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ORIGINAL ARTICLE

Sleep During Pregnancy: The nuMoM2b Pregnancy and Sleep Duration and Continuity Study

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Study Objectives: To characterize sleep duration, timing and continuity measures in pregnancy and their association with key demographic variables.
Methods: Multisite prospective cohort study. Women enrolled in the nuMoM2b study (nulliparous women with a singleton gestation) were recruited at the second study visit (16–21 weeks of gestation) to participate in the Sleep Duration and Continuity substudy. Women <18 years of age or with pregestational diabetes or chronic hypertension were excluded from participation. Women wore a wrist activity monitor and completed a sleep log for 7 consecutive days. Time in bed, sleep duration, fragmentation index, sleep efficiency, wake after sleep onset, and sleep midpoint were averaged across valid primary sleep periods for each participant.
Results: Valid data were available from 782 women with mean age of 27.3 (5.5) years. Median sleep duration was 7.4 hours. Approximately 27.9% of women had a sleep duration of <7 hours; 2.6% had a sleep duration of >9 hours. In multivariable models including age, race/ethnicity, body mass index, insurance status, and recent smoking history, sleep duration was significantly associated with race/ethnicity and insurance status, while time in bed was only associated with insurance status. Sleep continuity measures and sleep midpoint were significantly associated with all covariates in the model, with the exception of age for fragmentation index and smoking for wake after sleep onset.
Conclusions: Our results demonstrate the relationship between sleep and important demographic characteristics during pregnancy.
Keywords: pregnancy, sleep duration, sleep quality, epidemiology.

Statement of Significance
The current study represents one of the largest cohorts of objectively measured habitual sleep in pregnancy to date and demonstrates the feasibility of objectively assessing sleep over a week during pregnancy. Our data indicate that, in the second trimester of nulliparous pregnancy, sleep duration, continuity, and timing of sleep are associated with multiple demographic characteristics. Furthermore, more than 20% of women had a sleep duration that has previously been shown in nonpregnant cohorts to be associated with poor cardiometabolic health.

INTRODUCTION

Poor sleep quality is common in the general population, and women are more likely to have sleep disturbances than are men.[1] Poor sleep quality, defined here, as inadequate sleep duration and poor sleep continuity, can be the result of environmental and psychosocial factors, medical and psychiatric disorders, as well as sleep disorders such as insomnia, sleep apnea, and restless legs syndrome. There are mounting data linking poor sleep quality and adverse health outcomes. Experimental studies show that sleep restriction and fragmentation adversely affect appetite-regulating hormones, insulin sensitivity, markers of systemic inflammation, and autonomic regulation and function,[2–5] while epidemiologic studies demonstrate that short sleep duration is associated with an increased risk of obesity, diabetes, hypertension, and mortality.[6–12] Sleep duration in nonpregnant individuals has also been associated with cardiometabolic risk factors including age, body mass index, smoking, race/ethnicity, and socioeconomic status.[13,14] There is also a link between later sleep timing and unhealthy behaviors such as smoking, alcohol use, and poor diet.[15,16]

Recent studies suggest that pregnant women are a population at particularly increased risk for sleep disturbances.[17–19] However, most of these studies are conducted in select populations and have relied on self-reported sleep measures, which may overestimate sleep duration compared to objective sleep measures.[17,20–23] Those studies using actigraphy typically have less than 200 women and are often samples of convenience from a small geographic area.[21,24–26] One actigraphy-based study of 80 urban, low-income women reported a mean actigraphy-based sleep duration of 6.8 hours in comparison to a mean self-reported sleep duration of 7.2 hours.[21] Another more recent study, examining sleep across pregnancy using actigraphy, reported a mean second-trimester sleep duration of 6.6 hours.[25] Another important factor is that simply focusing on sleep duration ignores other characteristics of sleep such as sleep continuity, sleep timing, and variability, despite growing evidence

regarding the multidimensional nature of healthy sleep.[27,28] To date, systematic population-based prospective studies to determine the type and prevalence of sleep problems during pregnancy, and their association with patient demographic and behavioral characteristics, are lacking.

The Nulliparous Pregnancy Outcome Study: Monitoring Mothers-to-be (nuMoM2b) is a prospective cohort study of nulliparous women with singleton gestations. Enrolled women underwent research assessments over the course of their pregnancies to study the mechanisms and predictive factors of adverse pregnancy outcomes including hypertensive disease of pregnancy, preterm birth, and fetal growth restriction.[29] The nuMoM2b Sleep Duration and Continuity Substudy is a prospective study of a subset of the women enrolled in the nuMoM2b parent study. The primary objective of this Substudy was to examine the relationship of objectively assessed sleep duration, continuity, and timing, with cardiovascular and metabolic morbidity related to pregnancy.

This article describes sleep duration, sleep timing, sleep continuity, and sleep variability measures in pregnancy and their association with important demographic characteristics as well as the detailed methods for actigraphy acquisition and scoring used in the nuMoM2b Sleep Duration and Continuity Substudy.

