ± SD	p-value
Duration (hr)	129	7.60±1.94	854	8.24±2.11	0.0013**	150	7.52±1.98	982	8.10±2.06	0.0013**
Epworth Sleepiness Scale (ESS) Score	153	9.56±4.09	1019	8.43±4.66	0.0047**	178	7.69±4.56	1251	7.17±4.61	0.1617
Wake after sleep onset (WASO, min)	196	25.55±38.70	1336	18.83±32.07	0.0214*	196	31.09±39.40	1336	24.91±39.60	0.0414*
Midpoint sleep (a.m.) [b]	129	4:00 (1:50)	854	3:55 (2:15)	0.6269	150	4:02 (2:14)	982	4:01 (2:15)	0.7696
Weekend-weekday difference in bedtime (hr)	87	1.45±1.78	542	1.48±2.29	0.8710	98	1.25±1.88	606	1.20±1.99	0.8091
Weekend-weekday difference in waketime (hr)	86	1.73±1.69	543	1.92±2.12	0.3642	99	1.88±1.82	604	1.68±2.02	0.3402
Weekend-weekday difference in midpoint sleep (hr)	85	1.50±1.34	534	1.65±2.04	0.3783	98	1.50±1.70	596	1.34±1.81	0.5223

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 2,658 had data on sleep satisfaction and 1,474 had complete sleep data. The table is showing the 1,184 participants who had sleep satisfaction data but did not have all sleep dimension data available (2,658-1,474=1,184)

[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[c] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Appendix Table 18. Bivariable Estimates of the Cross-Sectional Associations between Racial Discrimination Experiences and Multidimensional Sleep Health Among Participants who had Data in Specific Sleep Dimension, Excluding the Complete Case Sample [a] – Non-Hispanic Black, Hispanics, Asians, and other Races (American Indian, Native Hawaiian, Multiracial) (cont).

Categorized by specified cutoffs [c]	n	n (%)	n	n (%)	p-value	n	n (%)	n	n (%)	p-value
Good sleep satisfaction, n (%)	154	43 (27.92)	1030	379 (36.80)	0.0320*	177	63 (35.59)	1252	455 (36.34)	0.8462
Sufficient duration, n (%)	129	53 (41.09)	854	369 (43.21)	0.6498	150	54 (36.00)	982	462 (47.05)	0.0114*
Daytime wakefulness, n (%)	153	74 (48.37)	1019	639 (62.71)	0.0007**	178	121 (67.98)	1251	898 (71.78)	0.2937
Efficient sleep, n (%)	196	163 (83.16)	1336	1162 (86.98)	0.1448	196	146 (74.49)	1336	1107 (82.86)	0.0046**
Appropriate sleep timing , n (%)	129	59 (45.74)	854	382 (44.73)	0.8305	150	64 (42.67)	982	434 (44.20)	0.7253
Regular bedtime, n (%)	87	60 (68.97)	542	398 (73.43)	0.3848	98	74 (75.51)	606	485 (80.03)	0.3043
Regular waketime, n (%)	86	53 (61.63)	543	304 (55.99)	0.3264	99	57 (57.58)	604	381 (63.08)	0.2949
Regular midpoint, n (%)	85	60 (70.59)	534	381 (71.35)	0.8857	98	72 (73.47)	596	468 (78.52)	0.2645

[a] The samples are those with data from each sleep dimension, excluding the complete case sample. For example, 2,658 had data on sleep satisfaction and 1,474 had complete sleep data. The table is showing the 1,184 participants who had sleep satisfaction data but did not have all sleep dimension data available (2,658-1,474=1,184)

[b] Midpoint is presented in median with interquartile range. We performed Wilcoxon sign-ranked tests to compare midpoint sleep between individuals with 3+ or <3 situations of racial discrimination experiences

[c] Satisfied sleep was defined as individuals rated "good" or "very good" sleep within the last 4 weeks; good sleep duration was weekly sleep duration 7-9 hours for adults aged 18 or more and 8-10 hours for adolescents; no excessive daytime sleepiness was ESS score <10; Good sleep continuity was WASO less than 40 minutes; Good sleep timing was midpoint sleep between 2-4 a.m.; Regular bedtime, waketime, and midpoint sleep were weekend-weekday differences less than 2 hours in bedtime, waketime, and midpoint sleep

*p<0.05; **p<0.01

Bibliography

Aasheim, V., Waldenström, U., Hjelmstedt, A., Rasmussen, S., Pettersson, H., & Schytt, E (2012). Associations between advanced maternal age and psychological distress in primiparous women, from early pregnancy to 18 months postpartum. *BJOG: An International Journal of Obstetrics & Gynaecology*, *119*(9), 1108-1116.

Abdullah, T., & Brown, T. L (2011). Mental illness stigma and ethnocultural beliefs, values, and norms: An integrative review. *Clinical psychology review*, *31*(6), 934-948.

Abramson, C. M., Hashemi, M., & Sánchez-Jankowski, M (2015). Perceived discrimination in US healthcare: Charting the effects of key social characteristics within and across racial groups. *Preventive medicine reports*, *2*, 615-621.

Adewuya, A. O., Ola, B. A., Aloba, O. O., Dada, A. O., & Fasoto, O. O (2007). Prevalence and correlates of depression in late pregnancy among Nigerian women. *Depression and anxiety*, *24*(1), 15-21.

Adouard, F., Glangeaud-Freudenthal, N. M. C., & Golse, B (2005). Validation of the Edinburgh postnatal depression scale (EPDS) in a sample of women with high-risk pregnancies in France. *Archives of Women's Mental Health*, *8*(2), 89-95.

Ahmed, A. T., Mohammed, S. A., & Williams, D. R (2007). Racial discrimination & health: Pathways & evidence. *Indian Journal of Medical Research*, *126*(4), 318.

Alhusen, J. L., Bower, K. M., Epstein, E., & Sharps, P (2016). Racial discrimination and adverse birth outcomes: an integrative review. *Journal of midwifery & women's health*, *61*(6), 707-720.

Ali, N. S., Azam, I. S., Ali, B. S., Tabbusum, G., & Moin, S. S (2012). Frequency and associated factors for anxiety and depression in pregnant women: a hospital-based cross-sectional study. *The Scientific World Journal*, *2012*.

Amankwaa, L. C (2003). Postpartum depression, culture and African-American women. *Journal of Cultural Diversity*, *10*(1), 23.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Appleton, S. L., Melaku, Y. A., Reynolds, A. C., Gill, T. K., de Batlle, J., & Adams, R. J. (2022). Multidimensional sleep health is associated with mental well-being in Australian adults. Journal of Sleep Research, 31(2), e13477.

Arber, S., Bote, M., & Meadows, R (2009). Gender and socio-economic patterning of self-reported sleep problems in Britain. *Social science & medicine*, *68*(2), 281-289.

Arnold, K. F., Davies, V., de Kamps, M., Tennant, P. W., Mbotwa, J., & Gilthorpe, M. S. (2020). Reflection on modern methods: generalized linear models for prognosis and intervention—theory, practice and implications for machine learning. International Journal of Epidemiology, 49(6), 2074-2082.

Bailey, Z. D., Krieger, N., Agénor, M., Graves, J., Linos, N., & Bassett, M. T (2017). Structural racism and health inequities in the USA: evidence and interventions. *The Lancet*, *389*(10077), 1453-1463.

Bailey, Z. D., Feldman, J. M., & Bassett, M. T (2021). How structural racism works—racist policies as a root cause of US racial health inequities. *New England Journal of Medicine*, *384*(8), 768-773.

Baker, J. H., Rothenberger, S. D., Kline, C. E., & Okun, M. L (2016). Exercise during early pregnancy is associated with greater sleep continuity. *Behavioral Sleep Medicine*, *16*(5), 482-493.

Balestrieri, M., Isola, M., Bisoffi, G., Calò, S., Conforti, A., Driul, L., ... & Bellantuono, C (2012). Determinants of Ante-Partum Depression: A Multicenter Study. *Social psychiatry and psychiatric epidemiology*, *47*(12), 1959-1965.

Barcelona de Mendoza, V., Harville, E. W., Savage, J., & Giarratano, G (2018). Experiences of intimate partner and neighborhood violence and their association with mental health in pregnant women. *Journal of interpersonal violence*, *33*(6), 938-959.

Basner, M (2008). Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. *Somnologie-Schlafforschung und Schlafmedizin*, *12*(2), 110-117.

Basner, M., Griefahn, B., & Van den Berg, M (2010). Aircraft noise effects on sleep: Mechanisms, mitigation and research needs. *Noise and health*, *12*(47), 95.

Beauvalet, J. C., Quiles, C. L., de Oliveira, M. A. B., Ilgenfritz, C. A. V., Hidalgo, M. P. L., & Tonon, A. C (2017). Social jetlag in health and behavioral research: a systematic review. *ChronoPhysiology and Therapy*, *7*, 19-31.

Bécares, L., & Atatoa-Carr, P (2016). The association between maternal and partner experienced racial discrimination and prenatal perceived stress, prenatal and postnatal depression: findings from the growing up in New Zealand cohort study. *International journal for equity in health*, *15*(1), 155.

Beck, A. T., Ward, C., Mendelson, M., Mock, J., & Erbaugh, J (1961). Beck depression inventory (BDI). *Arch Gen Psychiatry*, *4*(6), 561-571.

Beebe, K. R., & Lee, K. A (2007). Sleep disturbance in late pregnancy and early labor. *The Journal of perinatal & neonatal nursing*, *21*(2), 103-108.

Bennett, H. A., Einarson, A., Taddio, A., Koren, G., & Einarson, T. R (2004). Prevalence of depression during pregnancy: systematic review. *Obstetrics & Gynecology*, *103*(4), 698-709.