METHODS

General Design nuMoM2b Parent Study

Details of the nuMoM2b parent study have been previously published.[29] The nuMoM2b study was conducted at 8 clinical sites from 2010 through 2013: Case Western Reserve University, Columbia University, Indiana University, the University of Pittsburgh, Northwestern University, the University of California at Irvine, the University of Pennsylvania, and the University of Utah. Data were managed by a central data coordinating and analysis center (RTI International). Briefly, the nuMoM2b study was a prospective cohort of nulliparous women (no prior delivery at ≥20 weeks gestational age), with a viable singleton pregnancy at the time of screening between 6^0–13^6 weeks' gestation. Study visits were conducted at 4 times antepartum (Visits 1–4): 6^0–13^6, 16^0–21^6 and 22^0–29^6 weeks' gestation as well as at the time of delivery. Data were collected through interviews, self-administered questionnaires, clinical measurements, ultrasounds, and medical records review to obtain pertinent demographic, psychosocial, dietary, physiologic, and outcome information. In addition, maternal serum, plasma, urine, and cervicovaginal fluid were collected at each visit; maternal blood for DNA was collected at Visit 1; and cord blood and placental samples were collected at delivery. All types of samples were stored in a repository for later use.

General Design of nuMoM2b Sleep Duration and Continuity Substudy

Women were recruited into the Sleep Duration and Quality Substudy at the second nuMoM2b study visit (16^0–21^6 weeks of gestation) from 2011 through 2013. As part of this nuMoM2b Substudy, women were asked to wear a wrist actigraphy monitor (Spectrum, Phillips Respironics) for 7 consecutive days and to complete a daily sleep log. The 7 days of rest–activity collection was completed prior to 23^0 weeks of gestation. Women were compensated for participation with a $20 gift card. All actigraphy data were scored by a central reading center located at Northwestern University. The primary aim of the Sleep Duration and Quality Substudy was to determine the association between sleep quality and the pregnancy outcomes of gestational hypertension, preeclampsia, and gestational diabetes.

Prior to participation in the Substudy, women gave written informed consent. The Substudy was approved by the Institutional Review Board at each of the participating sites and the data coordinating center prior to initiation.

Study Population

The nuMoM2b study protocol included nulliparous women who were at least 13 years of age, although, in the Sleep Duration and Continuity Substudy, participants under 18 years of age were excluded. The decision to include only those aged 18 years and older was made because sleep characteristics are significantly different between children (<18 years of age) and adults, and there were not a sufficient number of women less than 18 years of age to meaningfully adjust for this difference in analysis.[30–32] In addition, while the parent study included women with chronic hypertension, these women were excluded from this substudy, given the difficulty in accurately diagnosing a new-onset hypertensive disorder in women with preexisting hypertension. Women with preexisting diabetes were also excluded, as they cannot be diagnosed with gestational diabetes.

Demographic Characteristics

Except for gestational age at screening, baseline demographic data were collected in early pregnancy (6–13 weeks' gestation). Insurance status was created as follows: If the participant indicated that her health care was paid for by commercial health insurance/commercial Health Maintenance Organization, then insurance status was set to Commercial. Otherwise if the participant indicated that her health care was paid for by government insurance, military insurance, personal household income, or other, then insurance status was set to Government/Self-pay.

Sleep Log

Participants were asked to maintain daily sleep logs for 7 consecutive days and to record bedtime, wake time, total sleep time, sleep latency, wake after sleep onset (WASO), naps, any unusual events during the day or night, overall sleep quality, and whether it was a free day or work/school day. The sleep log was a modified version of the Karolinska Sleep Log.[33] Participants were instructed to complete the sleep log every day within 1 hour of waking. Participants were encouraged to keep the sleep log next to their place of sleep so that they would not forget to fill out the log each day. The first page of the sleep log packet was an example page, and study personnel were instructed to complete this page with the participant. Study personnel marked the rest of the pages with the date and day of the week when they should be completed.

Data from all sleep logs that were returned were entered by a research technician into a data management system developed and managed by RTI. Each entry was checked by a separate research assistant, and any disagreements between

initial data and quality control review were adjudicated by a third party.

Actigraphy

Participants were instructed that the rest–activity monitor should be worn on and securely fastened around the nondominant wrist, just as a "wrist-watch" would be worn. Participants were instructed to press the event markers when going to bed for their main sleep period (i.e., when turning off the light or trying to fall asleep), when waking up in the morning, and when taking naps or falling asleep for more than 5 minutes. An actigraphy recording was considered successful if, during the 7 days of the study, there were at least 5 primary sleep periods recorded (out of a possible 7), there was less than 4 hours of off-wrist time during the 24-hour periods containing the included primary sleep periods, and there was no off-wrist time during the sleep period. If a participant's study data did not meet these criteria, she was asked to wear the watch again for an additional week as long as the recording could be completed by 23^0 weeks. Actiwatches were configured using Actiware Sleep V5.59 (Phillips-Respironics, Mini Mitter, Bend, OR) to record epochs with a 30-second duration and the presence of red, green, and blue light. The activity threshold was set at medium (i.e., 40 activity counts).

Training of Study Personnel at Each Site

Study personnel from all study sites attended an in-person training session held at RTI before recruitment began to review the operation of study equipment and other study procedures. This session was conducted by study investigators and a representative from Phillips Respironics. Study personnel at all sites were certified by the Actigraphy Reading Center after passing a written test and demonstrating successful transmission of valid actigraphy data and sleep logs.

Analysis and Scoring of Actigraphy

All actigraphy files and sleep log data were securely transmitted to the Actigraphy Reading Center. Actigraphy data were analyzed with Actiware Sleep V5.59. Data were processed through the Actiware Sleep scoring algorithm. The default setting was used and is presented in this article. The default scoring algorithm was set with 10 minutes of immobile time for sleep start, in reference to the set rest start, and 10 minutes of immobile time for sleep end, in reference to the set rest end.

Scoring Method

The analysis algorithm calculates sleep/wake within defined rest intervals, and these rest intervals were manually set by a trained technician using the event markers (EM) and/or sleep log entries (SL) when available. If neither an event marker nor sleep log was available, or if either were clearly inaccurate, the trained technician set the rest interval based on a reduction in activity and light levels.[34,35] All technician-scored rest intervals were reviewed by another scorer.

Each rest interval start and end was given a value ranging from 1 to 4 (with "1" indicating the data with the best concordance) that coincided with the cues that were used to set that interval. For example, if there was good concordance between the event marker, sleep diary, and a drop in the activity level, the interval would be given a value of 1. The number of primary sleep periods for each code is presented in the results section, but they were not used in the analysis. Details of the criteria used to code the rest intervals are outlined below.

1. If the start and/or end of a given rest interval had a time from the event markers (EM) and the sleep log (SL) that were within 15 minutes of each other and the actual activity reflected rest, it was assigned a score of *1*.
2. If the start and/or end of a given rest interval had an EM that differed from the SL entry by more than 15 minutes, it received a score of *2* (*provided the EM was supported by activity level*).
3. If the start and/or end of a given rest interval had an SL that was in agreement with the drop in *activity level* and the EM was considered unreliable or absent, it received a score of *3*.
4. In situations where the EM and SL were (a) completely absent, (b) present but in poor agreement with the activity drop/rise, or (c) limited to only one EM or SL entry either at the beginning or at the end of the rest interval, it received a score of *4*. This score implies that the interval was set by the technician's judgment based on the information available.

In addition to activity level, the device has the capability of recording photopic light, so when a study was "level 4," the technician also used light level as a guide to set the rest intervals.[36] To illustrate, in order to set the start of the rest interval, the technician would coalesce the drop in light level with a sequential series of activity counts that were <200 for a 5-minute period.[37] Conversely, in order to determine the end of the rest interval, the first epoch in a consecutive 5-minute sequence of nonzero counts >200 was used along with an accompanying rise in light level.

Review of Actigraphy Scoring

All studies were scored by a single experienced technician (MH). For studies with minor (<30 minutes) disagreement between the EMs or SLs and with actual activity/light levels, a second trained scorer reviewed the study, and if there was further disagreement in the study score, the study was adjudicated further by the reading center director (KJR) who made the final decision on rest interval placement. For studies with more than 30 minutes disagreement between the EMs and SLs with actual activity/light levels, the reading center director made the final decision on rest interval placement (typically these would be given a scoring value of 4). Also, all intervals given a value/score of 4 were reviewed by the reading center director. As a final check, all scored actograms were printed in color and visually reviewed by the reading center director.

Actigraphy-Derived Sleep Variables

The primary and secondary measures used to assess the domains of sleep duration and sleep continuity were as follows: time in bed, sleep duration, sleep fragmentation index (FI), sleep efficiency, WASO, and sleep midpoint. Data from the primary sleep period from all available valid days were averaged to provide a single value for each measure for each participant.

Time in bed was defined as the time between the start and end of the rest interval. Sleep duration was defined as the total amount of time scored as sleep, by the Actiware algorithm, during the main sleep period. Insufficient sleep was defined as a mean of <7 hours of sleep/night in the main sleep period, based on the consensus statement given by the American Academy of Sleep Medicine and Sleep Research Society[31] and prior research by the authors.[38] Sleep fragmentation index, sleep efficiency, and WASO provide measures of sleep quality. The sleep fragmentation index is calculated as the proportion of all epochs from sleep onset to sleep offset with an activity count of 2 or greater plus the proportion of all bouts of immobility (activity count less than 2 in every epoch) that were 1 minute or less in duration.[39,40] Sleep efficiency is calculated as the proportion of time from rest start to rest end scored as sleep. WASO is the total amount of minutes spent awake between sleep onset and the end of the rest interval. Sleep midpoint is the clock time that represents the midpoint between the clock time of sleep onset and the clock time of sleep offset. For each woman, the standard deviation value of time in bed, sleep duration, and sleep midpoint was calculated across the week of recording.[41,42]

Sample Size for Primary Outcome Analysis

The primary outcome measures for the Sleep Duration and Continuity Substudy are maternal cardiovascular and metabolic morbidity related to pregnancy. The reported prevalence of gestational diabetes ranges from 1.4% to 14%, gestational hypertension from 4% to 6%, and preeclampsia from 3% to 8%.[43,44] From prior data, we estimated a prevalence of short sleep duration of 25%.[18] In nonpregnant individuals, short sleep duration has been associated with a 1.5- to 4-fold increased risk of cardiovascular and metabolic disease.[45,46] Power calculations for detectable effect sizes (relative risk) for short sleep duration assessed by actigraphy are presented in Table 1. The power calculations take into account an outcome prevalence of 8–12%, an N of 760 subjects, a 5% level of statistical significance (2-sided), and an R^2 value of 0.01 for the association between the categorical exposure and the covariates included in a logistic regression model.[47]

Table 1—Statistical Power for Detection of Effect Size (Relative Risk) for Short Sleep Duration (SSD).