Bergink, V., Kooistra, L., Lambregtse-van den Berg, M. P., Wijnen, H., Bunevicius, R., Van Baar, A., & Pop, V (2011). Validation of the Edinburgh Depression Scale during pregnancy. *Journal of psychosomatic research*, *70*(4), 385-389.

Bertolazi, A. N., Fagondes, S. C., Hoff, L. S., Dartora, E. G., da Silva Miozzo, I. C., de Barba, M. E. F., & Barreto, S. S. M (2011). Validation of the Brazilian Portuguese version of the Pittsburgh sleep quality index. *Sleep medicine*, *12*(1), 70-75.

Bhattacharyya, N (2015). Sleep and health implications of snoring: a populational analysis. *The Laryngoscope*, *125*(10), 2413-2416.

Biaggi, A., Conroy, S., Pawlby, S., & Pariante, C. M (2016). Identifying the women at risk of antenatal anxiety and depression: a systematic review. *Journal of affective disorders*, *191*, 62-77.

Bilszta, J. L., Tang, M., Meyer, D., Milgrom, J., Ericksen, J., & Buist, A. E (2008). Single motherhood versus poor partner relationship: outcomes for antenatal mental health. *Australian & New Zealand Journal of Psychiatry*, *42*(1), 56-65.

Blackmore, E. R., Moynihan, J. A., Rubinow, D. R., Pressman, E. K., Gilchrist, M., & O'Connor, T. G (2011). Psychiatric symptoms and proinflammatory cytokines in pregnancy. *Psychosomatic medicine*, *73*(8), 656.

Blackmore, E. R., Gustafsson, H., Gilchrist, M., Wyman, C., & O'Connor, T. G (2016). Pregnancy-related anxiety: evidence of distinct clinical significance from a prospective longitudinal study. *Journal of Affective Disorders*, *197*, 251-258.

Blakely, T., Lynch, J., Simons, K., Bentley, R., & Rose, S. (2020). Reflection on modern methods: when worlds collide—prediction, machine learning and causal inference. International journal of epid

Bleich, S. N., Findling, M. G., Casey, L. S., Blendon, R. J., Benson, J. M., SteelFisher, G. K., ... & Miller, C (2019). Discrimination in the United States: experiences of black Americans. *Health services research*, *54*, 1399-1408.

Bloch, K. E (1997). Polysomnography: a systematic review. *Technology and health care*, *5*(4), 285-305.

Bödecs, T., Szilágyi, E., Cholnoky, P., Sándor, J., Gonda, X., Rihmer, Z., & Horváth, B (2013). Prevalence and psychosocial background of anxiety and depression emerging during the first trimester of pregnancy: data from a Hungarian population-based sample. *Psychiatria Danubina*, *25*(4), 0-358.

Bonilla-Silva, E., & Lewis, A (1996). The'new racism': Toward an analysis of the US racial structure, 1960s-1990s. Bottomley, K. L., & Lancaster, S. J (2008). The association between depressive symptoms and smoking in pregnant adolescents. *Psychology, health & medicine*, *13*(5), 574-582.

Bowman, M. A., Kline, C. E., Buysse, D. J., Kravitz, H. M., Joffe, H., Matthews, K. A., ... & Hall, M. H. (2021). Longitudinal association between depressive symptoms and multidimensional sleep health: The SWAN sleep study. Annals of Behavioral Medicine, 55(7), 641-652.

Brick, C. A., Seely, D. L., & Palermo, T. M (2010). Association between sleep hygiene and sleep quality in medical students. *Behavioral sleep medicine*, *8*(2), 113-121.

Brindle, R. C., Yu, L., Buysse, D. J., & Hall, M. H (2019). Empirical derivation of cutoff values for the sleep health metric and its relationship to cardiometabolic morbidity: results from the Midlife in the United States (MIDUS) study. *Sleep*, *42*(9), zsz116.

Brondolo, E., ver Halen, N. B., Libby, D., & Pencille, M (2011). Racism as a psychosocial stressor.

Brosschot, J. F., Pieper, S., & Thayer, J. F (2005). Expanding stress theory: Prolonged activation and perseverative cognition. Psychoneuroendocrinology, 30(10), 1043-1049.

Brown, T. A., Campbell, L. A., Lehman, C. L., Grisham, J. R., & Mancill, R. B (2001). Current and lifetime comorbidity of the DSM-IV anxiety and mood disorders in a large clinical sample. *Journal of abnormal psychology*, *110*(4), 585.

Brown, F. C., Buboltz Jr, W. C., & Soper, B (2002). Relationship of sleep hygiene awareness, sleep hygiene practices, and sleep quality in university students. *Behavioral medicine*, *28*(1), 33-38.

Brown, R. E., Basheer, R., McKenna, J. T., Strecker, R. E., & McCarley, R. W (2012). Control of sleep and wakefulness. *Physiological reviews*.

Brunner, D. P., Münch, M., Biedermann, K., Huch, R., Huch, A., & Borbély, A. A (1994). Changes in sleep and sleep electroencephalogram during pregnancy. *Sleep*, *17*(7), 576-582.

Burchfield, S. R (1979). The stress response: a new perspective. Psychosomatic Medicine.

Buysse, D. J., Reynolds III, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry research*, *28*(2), 193-213.

Buysse, D. J., Yu, L., Moul, D. E., Germain, A., Stover, A., Dodds, N. E., ... & Pilkonis, P. A (2010). Development and validation of patient-reported outcome measures for sleep disturbance and sleep-related impairments. *Sleep*, *33*(6), 781-792.

Buysse, D. J (2014). Sleep health: can we define it? Does it matter?. *Sleep*, *37*(1), 9-17.

Byun, J. H., Kim, K. T., Moon, H. J., Motamedi, G. K., & Cho, Y. W (2019). The first night effect during polysomnography, and patients’ estimates of sleep quality. *Psychiatry Research*, *274*, 27-29.

Cai, S., Tan, S., Gluckman, P. D., Godfrey, K. M., Saw, S. M., Teoh, O. H., ... & GUSTO Study Group (2017). Sleep quality and nocturnal sleep duration in pregnancy and risk of gestational diabetes mellitus. *Sleep*, *40*(2), zsw058.

Campbell, A. J., & Neill, A. M (2011). Home set-up polysomnography in the assessment of suspected obstructive sleep apnea. *Journal of sleep research*, *20*(1pt2), 207-213.

Canady, R. B., Bullen, B. L., Holzman, C., Broman, C., & Tian, Y (2008). Discrimination and symptoms of depression in pregnancy among African American and White women. *Women's Health Issues*, *18*(4), 292-300.

Carney, C. E., Buysse, D. J., Ancoli-Israel, S., Edinger, J. D., Krystal, A. D., Lichstein, K. L., & Morin, C. M (2012). The consensus sleep diary: standardizing prospective sleep self-monitoring. *Sleep*, *35*(2), 287-302.

Carpenter, J. S., & Andrykowski, M. A (1998). Psychometric evaluation of the Pittsburgh sleep quality index. *Journal of psychosomatic research*, *45*(1), 5-13.

Carroll, J. E., Teti, D. M., Hall, M. H., & Christian, L. M (2019). Maternal sleep in pregnancy and postpartum part II: biomechanisms and intervention strategies. *Current psychiatry reports*, *21*(3), 19.

Carskadon, M. A., Acebo, C., Richardson, G. S., Tate, B. A., & Seifer, R (1997). An approach to studying circadian rhythms of adolescent humans. *Journal of biological rhythms*, *12*(3), 278-289.

Carskadon, M. A., Labyak, S. E., Acebo, C., & Seifer, R (1999). Intrinsic circadian period of adolescent humans measured in conditions of forced desynchrony. *Neuroscience letters*, *260*(2), 129-132.

Cassidy-Bushrow, A. E., Peters, R. M., Johnson, D. A., & Templin, T. N (2012). Association of depressive symptoms with inflammatory biomarkers among pregnant African-American women. *Journal of reproductive immunology*, *94*(2), 202-209.

Champagne, K., Schwartzman, K., Opatrny, L., Barriga, P., Morin, L., Mallozzi, A., ... & Kimoff, R. J (2009). Obstructive sleep apnoea and its association with gestational hypertension. *European Respiratory Journal*, *33*(3), 559-565.

Chen, K. Y., & Bassett Jr, D. R (2005). The technology of accelerometry-based activity monitors: current and future. *Medicine and Science in Sports and Exercise*, *37*(11 Suppl), S490-500.

Christian, L. M., Kowalsky, J. M., Mitchell, A. M., & Porter, K (2018). Associations of postpartum sleep, stress, and depressive symptoms with LPS-stimulated cytokine production among African American and White women. *Journal of neuroimmunology*, *316*, 98-106.

Christian, L. M., Carroll, J. E., Porter, K., & Hall, M. H (2019). Sleep quality across pregnancy and postpartum: effects of parity and race. *Sleep health*, *5*(4), 327-334.

Clark, R., Anderson, N. B., Clark, V. R., & Williams, D. R (1999). Racism as a stressor for African Americans: A biopsychosocial model. American psychologist, 54(10), 805.

Cole, J. C., Motivala, S. J., Buysse, D. J., Oxman, M. N., Levin, M. J., & Irwin, M. R (2006). Validation of a 3-factor scoring model for the Pittsburgh sleep quality index in older adults. *Sleep*, *29*(1), 112-116.

Colen, C. G., Ramey, D. M., Cooksey, E. C., & Williams, D. R (2018). Racial disparities in health among nonpoor African Americans and Hispanics: The role of acute and chronic discrimination. *Social Science & Medicine*, *199*, 167-180.