Composite outcome rate		Difference in rates	Relative risk	Power[a]
Without SSD	With SSD			
0.08	0.12	50%	1.5	0.40
0.08	0.16	100%	2.0	0.86
0.10	0.15	50%	1.5	0.48
0.10	0.20	100%	2.0	0.93
0.12	0.18	50%	1.5	0.55
0.12	0.24	100%	2.0	0.97

[a]Assuming *N* = 760 participants included in the evaluation, 25% prevalence of SSD, an R^2 = 0.01 for association of SSD (categorical) with covariates included in the logistic regression model, and Type I error (2-sided) = 0.05.

Statistical Analysis

In this report, in addition to describing the study methods, we provide a descriptive analysis of the actigraphy data and examine sleep duration, sleep continuity, and sleep timing measures in relation to maternal age, race/ethnicity, body mass index (BMI), insurance status, and recent smoking history. Demographic characteristics were categorized and medians and interquartile ranges (IQRs) for sleep actigraphy measures were compared for each demographic characteristic tested using Kruskal-Wallis tests. For multivariable analyses, the main effects of association of the demographic characteristics with the sleep actigraphy measures were evaluated using F-tests associated with type III sums of squares from analysis of variance models. The actigraphy measures are analyzed on the original (time in bed and sleep duration) or, in some cases, a transformed scale to better satisfy normality assumptions of the model. For sleep fragmentation, WASO, and sleep midpoint, a log transform was used, while sleep efficiency was cubed. All tests were performed at a nominal significance level of $\alpha = .05$. No corrections are made for multiple comparisons. Analyses were conducted using SAS/STAT 9.3 and 9.4 software (SAS Institute Inc, Cary, North Carolina).

RESULTS

A total of 901 women in nuMoM2b enrolled in the Sleep Duration and Continuity Substudy. Valid actigraphy data were available for 782 (86.8%) women, 759 of whom also returned a sleep log (Table 2). There were 119 (13.2%) invalid studies. The two most frequent reasons for the invalid studies were participant noncompliance (60%, watch not worn at least 20 hours/day for at least 5 days) and watch failure (40%). Watch failure was primarily due to one of the following reasons: faulty off-wrist detection, a corrupted database, or constant low-level activity counts.

Baseline demographic characteristics of the 782 women with actigraphy data are presented in Table 3. The mean age of the women at entry into the Substudy was 27.3 years (standard deviation 5.5 years). Sixty-three percent (63.4%) of the women were non-Hispanic white, 11.8% were non-Hispanic black, 15.6% were Hispanic, 3.6% were Asian, and 5.6% were classified as "other" on race/ethnicity. Fourteen percent of the sample were neither employed or in school and 15% had less than a college education. Women were classified by their prepregnancy BMI as follows: 50.7% of women were normal

Table 2—Actigraphy Assessment.

Characteristic	*n* (%)
Eligible participants	901
Valid sleep actigraphy studies	782 (86.8)
Valid actigraphy with sleep log returned	759 (84.2)
Invalid actigraphy studies	119 (13.2)
Off wrist > 4 hours (participant noncompliance)	71 (60.0)
Watch failure	48 (40.0)

Table 3—Baseline Characteristics[a].

Characteristic (*N* = 782)	Statistic
Estimated gestational age at screening, *n* (%)	
<8 weeks 0 days	11 (1.4)
8 weeks 0 days to 9 weeks 6 days	78 (10.0)
10 weeks 0 days to 11 weeks 6 days	236 (30.2)
12 weeks 0 days to 13 weeks 6 days	457 (58.4)
Maternal age, years	
Mean (standard deviation)	27.3 (5.5)
Median (interquartile range)	27.0 (23, 31)
Category, *n* (%)	
<22	148 (18.9)
22–35	573 (73.3)
>35	61 (7.8)
Maternal race/ethnicity, *n* (%)	
Non-Hispanic white	496 (63.4)
Non-Hispanic black	92 (11.8)
Hispanic	122 (15.6)
Asian	28 (3.6)
Other	44 (5.6)
Maternal education status, *n* (%)	
Less than high school	28 (3.6)
Completed high school or GED	89 (11.4)
Some college	176 (22.5)
Associate or technical degree	87 (11.1)
Completed college	210 (26.9)
Degree work beyond college	192 (24.6)
Employment/school status, *n* (%)	
Employed and in school	116 (15.6)
Employed and not in school	474 (63.9)
Unemployed and in school	48 (6.5)
Unemployed and not in school	104 (14.0)
Insurance status, *n* (%)[b]	
Government insurance	188 (24.2)
Military insurance	2 (0.3)
Commercial health insurance	564 (72.5)
Personal household income	150 (19.3)
Other	9 (1.2)
BMI	
Underweight (<18.5)	21 (2.7)
Normal Weight (18.5–24.9)	391 (50.7)
Overweight (25.0–29.9)	194 (25.1)
Obese (30.0–34.9)	98 (12.7)
Morbidly Obese (>35)	68 (8.8)
Ever smoked, *n* (%)	322 (41.2)
Smoked during 3 months prior to pregnancy, *n* (%)	113 (14.5)
Among smokers during 3 months prior to pregnancy	
Cigarettes per day: n (%)	
<20 cigarettes per day	99 (87.6)
20–40 cigarettes per day	14 (12.4)
>40 cigarettes per day	0 (0.0)

Abbreviation: BMI, body mass index.
[a]Except for gestational age at screening, baseline data were collected in early pregnancy (6–13 weeks' gestation).
[b]Percentages do not add up to 100% as participants were allowed to select multiple methods of payment for healthcare.

weight (BMI 18.5–24.9 kg/m^2), 25.1% were overweight (BMI 25.0–29.9 kg/m^2), 21.5% were obese or morbidly obese (BMI ≥ 30 kg/m^2), and 2.7% were underweight (BMI < 18.5 kg/m^2). Approximately fourteen percent (14.5%) of the participants smoked during the 3 months prior to the pregnancy.

A summary of the characteristics of weekday/weekend, work/school, and nonwork/nonschool day, and scoring methods is provided in Table 4. Seventy-seven percent of women contributed 7 valid days of actigraphy data. Seventy-nine percent of women had actigraphy data collected on at least one work/school day. Only 2% of the sample had no data collected on nonwork/nonschool days. Of a total of 5253 primary sleep periods, 85% had an event marker and/or sleep log entry for scoring and 15% required technician only scoring.

Actigraphic measures of sleep duration, continuity, timing, and variability stratified by age, race, BMI, insurance status, and recent smoking history are provided in Tables 5 and 6. Overall, the median (IQR) of time in bed was 8.7 (1.1) hours and of sleep duration was 7.4 (1.0) hours, with 42.2 (23.4) minutes of WASO and a sleep midpoint of 3:38 am (100 minutes). Twenty-eight percent (27.9%) of women had a sleep duration of <7 hours and 2.6% had a sleep duration of >9 hours. Time in bed was associated with age and insurance status; it was longer for younger women and those with government/self-pay insurance. Sleep duration was significantly different by race/ethnicity, with non-Hispanic blacks and Asian women having the shortest sleep durations. The three measures of sleep continuity (sleep fragmentation, sleep efficiency, wake after sleep onset) and sleep midpoint were significantly related to all demographic characteristics (maternal age, BMI, race/ethnicity, insurance status, and recent smoking history).

The standard deviation as a measure of variability in sleep across the recording period was also assessed for time in bed, sleep duration, and sleep midpoint for each individual and stratified by baseline characteristics and is provided in Table 6. In the overall sample, more than 50% of women had a standard deviation in sleep duration that was over an hour across the week of recording, while sleep midpoint varied by more than 40 minutes. The three measures of sleep variability included in this analysis were significantly related to all demographic

Table 4—Actigraphy Data Quality Summary.

Characteristic			Statistic
Valid number of days recorded for *n* = 782 participants			
Total	n (%)	5	41 (5)
		6	139 (18)
		7	602 (77)
	Mean (SD)		6.7 (0.6)
Work/school days:	*n* (%)	None	164 (21)
		1-3	199 (25)
		4 or more	419 (54)
	Mean (SD)		3.1 (2.0)
Nonwork/school days:	*n* (%)	None	16 (2)
		1-2	295 (38)
		3 or more	471 (60)
	Mean (SD)		3.6 (2.0)
Week days:	*n* (%)	3	25 (3)
		4	125 (16)
		5	631 (81)
		6	1 (0)
	Mean (SD)		4.8 (0.5)
Weekend days:	*n* (%)	0	1 (0)
		1	51 (7)
		2	724 (93)
		3	6 (1)
	Mean (SD)		1.9 (0.3)
Score method summary for *n* = 5,253 primary sleep intervals, *n* (%)			
Matching marker and diary (1) used for start and end			1774 (34)
Marker (2) used for start & end			1207 (23)
Diary (3) used for start & end			1102 (21)
Different method (marker/diary) used for start & end			361 (7)
Technician (4) assigned start & end			809 (15)

characteristics examined including maternal age, BMI, race/ethnicity, insurance status, and recent smoking history.

After adjustment for the other baseline characteristics (age, race/ethnicity, education, employment, insurance status, BMI, and recent smoking history), time in bed remained associated with insurance status, and sleep duration remained associated with race/ethnicity and insurance status. Sleep midpoint and all sleep continuity measures (with the exception of age for sleep fragmentation index and smoking for wake after sleep onset) remained associated with age, race/ethnicity, BMI, insurance status, and recent smoking history.