Collado-Proctor, S. M (1999). *The Perceived Racism Scale for Latina/os: A multidimensional assessment of the experience of racism among Latina/os*. Duke University.

Conlon, R. P. K., Wang, B., Germeroth, L. J., Cheng, Y., Buysse, D. J., & Levine, M. D (2020). Demographic, Pregnancy-Related, and Health-Related Factors in Association with Changes in Sleep Among Pregnant Women with Overweight or Obesity. *International journal of behavioral medicine*.

Cox, J. L., Holden, J. M., & Sagovsky, R (1987). Detection of postnatal depression: development of the 10-item Edinburgh Postnatal Depression Scale. *The British journal of psychiatry*, *150*(6), 782-786.

Cox, J. L., Chapman, G., Murray, D., & Jones, P (1996). Validation of the Edinburgh Postnatal Depression Scale (EPDS) in non-postnatal women. *Journal of affective disorders*, *39*(3), 185-189.

Crowley, S. K., O'Buckley, T. K., Schiller, C. E., Stuebe, A., Morrow, A. L., & Girdler, S. S (2016). Blunted neuroactive steroid and HPA axis responses to stress are associated with reduced sleep quality and negative affect in pregnancy: a pilot study. *Psychopharmacology*, *233*(7), 1299-1310.

Cubbin, C., Heck, K., Powell, T., Marchi, K., & Braveman, P (2015). Racial/ethnic disparities in depressive symptoms among pregnant women vary by income and neighborhood poverty. *AIMS public health*, *2*(3), 411.

da Silva Rocha-Lopes, J., Machado, R. B., & Suchecki, D (2018). Chronic REM sleep restriction in juvenile male rats induces anxiety-like behavior and alters monoamine systems in the amygdala and hippocampus. *Molecular neurobiology*, *55*(4), 2884-2896.

de Souza, C. M., & Hidalgo, M. P. L (2014). Midpoint of sleep on school days is associated with depression among adolescents. *Chronobiology International*, *31*(2), 199-205.

Dear, B. F., Titov, N., Sunderland, M., McMillan, D., Anderson, T., Lorian, C., & Robinson, E (2011). Psychometric comparison of the generalized anxiety disorder scale-7 and the Penn State Worry Questionnaire for measuring response during treatment of generalised anxiety disorder. *Cognitive behaviour therapy*, *40*(3), 216-227.

Deurenberg, P., Yap, M., & Van Staveren, W. A. (1998). Body mass index and percent body fat: a meta analysis among different ethnic groups. International journal of obesity, 22(12), 1164-1171.

Dong, L., Martinez, A. J., Buysse, D. J., & Harvey, A. G (2019). A composite measure of sleep health predicts concurrent mental and physical health outcomes in adolescents prone to eveningness. *Sleep health*, *5*(2), 166-174.

Driver, H. S., & Shapiro, C. M (1992). A longitudinal study of sleep stages in young women during pregnancy and postpartum. *Sleep*, *15*(5), 449-453.

Duncan, D. T., Regan, S. D., & Chaix, B (2018). Operationalizing neighborhood definitions in health research: spatial misclassification and other issues. In *Neighborhoods and health* (pp. 19-56). Oxford University Press.

Ebert, R. M., Wood, A., & Okun, M. L (2015). Minimal effect of daytime napping behavior on nocturnal sleep in pregnant women. *Journal of Clinical Sleep Medicine*, *11*(6), 635-643.

Elek, S. M., Hudson, D. B., & Fleck, M. O (1997). Expectant parents' experience with fatigue and sleep during pregnancy. *Birth*, *24*(1), 49-54.

Ertel, K. A., James-Todd, T., Kleinman, K., Krieger, N., Gillman, M., Wright, R., & Rich-Edwards, J (2012). Racial discrimination, response to unfair treatment, and depressive symptoms among pregnant black and African American women in the United States. *Annals of epidemiology*, *22*(12), 840-846.

Facco, F. L., Grobman, W. A., Kramer, J., Ho, K. H., & Zee, P. C (2010). Self-reported short sleep duration and frequent snoring in pregnancy: impact on glucose metabolism. *American journal of obstetrics and gynecology*, *203*(2), 142-e1.

Facco, F. L., Parker, C. B., Reddy, U. M., Silver, R. M., Koch, M. A., Louis, J. M., ... & Zee, P. C (2017). Association between sleep-disordered breathing and hypertensive disorders of pregnancy and gestational diabetes mellitus. *Obstetrics and gynecology*, *129*(1), 31.

Facco, F. L., Grobman, W. A., Reid, K. J., Parker, C. B., Hunter, S. M., Silver, R. M., ... & Zee, P. C (2017). Objectively measured short sleep duration and later sleep midpoint in pregnancy are associated with a higher risk of gestational diabetes. *American journal of obstetrics and gynecology*, *217*(4), 447-e1.

Facco, F. L., Parker, C. B., Hunter, S., Reid, K. J., Zee, P. C., Silver, R. M., ... & NICHD NuMoM2b and NHLBI NuMoM2b Heart Health Study Networks (2018). Association of Adverse Pregnancy Outcomes with Self-Reported Measures of sleep duration and timing in women who are nulliparous. *Journal of Clinical Sleep Medicine*, *14*(12), 2047-2056.

Faisal-Cury, A., & Menezes, P. R (2007). Prevalence of anxiety and depression during pregnancy in a private setting sample. *Archives of women's mental health*, *10*(1), 25-32.

Fang, H., Tu, S., Sheng, J., & Shao, A (2019). Depression in sleep disturbance: A review on a bidirectional relationship, mechanisms and treatment. *Journal of cellular and molecular medicine*, *23*(4), 2324-2332.

Feinstein, L., McWhorter, K. L., Gaston, S. A., Troxel, W. M., Sharkey, K. M., & Jackson, C. L (2020). Racial/ethnic disparities in sleep duration and sleep disturbances among pregnant and non-pregnant women in the United States. *Journal of sleep research*, e13000.

Fellenzer, J. L., & Cibula, D. A (2014). Intendedness of pregnancy and other predictive factors for symptoms of prenatal depression in a population-based study. *Maternal and child health journal*, *18*(10), 2426-2436.

Ferraro, Z. M., Chaput, J. P., Gruslin, A., & Adamo, K. B (2014). The potential value of sleep hygiene for a healthy pregnancy: a brief review. *International Scholarly Research Notices*, *2014*.

Field, T., Diego, M., Hernandez-Reif, M., Figueiredo, B., Schanberg, S., & Kuhn, C (2007). Sleep disturbances in depressed pregnant women and their newborns. *Infant Behavior and Development*, *30*(1), 127-133.

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B (1995). The structured clinical interview for DSM-III-R personality disorders (SCID-II). Part I: Description. *Journal of Personality disorders*, *9*(2), 83-91.

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B (1997). *User's guide for the Structured clinical interview for DSM-IV axis I disorders SCID-I: clinician version*. American Psychiatric Pub.

Flemons, W. W., & Littner, M. R (2003). Measuring agreement between diagnostic devices. *Chest*, *124*(4), 1535-1542.

Ford, C. L., & Airhihenbuwa, C. O (2010). Critical race theory, race equity, and public health: toward antiracism praxis. *American journal of public health*, *100*(S1), S30-S35.

Francis, B., Klebanoff, M., & Oza-Frank, R (2017). Racial discrimination and perinatal sleep quality. *Sleep Health*, *3*(4), 300-305.

Franzen, P. L., & Buysse, D. J (2008). Sleep disturbances and depression: risk relationships for subsequent depression and therapeutic implications. *Dialogues in clinical neuroscience*, *10*(4), 473.

Fresco, D. M., Mennin, D. S., Heimberg, R. G., & Turk, C. L (2003). Using the Penn State Worry Questionnaire to identify individuals with generalized anxiety disorder: A receiver operating characteristic analysis. *Journal of behavior therapy and experimental psychiatry*, *34*(3-4), 283-291.

Fuller-Rowell, T. E., Curtis, D. S., El-Sheikh, M., Duke, A. M., Ryff, C. D., & Zgierska, A. E (2017). Racial discrimination mediates race differences in sleep problems: A longitudinal analysis. *Cultural Diversity and Ethnic Minority Psychology*, *23*(2), 165.

Gabrys, J. B., & Peters, K. A. Y (1985). Reliability, discriminant and predictive validity of the Zung Self-Rating Depression Scale. *Psychological Reports*, *57*(3_suppl), 1091-1096.

Ganzel, B. L., Morris, P. A., & Wethington, E (2010). Allostasis and the human brain: Integrating models of stress from the social and life sciences. Psychological review, 117(1), 134.

Garcia-Esteve, L., Ascaso, C., Ojuel, J., & Navarro, P (2003). Validation of the Edinburgh postnatal depression scale (EPDS) in Spanish mothers. *Journal of affective disorders*, *75*(1), 71-76.

Gavin, N. I., Gaynes, B. N., Lohr, K. N., Meltzer-Brody, S., Gartlehner, G., & Swinson, T (2005). Perinatal depression: a systematic review of prevalence and incidence. *Obstetrics & Gynecology*, *106*(5 Part 1), 1071-1083.

Gavin, A. R., Melville, J. L., Rue, T., Guo, Y., Dina, K. T., & Katon, W. J (2011). Racial differences in the prevalence of antenatal depression. *General hospital psychiatry*, *33*(2), 87-93.

Gao, M., Hu, J., Yang, L., Ding, N., Wei, X., Li, L., ... & Wen, D (2019). Association of sleep quality during pregnancy with stress and depression: a prospective birth cohort study in China. *BMC pregnancy and childbirth*, *19*(1), 444.