After adjustment, the standard deviation of time in bed and sleep duration remained significantly associated with all of the baseline characteristics (age, race/ethnicity, BMI, and recent smoking history) except insurance status while for the standard deviation of sleep midpoint only age remained significant.

DISCUSSION

In this initial report of the nuMoM2b Sleep Duration and Continuity Substudy, we have provided a descriptive analysis of our actigraphy data. Our results demonstrate the relationship between sleep variables and important baseline demographic characteristics.

Sleep disturbance is common in pregnancy[18]; however, there are limited objective sleep data available in this population. The current study represents one of the largest cohorts of objectively measured habitual sleep in pregnancy to date. Although the women in this study spent a median of 8.7 hours in bed for their primary sleep period each day, sleep efficiency was low, with a median sleep duration of 7.4 hours. In addition, sleep continuity and midpoint were significantly associated with age, BMI, race/ethnicity, insurance status, and recent smoking history; sleep duration varied only by race/ethnicity and insurance status.

Several studies have now shown that in nonpregnant adults both long (i.e., >8.5 hours) and short sleep duration (i.e., < 7 hours) are associated with poor cardiometabolic health.[13,31] There is also some evidence, from small studies using self-reported sleep measures, to suggest that short sleep is associated with an increased frequency of poor pregnancy outcomes.[38,48] Although the sleep duration in this cohort is longer than that reported for pregnant women in other studies,[24,26] of note is that 27.9% of the women in this cohort had a sleep duration of <7 hours, and 2.9% had a sleep duration of > 9 hours. In a recent consensus statement given by the American Academy of Sleep Medicine and Sleep Research Society, it is recommended that adults regularly obtain 7 or more hours of sleep a night to promote optimal health.[31]

Sleep duration is not the only measure of sleep health.[27] Disrupted sleep continuity may be just as important a risk factor for poor cardiometabolic health as short sleep duration. In healthy young adults, experimental fragmentation of sleep, without a reduction in sleep duration, has been shown to be associated with alterations in glucose metabolism.[49] In other population-based studies using actigraphy, fragmentation index (FI) has also been associated with significant differences in measures of metabolic function such as fasting insulin and glucose as well as insulin resistance.[50] There are several ways to measure sleep continuity and in this study, we report WASO, fragmentation index, and sleep efficiency.

Women in this study spent a relatively long time in bed attempting to sleep, with WASO accounting for the majority of the difference between time in bed and sleep duration. In fact, 50% of the sample had a WASO of >42 minutes. In pregnant women, a WASO ≥30 minutes has been shown to be associated with significant alterations in blood pressure.[24] Other studies of adults have shown that a long WASO is associated with depressive symptoms and cognitive decline. While WASO is a useful measure, it simply reflects how much time a person spent awake

Table 5—Actigraphic Measures of Sleep Duration and Continuity Averaged Over 7 Days by Baseline Characteristics.

Baseline characteristic	Sample size	Time in bed, hours		Sleep duration, hours		Sleep fragmentation index		Sleep efficiency, %		Wake after sleep onset, minutes		Sleep Midpoint, hours:minutes	
		Median (IQR)	p[a]	Median (IQR)	p[a]	Median (IQR)	p[a]	Median (IQR)	p[a]	Median (IQR)	p value[a]	Median (IQR)	p value[a]
Overall	782	8.7 (1.1)		7.4 (1.0)		17.5 (7.6)		85.2 (6.9)		42.2 (23.4)		3:38 (1:40)	
Maternal age, years													
<22	148	9.1 (1.3)	<.0001	7.4 (1.1)	.5063	19.7 (8.7)	<.0001	82.0 (7.3)	<.0001	50.9 (31.3)	<.0001	4:33 (1:40)	<.0001
22–35	573	8.6 (1.1)		7.5 (0.9)		17.0 (7.2)		85.8 (6.2)		40.6 (21.1)		3:25 (1:28)	
>35	61	8.6 (1.1)		7.3 (0.8)		18.6 (8.2)		84.6 (6.7)		42.9 (20.9)		2:59 (1:19)	
Race/ethnicity													
Non-Hispanic white	496	8.7 (1.0)	.1140	7.5 (0.9)	<.0001	16.4 (6.9)	<.0001	86.6 (5.5)	<.0001	39.9 (20.0)	<.0001	3:19 (1:19)	<.0001
Non-Hispanic black	92	8.9 (1.5)		7.1 (1.0)		21.5 (7.8)		80.6 (6.5)		54.6 (30.4)		4:20 (1:54)	
Hispanic	122	8.8 (1.1)		7.4 (1.0)		18.5 (7.4)		83.4 (7.6)		47.0 (30.4)		4:15 (2:11)	
Asian	28	8.5 (1.3)		7.0 (1.0)		18.3 (8.1)		82.9 (7.8)		43.9 (21.8)		3:41 (1:23)	
Other	44	8.7 (1.4)		7.4 (1.3)		18.1 (9.5)		83.1 (7.4)		45.8 (24.6)		4:00 (2:02)	
BMI, kg/m^2													
<18.5	21	9.0 (1.1)	.0939	7.7 (0.8)	.3279	17.9 (8.8)	<.0001	84.5 (7.9)	<.0001	42.9 (35.7)	<.0001	5:04 (2:07)	.0029
18.5 to <25	391	8.6 (1.0)		7.4 (0.9)		16.7 (7.3)		85.6 (6.9)		39.4 (20.9)		3:33 (1:22)	
25 to <30	194	8.8 (1.1)		7.5 (0.9)		17.5 (6.8)		86.0 (5.7)		42.8 (20.3)		3:34 (1:41)	
30 to <35	98	8.7 (1.3)		7.5 (1.0)		18.4 (7.3)		84.6 (6.6)		42.3 (21.8)		3:52 (2:02)	
≥35	68	8.8 (1.4)		7.1 (1.2)		20.9 (7.5)		81.8 (7.8)		54.7 (26.4)		3:48 (2:26)	
Insurance Status													
Commercial	564	8.6 (1.1)	<.0001	7.4 (0.9)	.2713	16.5 (7.1)	<.0001	86.2 (6.2)	<.0001	39.6 (19.7)	<.0001	3:19 (1:19)	<.0001
Government/ Self-pay	214	9.0 (1.3)		7.5 (1.2)		19.8 (7.3)		82.1 (7.5)		51.7 (29.2)		4:30 (1:54)	
Smoked during 3 months prior to pregnancy:													
Yes	113	8.8 (1.4)	.0818	7.3 (1.3)	.4537	19.5 (7.7)	<.0001	83.1 (6.0)	<.0001	48.3 (21.1)	<.0001	4:25 (2:15)	<.0001
No	669	8.7 (1.1)		7.5 (0.9)		17.0 (7.5)		85.6 (6.9)		41.0 (22.7)		3:32 (1:28)	