Gay, C. L., Richoux, S. E., Beebe, K. R., & Lee, K. A (2017). Sleep disruption and duration in late pregnancy is associated with excess gestational weight gain among overweight and obese women. *Birth*, *44*(2), 173-180.

Gehrman, P. R., Meltzer, L. J., Moore, M., Pack, A. I., Perlis, M. L., Eaves, L. J., & Silberg, J. L (2011). Heritability of insomnia symptoms in youth and their relationship to depression and anxiety. *Sleep*, *34*(12), 1641-1646.

Gimeno, D., Kivimäki, M., Brunner, E. J., Elovainio, M., De Vogli, R., Steptoe, A., ... & Ferrie, J. E (2009). Associations of C-reactive protein and interleukin-6 with cognitive symptoms of depression: 12-year follow-up of the Whitehall II study. *Psychological medicine*, *39*(3), 413.

Giurgescu, C., McFarlin, B. L., Lomax, J., Craddock, C., & Albrecht, A. (2011). Racial discrimination and the Black-White gap in adverse birth outcomes: a review. Journal of midwifery & women's health, 56(4), 362-370.

Giurgescu, C., Zenk, S. N., Templin, T. N., Engeland, C. G., Dancy, B. L., Park, C. G., ... & Misra, D. P (2015). The impact of neighborhood environment, social support, and avoidance coping on depressive symptoms of pregnant African-American women. *Women's Health Issues*, *25*(3), 294-302.

Goldfinger, C., Green, S. M., Furtado, M., & McCabe, R. E (2020). Characterizing the nature of worry in a sample of perinatal women with generalized anxiety disorder. *Clinical Psychology & Psychotherapy*, *27*(2), 136-145.

Gomà, M., Martínez, M., Blancafort, X., Muniente, G., Antón, S., Lara, S., ... & Nanzer, N (2020). Detection of depressive-anxiety symptomatology and associated risk factors among pregnant women in a low-income neighborhood. *Journal of Psychosomatic Obstetrics & Gynecology*, 1-7.

Gordon, A. M., Prather, A. A., Dover, T., Espino-Pérez, K., Small, P., & Major, B (2020). Anticipated and experienced ethnic/racial discrimination and sleep: a longitudinal study. *Personality and Social Psychology Bulletin*, *46*(12), 1724-1735.

Gottlieb, D. J., Punjabi, N. M., Newman, A. B., Resnick, H. E., Redline, S., Baldwin, C. M., & Nieto, F. J (2005). Association of sleep time with diabetes mellitus and impaired glucose tolerance. *Archives of internal medicine*, *165*(8), 863-867.

Goyal, D., Gay, C., & Lee, K. A (2010). How much does low socioeconomic status increase the risk of prenatal and postpartum depressive symptoms in first-time mothers? Women's Health Issues, 20(2), 96-104.

Grandner, M. A., Patel, N. P., Gehrman, P. R., Xie, D., Sha, D., Weaver, T., & Gooneratne, N (2010). Who gets the best sleep? Ethnic and socioeconomic factors related to sleep complaints. *Sleep medicine*, *11*(5), 470-478.

Greenberg, J. (2006). Losing sleep over organizational injustice: attenuating insomniac reactions to underpayment inequity with supervisory training in interactional justice. Journal of applied psychology, 91(1), 58.

Greenland, S., Pearl, J., & Robins, J. M. (1999). Causal diagrams for epidemiologic research. Epidemiology, 37-48.

Grobman, W. A., Parker, C., Wadhwa, P. D., Willinger, M., Simhan, H., Silver, B., ... & Peaceman, A. M (2016). Racial/ethnic disparities in measures of self-reported psychosocial states and traits during pregnancy. *American journal of perinatology*, *33*(14), 1426.

Grosfoguel, R (2011). Decolonizing post-colonial studies and paradigms of political-economy: Transmodernity, decolonial thinking, and global coloniality. *Transmodernity: journal of peripheral cultural production of the luso-hispanic world*, *1*(1).

Grosfoguel, R (2016). What is racism?. *Journal of World-Systems Research*, *22*(1), 9-15.

Guinhouya, B. C., Bisson, M., Dubois, L., Series, F., Kimoff, J. R., Fraser, W. D., & Marc, I (2019). Body weight status and sleep disturbances during pregnancy: does adherence to gestational weight gain guidelines matter?. *Journal of Women's Health*, *28*(4), 535-543.

Gurung, R. A., Dunkel-Schetter, C., Collins, N., Rini, C., & Hobel, C. J (2005). Psychosocial predictors of prenatal anxiety. *Journal of Social and Clinical Psychology*, *24*(4), 497-519.

Haas, D. M., Parker, C. B., Wing, D. A., Parry, S., Grobman, W. A., Mercer, B. M., ... & Reddy, U. M (2015). A description of the methods of the Nulliparous Pregnancy Outcomes Study: monitoring mothers-to-be (nuMoM2b). *American journal of obstetrics and gynecology*, *212*(4), 539-e1.

Hale, L., & Guan, S (2015). Screen time and sleep among school-aged children and adolescents: a systematic literature review. *Sleep medicine reviews*, *21*, 50-58.

Halfaker, D. A., Akeson, S. T., Hathcock, D. R., Mattson, C., & Wunderlich, T. L (2011). Psychological aspects of pain. In *Pain procedures in clinical practice* (pp. 13-22).

Hamilton, M (1989). Frequency of symptoms in melancholia (depressive illness). *The British Journal of Psychiatry*, *154*(2), 201-206.

Haney, A., Buysse, D. J., Rosario, B. L., Chen, Y. F., & Okun, M. L (2014). Sleep disturbance and cardiometabolic risk factors in early pregnancy: a preliminary study. *Sleep medicine*, *15*(4), 444-450.

Harrell, S. P., Merchant, M. A., & Young, S. A (1997). Psychometric properties of the racism and life experiences scales (RaLES). *Unpublished manuscript*.

Hartley, M., Tomlinson, M., Greco, E., Comulada, W. S., Stewart, J., Le Roux, I., ... & Rotheram-Borus, M. J (2011). Depressed mood in pregnancy: prevalence and correlates in two Cape Town peri-urban settlements. *Reproductive health*, *8*(1), 9.

Harvey, A. G (2000). Sleep hygiene and sleep-onset insomnia. *The Journal of nervous and mental disease*, *188*(1), 53-55.

Healthy People 2020 (2020). Sleep Health. Retrieved January 19th, 2021, from: https://www.healthypeople.gov/2020/topics-objectives/topic/sleep-health.

Hedman, C., Pohjasvaara, T., Tolonen, U., Suhonen-Malm, A. S., & Myllylä, V. V (2002). Effects of pregnancy on mothers' sleep. *Sleep medicine*, *3*(1), 37-42

Heh, S. S (2001). Validation of the Chinese version of the Edinburgh Postnatal Depression Scale: detecting postnatal depression in Taiwanese women. *Hu li yan jiu= Nursing Research*, *9*(2), 105-113.

Hertz, G., Fast, A., Feinsilver, S. H., Albertario, C. L., Schulman, H., & Fein, A. M (1992). Sleep in normal late pregnancy. *Sleep*, *15*(3), 246-251.

Hicken, M. T., Lee, H., Ailshire, J., Burgard, S. A., & Williams, D. R (2013). "Every shut eye, ain't sleep": The role of racism-related vigilance in racial/ethnic disparities in sleep difficulty. *Race and social problems*, *5*(2), 100-112.

Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., ... & Ware, J. C (2015). National Sleep Foundation's updated sleep duration recommendations. *Sleep health*, *1*(4), 233-243.

Hoggard, L. S., & Hill, L. K (2018). Examining how racial discrimination impacts sleep quality in African Americans: is perseveration the answer?. *Behavioral sleep medicine*, *16*(5), 471-481.

Hübers, M., Pourhassan, M., Braun, W., Geisler, C., & Müller, M. J. (2017). Definition of new cut-offs of BMI and waist circumference based on body composition and insulin resistance: differences between children, adolescents and adults. Obesity Science & Practice, 3(3), 272-281.

Huizink, A. C., Mulder, E. J., de Medina, P. G. R., Visser, G. H., & Buitelaar, J. K (2004). Is pregnancy anxiety a distinctive syndrome?. *Early human development*, *79*(2), 81-91.

Hutchison, B. L., Stone, P. R., McCowan, L. M., Stewart, A. W., Thompson, J. M., & Mitchell, E. A (2012). A postal survey of maternal sleep in late pregnancy. *BMC pregnancy and childbirth*, *12*(1), 144.

Hux, V. J., Roberts, J. M., & Okun, M. L (2017). Allostatic load in early pregnancy is associated with poor sleep quality. *Sleep medicine*, *33*, 85-90.

Irwin, M. R., Wang, M., Ribeiro, D., Cho, H. J., Olmstead, R., Breen, E. C., ... & Cole, S (2008). Sleep loss activates cellular inflammatory signaling. *Biological psychiatry*, *64*(6), 538-540.

Irwin, M. R., & Cole, S. W (2011). Reciprocal regulation of the neural and innate immune systems. *Nature Reviews Immunology*, *11*(9), 625-632.

Irwin, M. R., & Piber, D (2018). Insomnia and inflammation: a two hit model of depression risk and prevention. *World Psychiatry*, *17*(3), 359.

Izci-Balserak, B., Keenan, B. T., Corbitt, C., Staley, B., Perlis, M., & Pien, G. W (2018). Changes in sleep characteristics and breathing parameters during sleep in early and late pregnancy. *Journal of Clinical Sleep Medicine*, *14*(7), 1161-1168.