Abbreviation: BMI, body mass index; IQR, Interquartile range.
[a]The p values associated with Kruskal-Wallis tests.

after initially falling asleep, and it does not provide information on how fragmented the sleep was during this time. For example, a person who is awake for 50 consecutive minutes, and a person awake 10 times for 5 minutes each time, would both have a WASO of 50 minutes. The consequences for sleep architecture in these scenarios is likely considerably different. The FI is an additional measure of the degree of sleep disturbance that has been shown to be associated with cardiometabolic health. The median FI in the nuMoM2b Substudy was 17.5%. In a group of diabetic women with a mean FI of 20%, a 10% increase in FI was associated with 43% greater insulin resistance even in a fully adjusted model.[50]

In addition to sleep duration and continuity, there are other measures of sleep that have been shown to be associated with health and health behaviors, such as sleep timing and variability in sleep measures from day-to-day. The median sleep midpoint, a measure of sleep timing, reported in this study of pregnant women is similar to that previously reported for adults,[15,51] while the variability in sleep duration and timing are similar to that reported in older adults with insomnia.[41,42]

In addition to describing sleep during pregnancy the nuMoM2b Substudy examined, the association between sleep duration, sleep timing, and continuity and key demographic factors, including age, race/ethnicity, BMI, insurance status, and prepregnancy smoking. Sleep duration was not associated with most demographic characteristics other than race/ethnicity and insurance status after adjustment. However, there was an association between sleep continuity, timing and variability, and demographic characteristics. For example, while after adjustment, age was not significantly associated with sleep duration,

Table 6—Actigraphic Measures of Variability in Sleep Duration and Timing Averaged Over 7 Days by Baseline Characteristics.

Baseline characteristic	Sample size	Standard deviation of time in bed, minutes		Standard deviation of sleep duration, minutes		Standard deviation of sleep midpoint, minutes	
		Median (IQR)	p[a]	Median (IQR)	p[a]	Median (IQR)	p[a]
Overall	782	67.9 (47.9)		62.6 (41.6)		48.6 (32.6)	
Maternal age, years							
<22	148	90.2 (51.1)	<.0001	81.3 (50.4)	<.0001	61.0 (38.2)	<.0001
22–35	573	64.8 (46.4)		58.4 (38.7)		47.2 (31.8)	
>35	61	61.0 (34.0)		56.7 (29.0)		43.2 (23.9)	
Race/ethnicity							
White Non-Hispanic	496	61.8 (44.2)	<.0001	57.5 (36.8)	<.0001	46.1 (31.7)	<.0001
Black Non-Hispanic	92	90.4 (52.6)		80.5 (47.7)		59.4 (35.6)	
Hispanic	122	81.1 (46.4)		72.5 (43.8)		53.3 (28.6)	
Asian	28	67.7 (26.6)		62.4 (29.5)		45.6 (25.9)	
Other	44	75.6 (51.5)		75.4 (54.8)		52.2 (43.7)	
BMI, in kg/m^2							
<18.5	21	85.1 (46.9)	<.0001	68.8 (48.1)	.0002	46.5 (25.4)	.0499
18.5 to <25	391	64.8 (44.4)		59.6 (36.5)		47.5 (32.0)	
25 to <30	194	67.8 (45.2)		61.8 (40.7)		47.9 (34.1)	
30 to <35	98	72.9 (53.3)		66.1 (51.5)		52.8 (36.5)	
≥35	68	94.0 (63.5)		82.4 (47.4)		53.8 (43.2)	
Insurance status							
Commercial	564	63.6 (43.6)	<.0001	58.4 (36.0)	<.0001	47.3 (32.2)	.0056
Government/Self-pay	214	87.5 (54.0)		77.9 (53.5)		52.2 (37.4)	
Smoked during 3 months prior to pregnancy							
Yes	113	80.5 (56.3)	.0002	74.2 (50.9)	<.0001	54.9 (34.0)	.0059
No	669	66.8 (47.3)		60.7 (39.2)		47.8 (33.2)	

Abbreviation: BMI, body mass index; IQR, Interquartile range.
[a]The p values associated with Kruskal-Wallis tests.

younger women (<22 years) had the highest WASO, lowest sleep efficiency, latest sleep midpoint, and most variable sleep.

Non-Hispanic black and Asian women had the shortest sleep duration, and non-Hispanic black women also had the worst sleep continuity and latest sleep midpoint. Our findings are in agreement with similar results from nonpregnant cohorts.[52–54] Adverse pregnancy outcomes such as preeclampsia and preterm birth are also more common among black women.[55,56] The racial differences we documented in sleep duration, continuity, and timing may be contributing factors in this important health disparity.

Women who were obese (BMI ≥35) at screening had high sleep fragmentation, low sleep efficiency, and a long WASO; while sleep duration was not associated with BMI, obese women had a median sleep duration that was 36 minutes less than the lowest BMI group. It is possible given that obesity is a risk factor for sleep disordered breathing (SDB) that the level of sleep disturbance in the obese group could be due to SDB[57] which was not assessed as part of this Substudy. In contrast, women with a low BMI (<18.5) had the longest sleep duration but latest sleep midpoint by almost 1.5 hours.

Health-related behavior, like smoking in the 3 months prior to pregnancy, was not significantly associated with sleep duration, but it was associated with higher FI, lower sleep efficiency, later sleep midpoint, and greater variability in sleep duration after controlling for other factors. Overall, these findings suggest that demographic characteristics are associated with sleep characteristics and should be considered when examining sleep during pregnancy.

While this is one of the first large-scale studies to systematically measure objective sleep during pregnancy using actigraphy, we recognize the limitations of the study. The gold standard for documenting sleep is polysomnography (PSG). The correlation between actigraphy and PSG in measuring sleep duration has been shown to be high (0.7–0.97), and actigraphy is considered by the American Academy of Sleep Medicine to be a valid method to determine sleep patterns in healthy adult populations.[58]

However, actigraphy does not measure sleep or wake directly and does not differentiate sleep stages. Given feasibility constraints and the advantages of having multiple day recordings, we believe that collecting sleep data with actigraphy is an appropriate method and provides reliable information on habitual sleep patterns. A further limitation of this study is that the study design does not allow us to address the underlying cause of the sleep disturbance, which could be addressed in future studies.

This article also adds to the literature by describing the general level of compliance with actigraphy (i.e., wearing the watch successfully) during the second trimester of pregnancy, including the use of markers (i.e., event markers and daily sleep logs) to determine rest intervals. The majority (85%) of rest intervals had a useful marker at both the beginning and the end of the rest interval. Overall, with minimal incentive more than 85% of the women enrolled were able to provide usable data, suggesting that actigraphy can be used successfully on a large scale to determine objective sleep in this population.

Given that the degree of sleep disturbance has been shown to vary as pregnancy progresses,[18] assessing sleep at a single point in pregnancy could be considered a limitation. However, while objective assessment of sleep across pregnancy may be advantageous, there are several reasons why sleep duration and continuity in the second trimester is likely to be important. First, studies have shown that many important physiological events (e.g., remodeling of maternal vessels and trophoblastic invasion) take place in the first and second trimester and that early changes in inflammatory, oxidative stress and metabolic pathways can adversely affect these physiologic processes and thereby lead to abnormal pregnancy development.[59,60] Second, assessment too early (i.e., first trimester) might have decreased our ability to capture sleep disturbances that develop during the early second trimester, as sleep often worsens as pregnancy progresses. Therefore, assessment of sleep in the mid-second trimester likely represents a time period when the probability of sleep disturbance is prevalent and yet early enough for assessing/screening for sleep problems to initiate interventions that optimize sleep.

In summary, in the second trimester of nulliparous pregnancy, sleep duration varies by race/ethnicity and insurance status, while sleep continuity and timing measures vary by race/ethnicity, age, BMI, insurance status, and recent smoking history. Given the known associations of short sleep duration, poor sleep continuity, and later sleep timing with poor cardiometabolic health, further analysis of this cohort to investigate the association between sleep and adverse cardiometabolic maternal and fetal pregnancy outcomes and how these may be influenced by demographic characteristics is warranted.

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Not applicable.

CONFLICTS OF INTEREST

Basner, Wing, Facco, Grobman, Reid, Parker, Hunter, Iams, Herbas, Saade, Pien, Manchanda, Haas, Chung, Silver, Louis, Nhan-Chang, Simhan, and Parry have nothing to report. Zee reports receiving grant support from Jazz and Technogel and is a consultant for Merck, Eisai, Philips, and Teva none of these activities are related to this manuscript. Also see COI forms for authors.