Jackson, A. S., Stanforth, P. R., Gagnon, J., Rankinen, T., Leon, A. S., Rao, D. C., ... & Wilmore, J. H. (2002). The effect of sex, age and race on estimating percentage body fat from body mass index: The Heritage Family Study. International journal of obesity, 26(6), 789-796.

Jackson, C. L (2017). Determinants of racial/ethnic disparities in disordered sleep and obesity. *Sleep Health*, *3*(5), 401-415.

Jafari, B., & Mohsenin, V (2010). Polysomnography. *Clinics in chest medicine*, *31*(2), 287-297.

Jansson-Fröjmark, M., & Lindblom, K (2008). A bidirectional relationship between anxiety and depression, and insomnia? A prospective study in the general population. *Journal of psychosomatic research*, *64*(4), 443-449.

Jeong, H. G., Lim, J. S., Lee, M. S., Kim, S. H., Jung, I. K., & Joe, S. H (2013). The association of psychosocial factors and obstetric history with depression in pregnant women: focus on the role of emotional support. *General hospital psychiatry*, *35*(4), 354-358.

Johns, M. W (1991). A new method for measuring daytime sleepiness: the Epworth sleepiness scale. *sleep*, *14*(6), 540-545.

Johns, M. W (1992). Reliability and factor analysis of the Epworth Sleepiness Scale. *Sleep*, *15*(4), 376-381.

Johns, M., & Hocking, B (1997). Daytime sleepiness and sleep habits of Australian workers. *Sleep*, *20*(10), 844-847.

Johns, M. W (2000). Sensitivity and specificity of the multiple sleep latency test (MSLT), the maintenance of wakefulness test and the epworth sleepiness scale: failure of the MSLT as a gold standard. *Journal of sleep research*, *9*(1), 5-11.

Johnson, S. L., Solomon, B. S., Shields, W. C., McDonald, E. M., McKenzie, L. B., & Gielen, A. C (2009). Neighborhood violence and its association with mothers' health: assessing the relative importance of perceived safety and exposure to violence. *Journal of Urban Health*, *86*(4), 538-550.

Johnson, D. A., Billings, M. E., & Hale, L (2018). Environmental determinants of insufficient sleep and sleep disorders: implications for population health. *Current epidemiology reports*, *5*(2), 61-69.

Jomeen, J., & Martin, C. R (2007). Assessment and relationship of sleep quality to depression in early pregnancy. *Journal of Reproductive and Infant Psychology*, *25*(1), 87-99.

Jones, C. P (2000). Levels of racism: a theoretic framework and a gardener's tale. *American journal of public health*, *90*(8), 1212.

Julian, L. J (2011). Measures of Anxiety. *Arthritis care and research*, *63*(11).

Kalmbach, D. A., Cheng, P., Sangha, R., O'Brien, L. M., Swanson, L. M., Palagini, L., ... & Drake, C. L (2019). Insomnia, Short Sleep, And Snoring In Mid-To-Late Pregnancy: Disparities Related To Poverty, Race, And Obesity. *Nature and science of sleep*, *11*, 301.

Kang, Y. T., Yao, Y., Dou, J., Guo, X., Li, S. Y., Zhao, C. N., ... & Li, B (2016). Prevalence and risk factors of maternal anxiety in late pregnancy in China. *International journal of environmental research and public health*, *13*(5), 468.

Katz, J., Crean, H. F., Cerulli, C., & Poleshuck, E. L (2018). Material hardship and mental health symptoms among a predominantly low income sample of pregnant women seeking prenatal care. *Maternal and child health journal*, *22*(9), 1360-1367.

Kitamura, T., Sugawara, M., Shima, S., & Toda, M. A (1999). Temporal variation of validity of self-rating questionnaires: improved validity of repeated use of Zung's Self-Rating Depression Scale among women during the perinatal period. *Journal of Psychosomatic Obstetrics & Gynecology*, *20*(2), 112-117.

Ko, S. H., Chang, S. C., & Chen, C. H (2010). A comparative study of sleep quality between pregnant and nonpregnant Taiwanese women. *Journal of Nursing Scholarship*, *42*(1), 23-30.

Krystal, A. D., & Edinger, J. D (2008). Measuring sleep quality. *Sleep medicine*, *9*, S10-S17.

Ladyman, C., & Signal, T. L (2018). Sleep health in pregnancy: a scoping review. *Sleep medicine clinics*, *13*(3), 307-333.

LeBourgeois, M. K., Giannotti, F., Cortesi, F., Wolfson, A. R., & Harsh, J (2005). The relationship between reported sleep quality and sleep hygiene in Italian and American adolescents. *Pediatrics*, *115*(Supplement 1), 257-265.

Lee, C. D., Spencer, M. B., & Harpalani, V (2003). "Every shut eye ain't sleep": Studying how people live culturally. *Educational Researcher*, *32*(5), 6-13.

Lee, K. A (1998). Alterations in sleep during pregnancy and postpartum: a review of 30 years of research. *Sleep medicine reviews*, *2*(4), 231-242.

Lee, K. A., McEnany, G., & Zaffke, M. E (2000). REM sleep and mood state in childbearing women: sleepy or weepy?. *Sleep*, *23*(7), 877.

Lee, K. A., Zaffke, M. E., & McEnany, G (2000). Parity and sleep patterns during and after pregnancy. *Obstetrics & Gynecology*, *95*(1), 14-18.

Lee, K. A., & Gay, C. L (2004). Sleep in late pregnancy predicts length of labor and type of delivery. *American journal of obstetrics and gynecology*, *191*(6), 2041-2046.

Lee, A. M., Lam, S. K., Lau, S. M. S. M., Chong, C. S. Y., Chui, H. W., & Fong, D. Y. T (2007). Prevalence, course, and risk factors for antenatal anxiety and depression. *Obstetrics & Gynecology*, *110*(5), 1102-1112.

Lee, R. T., Perez, A. D., Boykin, C. M., & Mendoza-Denton, R (2019). On the prevalence of racial discrimination in the United States. *PloS one*, *14*(1), e0210698.

Lind, M. J., Aggen, S. H., Kirkpatrick, R. M., Kendler, K. S., & Amstadter, A. B (2015). A longitudinal twin study of insomnia symptoms in adults. *Sleep*, *38*(9), 1423-1430.

Lopes, E. A., Carvalho, L. B. C. D., Seguro, P. B. D. C., Mattar, R., Silva, A. B., Prado, L. B., & Prado, G. F. D (2004). Sleep disorders in pregnancy. *Arquivos de Neuro-psiquiatria*, *62*(2a), 217-221.

Maasilta, P., Bachour, A., Teramo, K., Polo, O., & Laitinen, L. A (2001). Sleep-related disordered breathing during pregnancy in obese women. *Chest*, *120*(5), 1448-1454.

Madhavanprabhakaran, G. K., D'Souza, M. S., & Nairy, K. S (2015). Prevalence of pregnancy anxiety and associated factors. *International Journal of Africa Nursing Sciences*, *3*, 1-7.

Marcus, S. M., Flynn, H. A., Blow, F. C., & Barry, K. L (2003). Depressive symptoms among pregnant women screened in obstetrics settings. *Journal of women's health*, *12*(4), 373-380.

Marcus, S. M (2009). Depression during pregnancy: rates, risks and consequences. *Journal of Population Therapeutics and Clinical Pharmacology*, *16*(1).

Manikkam, L., & Burns, J. K (2012). Antenatal depression and its risk factors: an urban prevalence study in KwaZulu-Natal. *South African Medical Journal*, *102*(12), 940-944.

Martin, J. L., & Hakim, A. D (2011). Wrist actigraphy. *Chest*, *139*(6), 1514-1527.

Martini, J., Petzoldt, J., Einsle, F., Beesdo-Baum, K., Höfler, M., & Wittchen, H. U (2015). Risk factors and course patterns of anxiety and depressive disorders during pregnancy and after delivery: a prospective-longitudinal study. *Journal of affective disorders*, *175*, 385-395.

McCall, C., & McCall, W. V (2012). Objective vs. subjective measurements of sleep in depressed insomniacs: first night effect or reverse first night effect?. *Journal of Clinical Sleep Medicine*, *8*(1), 59-65.

McLemore, M. R., Altman, M. R., Cooper, N., Williams, S., Rand, L., & Franck, L (2018). Health care experiences of pregnant, birthing and postnatal women of color at risk for preterm birth. *Social Science & Medicine*, *201*, 127-135.

McNeilly, M. D., Anderson, N. B., Armstead, C. A., Clark, R., Corbett, M., Robinson, E. L., ... & Lepisto, E. M (1996). The perceived racism scale: a multidimensional assessment of the experience of white racism among African Americans. *Ethnicity & disease*.

Melville, J. L., Gavin, A., Guo, Y., Fan, M. Y., & Katon, W. J (2010). Depressive disorders during pregnancy: prevalence and risk factors in a large urban sample. *Obstetrics and gynecology*, *116*(5), 1064.

Mendez, D. D., Hogan, V. K., & Culhane, J (2011). Institutional racism and pregnancy health: using Home Mortgage Disclosure Act data to develop an index for mortgage discrimination at the community level. *Public Health Reports*, *126*(3_suppl), 102-114.

Mendez, D. D., Hogan, V. K., & Culhane, J. F (2013). Stress during pregnancy: The role of institutional racism. *Stress and Health*, *29*(4), 266-274.

Mendez, D. D., Hogan, V. K., & Culhane, J. F (2014). Institutional racism, neighborhood factors, stress, and preterm birth. *Ethnicity & health*, *19*(5), 479-499.

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D (1990). Development and validation of the penn state worry questionnaire. *Behaviour research and therapy*, *28*(6), 487-495.

Miller, M. A., Kandala, N. B., Kivimaki, M., Kumari, M., Brunner, E. J., Lowe, G. D., ... & Cappuccio, F. P (2009). Gender differences in the cross-sectional relationships between sleep duration and markers of inflammation: Whitehall II study. *Sleep*, *32*(7), 857-864.

Mindell, J. A., & Jacobson, B. J (2000). Sleep disturbances during pregnancy. *Journal of Obstetric, Gynecologic, & Neonatal Nursing*, *29*(6), 590-597.

Mindell, J. A., Cook, R. A., & Nikolovski, J (2015). Sleep patterns and sleep disturbances across pregnancy. *Sleep medicine*, *16*(4), 483-488.

Mirabzadeh, A., Dolatian, M., Forouzan, A. S., Sajjadi, H., Majd, H. A., & Mahmoodi, Z (2013). Path analysis associations between perceived social support, stressful life events and other psychosocial risk factors during pregnancy and preterm delivery. *Iranian Red Crescent Medical Journal*, *15*(6), 507.

Montazeri, A., Torkan, B., & Omidvari, S (2007). The Edinburgh Postnatal Depression Scale (EPDS): translation and validation study of the Iranian version. *BMC psychiatry*, *7*(1), 11.

Moraes, W., Piovezan, R., Poyares, D., Bittencourt, L. R., Santos-Silva, R., & Tufik, S (2014). Effects of aging on sleep structure throughout adulthood: a population-based study. *Sleep medicine*, *15*(4), 401-409.

Morin, C. M (1993). *Insomnia: psychological assessment and management*. Guilford press.

Naghi, I., Keypour, F., Ahari, S. B., Tavalai, S. A., & Khak, M (2011). Sleep disturbance in late pregnancy and type and duration of labour. *Journal of Obstetrics and Gynaecology*, *31*(6), 489-491.

National Institute of Neurological Disorders and Stroke (NINDS) (2019). Brain Basics: Understanding Sleep. Retrieved January 19th, 2021, from: https://www.ninds.nih.gov/Disorders/patient-caregiver-education/understanding-sleep.

National Research Council (2004). *Measuring racial discrimination*. National Academies Press.

Naud, K., Ouellet, A., Brown, C., Pasquier, J. C., & Moutquin, J. M (2010). Is sleep disturbed in pregnancy?. *Journal of Obstetrics and Gynaecology Canada*, *32*(1), 28-34.

Nodine, P. M., & Matthews, E. E (2013). Common sleep disorders: management strategies and pregnancy outcomes. *Journal of midwifery & women's health*, *58*(4), 368-377.

Noh, S., Beiser, M., Kaspar, V., Hou, F., & Rummens, J (1999). Perceived racial discrimination, depression, and coping: A study of Southeast Asian refugees in Canada. *Journal of health and social behavior*, 193-207.

Nonacs, R., & Cohen, L. S (2002). Depression during pregnancy: diagnosis and treatment options. *The Journal of clinical psychiatry*, *63*, 24.

Odom, E. C., Vernon-Feagans, L., & Family Life Project Key Investigators (2010). Buffers of racial discrimination: Links with depression among rural African American mothers. *Journal of Marriage and Family*, *72*(2), 346-359.

Ohayon, M., Wickwire, E. M., Hirshkowitz, M., Albert, S. M., Avidan, A., Daly, F. J., ... & Vitiello, M. V (2017). National Sleep Foundation's sleep quality recommendations: first report. *Sleep health*, *3*(1), 6-19.

Okada, K., Saito, I., Katada, C., & Tsujino, T (2019). Influence of quality of sleep in the first trimester on blood pressure in the third trimester in primipara women. *Blood pressure*, *28*(5), 345-355.

Okagbue, H. I., Adamu, P. I., Bishop, S. A., Oguntunde, P. E., Opanuga, A. A., & Akhmetshin, E. M (2019). Systematic review of prevalence of antepartum depression during the trimesters of pregnancy. *Open access Macedonian journal of medical sciences*, *7*(9), 1555.

Okun, M. L., Hall, M., & Coussons-Read, M. E (2007). Sleep disturbances increase interleukin-6 production during pregnancy: implications for pregnancy complications. *Reproductive Sciences*, *14*(6), 560-567.

Okun, M. L., Kiewra, K., Luther, J. F., Wisniewski, S. R., & Wisner, K. L (2011). Sleep disturbances in depressed and nondepressed pregnant women. *Depression and anxiety*, *28*(8), 676-685.

Okun, M. L., Tolge, M., & Hall, M (2014). Low socioeconomic status negatively affects sleep in pregnant women. *Journal of Obstetric, Gynecologic & Neonatal Nursing*, *43*(2), 160-167.

Okun, M. L., Buysse, D. J., & Hall, M. H (2015). Identifying insomnia in early pregnancy: validation of the insomnia symptoms questionnaire (ISQ) in pregnant women. *Journal of Clinical Sleep Medicine*, *11*(6), 645-654.

Okun, M. L., & O'Brien, L. M (2018). Concurrent insomnia and habitual snoring are associated with adverse pregnancy outcomes. *Sleep medicine*, *46*, 12-19.

Palagini, L., Gemignani, A., Banti, S., Manconi, M., Mauri, M., & Riemann, D (2014). Chronic sleep loss during pregnancy as a determinant of stress: impact on pregnancy outcome. *Sleep medicine*, *15*(8), 853-859.

Pan, Y (2020). Association between marital status and mental health among pregnant women in the United States. Retrieved January 19th, 2021, from: https://etda.libraries.psu.edu/catalog/17923yxp151

Paradies, Y (2006). A systematic review of empirical research on self-reported racism and health. *International journal of epidemiology*, *35*(4), 888-901.

Parry, B. L., & Newton, R. P (2001). Chronobiological basis of female-specific mood disorders. *Neuropsychopharmacology*, *25*(1), S102-S108.

Pascoe, E. A., & Smart Richman, L (2009). Perceived discrimination and health: a meta-analytic review. *Psychological bulletin*, *135*(4), 531.

Patel, N. P., Grandner, M. A., Xie, D., Branas, C. C., & Gooneratne, N (2010). " Sleep disparity" in the population: poor sleep quality is strongly associated with poverty and ethnicity. *BMC Public Health*, *10*(1), 475.

Patel, A. K., Reddy, V., & Araujo, J. F (2020). Physiology, sleep stages. Retrieved January 19th, 2021, from: https://www.ncbi.nlm.nih.gov/books/NBK526132/.

Paterson, L. M., Nutt, D. J., & Wilson, S. J (2009). NAPSAQ-1: National Patient Sleep Assessment Questionnaire in depression. *International journal of psychiatry in clinical practice*, *13*(1), 48-58.

Perlis, M. L., Giles, D. E., Buysse, D. J., Tu, X., & Kupfer, D. J (1997). Self-reported sleep disturbance as a prodromal symptom in recurrent depression. *Journal of affective disorders*.

Polo-Kantola, P., Aukia, L., Karlsson, H., Karlsson, L., & Paavonen, E. J (2017). Sleep quality during pregnancy: associations with depressive and anxiety symptoms. *Acta obstetricia et gynecologica Scandinavica*, *96*(2), 198-206.

Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. Obesity reviews, 2(3), 141-147.

Qiu, C., Gelaye, B., Zhong, Q. Y., Enquobahrie, D. A., Frederick, I. O., & Williams, M. A (2016). Construct validity and factor structure of the Pittsburgh Sleep Quality Index among pregnant women in a Pacific-Northwest cohort. *Sleep and Breathing*, *20*(1), 293-301.

Räisänen, S., Lehto, S. M., Nielsen, H. S., Gissler, M., Kramer, M. R., & Heinonen, S (2014). Risk factors for and perinatal outcomes of major depression during pregnancy: a population-based analysis during 2002–2010 in Finland. *BMJ open*, *4*(11).

Raison, C. L., Rutherford, R. E., Woolwine, B. J., Shuo, C., Schettler, P., Drake, D. F., ... & Miller, A. H (2013). A randomized controlled trial of the tumor necrosis factor antagonist infliximab for treatment-resistant depression: the role of baseline inflammatory biomarkers. *JAMA psychiatry*, *70*(1), 31-41.

Records, K., & Rice, M (2007). Psychosocial correlates of depression symptoms during the third trimester of pregnancy. *Journal of Obstetric, Gynecologic & Neonatal Nursing*, *36*(3), 231-242.

Reid Marks, L., Thurston, I. B., Kamody, R. C., & Schaeffer-Smith, M (2020). The role of multiracial identity integration in the relation between racial discrimination and depression in multiracial young adults. *Professional Psychology: Research and Practice*, *51*(4), 317.

Reutrakul, S., Zaidi, N., Wroblewski, K., Kay, H. H., Ismail, M., Ehrmann, D. A., & Van Cauter, E (2011). Sleep disturbances and their relationship to glucose tolerance in pregnancy. *Diabetes care*, *34*(11), 2454-2457.

Rhodes, J. A., Lane, J. M., Vlasac, I. M., Rutter, M. K., Czeisler, C. A., & Saxena, R (2019). Association of DAT1 genetic variants with habitual sleep duration in the UK Biobank. *Sleep*, *42*(1), zsy193.

Rich-Edwards, J. W., Kleinman, K., Abrams, A., Harlow, B. L., McLaughlin, T. J., Joffe, H., & Gillman, M. W (2006). Sociodemographic predictors of antenatal and postpartum depressive symptoms among women in a medical group practice. *Journal of Epidemiology & Community Health*, *60*(3), 221-227.

Riley, A. R (2018). Neighborhood disadvantage, residential segregation, and beyond—lessons for studying structural racism and health. *Journal of racial and ethnic health disparities*, *5*(2), 357-365.

Robert, E (1996). Treating depression in pregnancy. *The New England journal of medicine*, *335*(14), 1056.

Roca, G. Q., Anyaso, J., Redline, S., & Bello, N. A (2020). Associations between sleep disorders and hypertensive disorders of pregnancy and materno-fetal consequences. *Current Hypertension Reports*, *22*(8), 1-9.

Roepke, S. E., & Duffy, J. F (2010). Differential impact of chronotype on weekday and weekend sleep timing and duration. *Nature and science of sleep*, *2*, 213.

Rogers, A. E., Caruso, C. C., & Aldrich, M. S (1993). Reliability of sleep diaries for assessment of sleep/wake patterns. *Nursing research*.

Rubertsson, C., Waldenström, U., & Wickberg, B (2003). Depressive mood in early pregnancy: prevalence and women at risk in a national Swedish sample. *Journal of Reproductive and Infant Psychology*, *21*(2), 113-123.

Rubertsson, C., Börjesson, K., Berglund, A., Josefsson, A., & Sydsjö, G (2011). The Swedish validation of Edinburgh postnatal depression scale (EPDS) during pregnancy. *Nordic journal of psychiatry*, *65*(6), 414-418.

Ruiz-Robledillo, N., Canário, C., Dias, C. C., Moya-Albiol, L., & Figueiredo, B (2015). Sleep during the third trimester of pregnancy: the role of depression and anxiety. *Psychology, health & medicine*, *20*(8), 927-932.

Rundo, J. V., & Downey III, R (2019). Polysomnography. In *Handbook of clinical neurology* (Vol. 160, pp. 381-392). Elsevier.

Sadeh, A., & Acebo, C (2002). The role of actigraphy in sleep medicine. *Sleep medicine reviews*, *6*(2), 113-124.

Sahota, P. K., Jain, S. S., & Dhand, R (2003). Sleep disorders in pregnancy. *Current opinion in pulmonary medicine*, *9*(6), 477-483.

Santiago, J. R., Nolledo, M. S., Kinzler, W., & Santiago, T. V (2001). Sleep and sleep disorders in pregnancy. *Annals of Internal Medicine*, *134*(5), 396-408.

Schäfer, V., & Bader, K (2013). Relationship between early-life stress load and sleep in psychiatric outpatients: A sleep diary and actigraphy study. *Stress and Health*, *29*(3), 177-189.

Scrima, L., Emsellem, H. A., Becker, P. M., Ruoff, C., Lankford, A., Bream, G., ... & Black, J (2017). Identifying clinically important difference on the Epworth Sleepiness Scale: results from a narcolepsy clinical trial of JZP-110. *Sleep medicine*, *38*, 108-112.

Sedov, I. D., Cameron, E. E., Madigan, S., & Tomfohr-Madsen, L. M (2018). Sleep quality during pregnancy: A meta-analysis. *Sleep medicine reviews*, *38*, 168-176.

Segre, L. S., O'Hara, M. W., & Losch, M. E (2006). Race/ethnicity and perinatal depressed mood. *Journal of Reproductive and Infant Psychology*, *24*(02), 99-106.

Signal, T. L., Gander, P. H., Sangalli, M. R., Travier, N., Firestone, R. T., & Tuohy, J. F (2007). Sleep duration and quality in healthy nulliparous and multiparous women across pregnancy and post-partum. *Australian and New Zealand journal of obstetrics and gynaecology*, *47*(1), 16-22.

Sivertsen, B., Salo, P., Mykletun, A., Hysing, M., Pallesen, S., Krokstad, S., ... & Øverland, S (2012). The bidirectional association between depression and insomnia: the HUNT study. *Psychosomatic medicine*, *74*(7), 758-765.

Skouteris, H., Germano, C., Wertheim, E. H., Paxton, S. J., & Milgrom, J (2008). Sleep quality and depression during pregnancy: a prospective study. *Journal of sleep research*, *17*(2), 217-220.

Slopen, N., Lewis, T. T., & Williams, D. R (2016). Discrimination and sleep: a systematic review. *Sleep medicine*, *18*, 88-95.

Smith, M. T., McCrae, C. S., Cheung, J., Martin, J. L., Harrod, C. G., Heald, J. L., & Carden, K. A (2018). Use of actigraphy for the evaluation of sleep disorders and circadian rhythm sleep-wake disorders: an American Academy of Sleep Medicine clinical practice guideline. *Journal of Clinical Sleep Medicine*, *14*(7), 1231-1237.

Soltani, M., Haytabakhsh, M. R., Najman, J. M., Williams, G. M., O'Callaghan, M. J., Bor, W., ... & Clavarino, A (2012). Sleepless nights: the effect of socioeconomic status, physical activity, and lifestyle factors on sleep quality in a large cohort of Australian women. *Archives of women's mental health*, *15*(4), 237-247.

Somerville, S., Dedman, K., Hagan, R., Oxnam, E., Wettinger, M., Byrne, S., ... & Page, A. C (2014). The perinatal anxiety screening scale: development and preliminary validation. *Archives of women's mental health*, *17*(5), 443-454.

Spiegel, K., Knutson, K., Leproult, R., Tasali, E., & Cauter, E. V (2005). Sleep loss: a novel risk factor for insulin resistance and Type 2 diabetes. *Journal of applied physiology*, *99*(5), 2008-2019.

Spielberger, C. D (1989). *State-trait anxiety inventory: a comprehensive bibliography*. Consulting Psychologists Press.

Srinivasan, N., Murthy, S., Singh, A. K., Upadhyay, V., Mohan, S. K., & Joshi, A (2015). Assessment of burden of depression during pregnancy among pregnant women residing in rural setting of Chennai. *Journal of clinical and diagnostic research: JCDR*, *9*(4), LC08.

Stamatakis, K. A., Kaplan, G. A., & Roberts, R. E (2007). Short sleep duration across income, education, and race/ethnic groups: population prevalence and growing disparities during 34 years of follow-up. *Annals of epidemiology*, *17*(12), 948-955.

Stein, M. B., McCarthy, M. J., Chen, C. Y., Jain, S., Gelernter, J., He, F., ... & Sun, X (2018). Genome-wide analysis of insomnia disorder. *Molecular psychiatry*, *23*(11), 2238-2250.

Strange, L. B., Parker, K. P., Moore, M. L., Strickland, O. L., & Bliwise, D. L (2009). Disturbed sleep and preterm birth: a potential relationship. *Clin Exp Obstet Gynecol*, *36*(3), 166-8.

Steiger, A., & Pawlowski, M (2019). Depression and sleep. *International journal of molecular sciences*, *20*(3), 607.

Su, K. P., Chiu, T. H., Huang, C. L., Ho, M., Lee, C. C., Wu, P. L., ... & Pariante, C. M (2007). Different cutoff points for different trimesters? The use of Edinburgh Postnatal Depression Scale and Beck Depression Inventory to screen for depression in pregnant Taiwanese women. *General hospital psychiatry*, *29*(5), 436-441.

Sullivan, P. F., Neale, M. C., & Kendler, K. S (2000). Genetic epidemiology of major depression: review and meta-analysis. *American Journal of Psychiatry*, *157*(10), 1552-1562.

Sun, Y., Shi, L., Bao, Y., Sun, Y., Shi, J., & Lu, L (2018). The bidirectional relationship between sleep duration and depression in community-dwelling middle-aged and elderly individuals: evidence from a longitudinal study. *Sleep medicine*, *52*, 221-229.

Swanson, L. M., Pickett, S. M., Flynn, H., & Armitage, R (2011). Relationships among depression, anxiety, and insomnia symptoms in perinatal women seeking mental health treatment. *Journal of Women's Health*, *20*(4), 553-558.

Teong, A. C. A., Diong, A. X., Omar, S. Z., & Tan, P. C (2017). The impact of self-reported sleep on caesarean delivery in women undergoing induction of labour: a prospective study. *Scientific reports*, *7*(1), 1-8.

Tendais, I., Costa, R., Conde, A., & Figueiredo, B (2014). Screening for depression and anxiety disorders from pregnancy to postpartum with the EPDS and STAI.

Tennant, P. W., Murray, E. J., Arnold, K. F., Berrie, L., Fox, M. P., Gadd, S. C., ... & Ellison, G. T. (2021). Use of directed acyclic graphs (DAGs) to identify confounders in applied health research: review and recommendations. International journal of epidemiology, 50(2), 620-632.

Tighe, C. A., Brindle, R. C., Stahl, S. T., Wallace, M. L., Bramoweth, A. D., Forman, D. E., & Buysse, D. J. (2021). Multidimensional Sleep Health and Physical Functioning in Older Adults. Gerontology and Geriatric Medicine, 7, 23337214211016222.

Tomfohr, L. M., Buliga, E., Letourneau, N. L., Campbell, T. S., & Giesbrecht, G. F (2015). Trajectories of sleep quality and associations with mood during the perinatal period. *Sleep*, *38*(8), 1237-1245.

Tsai, S. Y., Kuo, L. T., Lai, Y. H., & Lee, C. N (2011). Factors associated with sleep quality in pregnant women: a prospective observational study. *Nursing Research*, *60*(6), 405-412.

Tsai, S. Y., Lin, J. W., Kuo, L. T., & Thomas, K. A (2012). Daily sleep and fatigue characteristics in nulliparous women during the third trimester of pregnancy. *Sleep*, *35*(2), 257-262.

Tsai, S. Y., Kuo, L. T., Lee, C. N., Lee, Y. L., & Landis, C. A (2013). Reduced sleep duration and daytime naps in pregnant women in Taiwan. *Nursing research*, *62*(2), 99-105.

Tsai, S. Y., Lin, J. W., Kuo, L. T., Lee, C. N., & Landis, C. A (2013). Nighttime sleep, daytime napping, and labor outcomes in healthy pregnant women in Taiwan. *Research in nursing & health*, *36*(6), 612-622.

Tsai, S. Y., Lee, C. N., Wu, W. W., & Landis, C. A (2016). Sleep hygiene and sleep quality of third-trimester pregnant women. *Research in Nursing & Health*, *39*(1), 57-65.

Tsai, S. Y., Lee, P. L., Lin, J. W., & Lee, C. N (2016). Cross-sectional and longitudinal associations between sleep and health-related quality of life in pregnant women: a prospective observational study. *International journal of nursing studies*, *56*, 45-53.

Tsai, S. Y., Lin, J. W., Wu, W. W., Lee, C. N., & Lee, P. L (2016). Sleep disturbances and symptoms of depression and daytime sleepiness in pregnant women. *Birth*, *43*(2), 176-183.

Tsai, S. Y., Lee, P. L., Lin, J. W., & Lee, C. N (2017). Persistent and new-onset daytime sleepiness in pregnant women: a prospective observational cohort study. *International journal of nursing studies*, *66*, 1-6.

Tzeng, Y. L., Chen, S. L., Chen, C. F., Wang, F. C., & Kuo, S. Y (2015). Sleep trajectories of women undergoing elective cesarean section: effects on body weight and psychological well-being. *PLoS One*, *10*(6), e0129094.

Van den Bergh PhD, B. R. H (1990). The influence of maternal emotions during pregnancy on fetal and neonatal behavior. *Journal of Prenatal & Perinatal Psychology & Health*, *5*(2), 119.

Voegtline, K., Payne, J. L., Standeven, L. R., Sundel, B., Pangtey, M., & Osborne, L. M (2021). Using the Penn State Worry Questionnaire in the Peripartum. *Journal of Women's Health*.

Vyazovskiy, V. V (2015). Sleep, recovery, and metaregulation: explaining the benefits of sleep. *Nature and science of sleep*, *7*, 171.

Wallace, M. L., Buysse, D. J., Redline, S., Stone, K. L., Ensrud, K., Leng, Y., ... & Hall, M. H (2019). Multidimensional sleep and mortality in older adults: a machine-learning comparison with other risk factors. *The Journals of Gerontology: Series A*, *74*(12), 1903-1909.

Wallace, M. L., Yu, L., Buysse, D. J., Stone, K. L., Redline, S., Smagula, S. F., ... & Hall, M. H. (2021). Multidimensional sleep health domains in older men and women: an actigraphy factor analysis. Sleep, 44(2), zsaa181.

Wang, J., Thornton, J. C., Russell, M., Burastero, S., Heymsfield, S., & Pierson Jr, R. N. (1994). Asians have lower body mass index (BMI) but higher percent body fat than do whites: comparisons of anthropometric measurements. The American journal of clinical nutrition, 60(1), 23-28.

Wang, Y. Q., Tu, Z. C., Xu, X. Y., Li, R., Qu, W. M., Urade, Y., & Huang, Z. L (2012). Acute administration of fluoxetine normalizes rapid eye movement sleep abnormality, but not depressive behaviors in olfactory bulbectomized rats. *Journal of neurochemistry*, *120*(2), 314-324.

Wang, Y. P., & Gorenstein, C (2013). Psychometric properties of the Beck Depression Inventory-II: a comprehensive review. *Brazilian Journal of Psychiatry*, *35*(4), 416-431.

Waters, M. A., & Lee, K. A (1996). Differences between primigravidae and multigravidae mothers in sleep disturbances, fatigue, and functional status. *Journal of Nurse-Midwifery*, *41*(5), 364-367.

Westreich, D., & Greenland, S. (2013). The table 2 fallacy: presenting and interpreting confounder and modifier coefficients. American journal of epidemiology, 177(4), 292-298.

Weobong, B., Soremekun, S., Ten Asbroek, A. H., Amenga-Etego, S., Danso, S., Owusu-Agyei, S., ... & Kirkwood, B. R (2014). Prevalence and determinants of antenatal depression among pregnant women in a predominantly rural population in Ghana: The DON population-based study. *Journal of affective disorders*, *165*, 1-7.

Williams, D. R., Yu, Y., Jackson, J. S., & Anderson, N. B (1997). Racial differences in physical and mental health: Socio-economic status, stress and discrimination. *Journal of health psychology*, *2*(3), 335-351.

Williams, D. R (1997). Race and health: basic questions, emerging directions. *Annals of epidemiology*, *7*(5), 322-333.

Williams, D. R., & Williams-Morris, R (2000). Racism and mental health: The African American experience. *Ethnicity & Health*.

Williams, D. R., & Mohammed, S. A (2009). Discrimination and racial disparities in health: evidence and needed research. *Journal of behavioral medicine*, *32*(1), 20-47.

Williams, D. R., & Mohammed, S. A (2013). Racism and health I: Pathways and scientific evidence. *American behavioral scientist*, *57*(8), 1152-1173.

Williams, N. J., Grandner, M. A., Snipes, S. A., Rogers, A., Williams, O., Airhihenbuwa, C., & Jean-Louis, G (2015). Racial/ethnic disparities in sleep health and health care: importance of the sociocultural context. *Sleep Health: Journal of the National Sleep Foundation*, *1*(1), 28-35.

Win, T., Yamazaki, T., Kanda, K., Tajima, K., & Sokejima, S (2018). Neighborhood social capital and sleep duration: a population based cross-sectional study in a rural Japanese town. *BMC public health*, *18*(1), 343.

Wilson, D. L., Barnes, M., Ellett, L., Permezel, M., Jackson, M., & Crowe, S. F (2011). Decreased sleep efficiency, increased wake after sleep onset and increased cortical arousals in late pregnancy. *Australian and New Zealand Journal of Obstetrics and Gynaecology*, *51*(1), 38-46.

Wittmann, M., Dinich, J., Merrow, M., & Roenneberg, T (2006). Social jetlag: misalignment of biological and social time. *Chronobiology international*, *23*(1-2), 497-509.

Wolfson, A. R., Crowley, S. J., Anwer, U., & Bassett, J. L (2003). Changes in sleep patterns and depressive symptoms in first-time mothers: last trimester to 1-year postpartum. *Behavioral sleep medicine*, *1*(1), 54-67.

Xu, Y. H., Shi, L., Bao, Y. P., Chen, S. J., Shi, J., Zhang, R. L., & Lu, L (2018). Association between sleep duration during pregnancy and gestational diabetes mellitus: a meta-analysis. *Sleep medicine*, *52*, 67-74.

Yang, S., Kestens, Y., Dahhou, M., Daniel, M., & Kramer, M. S (2015). Neighborhood deprivation and maternal psychological distress during pregnancy: a multilevel analysis. *Maternal and child health journal*, *19*(5), 1142-1151.

Yang, Y., Mao, J., Ye, Z., Zeng, X., Zhao, H., Liu, Y., & Li, J (2018). Determinants of sleep quality among pregnant women in China: a cross-sectional survey. *The Journal of Maternal-Fetal & Neonatal Medicine*, *31*(22), 2980-2985.

Yates, W. R., Mitchell, J., Rush, A. J., Trivedi, M., Wisniewski, S. R., Warden, D., ... & Gaynes, B. N (2007). Clinical features of depression in outpatients with and without co-occurring general medical conditions in STAR* D: confirmatory analysis. *Primary care companion to the Journal of clinical psychiatry*, *9*(1), 7.

Yu, Y., Li, M., Pu, L., Wang, S., Wu, J., Ruan, L., ... & Jiang, W (2017). Sleep was associated with depression and anxiety status during pregnancy: a prospective longitudinal study. *Archives of Women's Mental Health*, *20*(5), 695-701.

Zafarghandi, N., Hadavand, S., Davati, A., Mohseni, S. M., Kimiaiimoghadam, F., & Torkestani, F (2012). The effects of sleep quality and duration in late pregnancy on labor and fetal outcome. *The Journal of Maternal-Fetal & Neonatal Medicine*, *25*(5), 535-537.

Zeng, Y., Cui, Y., & Li, J (2015). Prevalence and predictors of antenatal depressive symptoms among Chinese women in their third trimester: a cross-sectional survey. *BMC psychiatry*, *15*(1), 66.

Zhang, L., & Zhao, Z. X (2007). Objective and subjective measures for sleep disorders. *Neuroscience Bulletin*, *23*(4), 236-240.

Zimet, G. D., Powell, S. S., Farley, G. K., Werkman, S., & Berkoff, K. A (1990). Psychometric characteristics of the multidimensional scale of perceived social support. *Journal of personality assessment*, *55*(3-4), 610-617.

Zizi, F., Jean-Louis, G., Brown, C. D., Ogedegbe, G., Boutin-Foster, C., & McFarlane, S. I (2010). Sleep duration and the risk of diabetes mellitus: epidemiologic evidence and pathophysiologic insights. *Current diabetes reports*, *10*(1), 43-47.

Zou, D., Grote, L., Peker, Y., Lindblad, U., & Hedner, J (2006). Validation a portable monitoring device for sleep apnea diagnosis in a population based cohort using synchronized home polysomnography. *Sleep*, *29*(3), 367-374.

Zung, W. W (1971). A rating instrument for anxiety disorders. *Psychosomatics: Journal of Consultation and Liaison Psychiatry*.

Zung, W. W (1965). A self-rating depression scale. *Archives of general psychiatry*, *12*(1), 63-70.