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Sleep Duration during Pregnancy using an Activity Tracking Device

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Abstract

Objective The aim of this study was to describe sleep duration across gestation in women who wore an activity-tracking device (ATD) during pregnancy, and to study the association between sleep duration and adverse maternal and neonatal outcomes

Study Design Women ≥ 18 years old who owned a smartphone were approached to participate in 2016 to 2017. Participants received instructions to wear and sync an ATD daily. Steps, sedentary hours, and sleep duration were wirelessly transmitted via cellular technology. We measured sleep duration for the main episode of sleep and excluded sleep times < 120 minutes. Mixed models were used to assess the trajectory of mean weekly hours of sleep by gestational age. Secondary analyses evaluated differences in pregnancy outcomes between insufficient ($< 7/24$ hours) and sufficient sleep ($\geq 7/24$ hours) groups, based on mean hours of sleep within the first 7 days of ATD use.

Results The majority of 94 participants self-reported minority racial–ethnic status (33% non-Hispanic black and 51% Hispanic), had government insurance (83%), were nulliparous (61%), and had pre-pregnancy overweight or obesity (56%). The mean (standard deviation) duration of sleep was 7.2 ± 2.4 hours per 24 hours. In mixed models analyses, gestational age was statistically significantly associated with mean hours of sleep ($\beta = -0.02$; 95% confidence interval: -0.04 to -0.01; $p < 0.001$). Women who had < 7 hours of sleep had greater median daily steps compared with those who had ≥ 7 hours of sleep (median: 7,122; interquartile range [IQR]: 5,167–8,338 vs. median: 5,005; IQR: 4,115–7,059; $p < 0.01$), but there were no significant differences in other outcomes (sedentary time, gestational weight gain, pregnancy associated hypertension, gestational diabetes, gestational age at delivery, cesarean delivery, or mean birthweight), $p > 0.05$ for all comparisons.

Conclusion The mean sleep duration was 7.2 ± 2.4 hours among the 94 women in this cohort and decreased with advancing gestational age. Further research is required to evaluate sleep measurements with ATD in pregnant women and how sleep duration and quality is related to maternal and neonatal outcomes.

Keywords
- pregnancy
- sleep
- activity tracking device

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Disordered and deficient sleep is common during pregnancy and linked with several adverse outcomes,[1,2] yet sleep disorders are often dismissed as an expected physiological change in pregnancy. Furthermore, measures of sleep during pregnancy are often limited to self-reported surveys which may overestimate sleep duration compared with objective measures.[1,3] However, laboratory-based sleep studies such as polysomnography (PSG) may not reflect free-living conditions. Commercially available activity tracking devices (ATD) have the capability not only to measure activity including steps taken, heart rate, and energy expenditure but also to measure sleep duration. However, prior studies of ATD use in pregnancy have not evaluated sleep duration.[4–6]

The primary objective of this study was to describe sleep duration, as measured by the main sleep event in a 24-hour period, across gestation in women who wore a commercially available ATD during pregnancy. A secondary objective was to study the association between sleep duration and adverse maternal and neonatal outcomes such as excessive gestational weight gain, pregnancy associated hypertension, and birthweight. We hypothesized that women with <7 hours of sleep per 24 hours would have more frequent adverse outcomes compared with those with ≥ 7 hours per 24 hours.

Materials and Methods

For this study, women who were enrolled in prenatal care at one of two sites (one federally qualified health center and one academic medical center with an outpatient clinic, both located in Chicago, IL) were approached during their prenatal visit and asked to participate in a study about "activity monitoring devices and pregnancy." Other inclusion criteria were English or Spanish speaking, $\geq$18 years old, and personal ownership of a smartphone. Exclusion criteria were restrictions or inability to exercise, defined as at least 30 minutes of walking per day. The study period extended from April 2016 to December 2017.

After written informed consent was obtained, participants chose a wrist Fitbit Flex (San Francisco, CA) (i.e., the ATD) in their color preference. In-person instructions were given on how to install the ATD app on their smartphone, charge and sync the ATD, wear the ATD, and interpret the ATD data from the dashboard. Members of the research team registered the participants' ATD online and created user accounts authorizing access to the ATD data for the research personnel. The user accounts were available in both English and Spanish according to the participants' preferences. No specific instructions were given regarding sleep monitoring. Steps, sedentary hours, and total sleep duration in hours were wirelessly transmitted via cellular and bluetooth technology and plotted on a graph in the ATD app that participants could view on their device or personal dashboard at all times (e.g., participants not blinded to data). Members of the research team contacted the participant via text, phone calls, or email if more than 72 hours lapsed since the ATD was synced. In-person visits with the research team also occurred when these contact methods were not successful. Lost, stolen, or broken ATDs were not replaced. The research team provided technical support for the ATD throughout the pregnancy with text messages, phone calls, emails, or in-person troubleshooting sessions.

The total sleep duration in hours was measured from the main sleep episode in a 24-hour period. Other sleep episodes that were shorter in duration, which may have represented naps, were not included in the total sleep duration measure. Also, we did not evaluate when the main sleep episode occurred (e.g., daytime vs. nighttime). Similar to Xu et al, we required that a minimum value to count a record as having sufficient sleep data was more than 2 hours, but there was no upper limit on the maximum amount of hours of sleep per day.[7] For primary analyses, we averaged all sleep times meeting these criteria by gestational week for each participant.

We calculated descriptive statistics for all variables of interest. Categorical variables were summarized with frequencies and percentages, and continuous variables were summarized with means and standard deviations or medians and interquartile ranges, as appropriate. Primary analyses utilized mixed effect models to examine the trajectory of mean weekly hours of sleep by gestational age. Specifically, models included a fixed effect for gestational age and a random subject effect to account for repeated measures. We evaluated whether site should be included as a fixed effect, with the plan to retain it in the multivariable models if it was significantly associated with sleep duration.

Insufficient sleep was defined as <7 hours in a 24-hour period per the American Academy of Sleep Medicine and Sleep Research Society.[8] Secondary analyses evaluated differences in pregnancy outcomes between insufficient and sufficient sleep groups, based on mean hours of sleep within the first 7 days of ATD use. Women were included in the secondary analyses if they had at least two main sleep observations within the first 7 days. The means of the sleep times for each possible day were calculated to determine if the sleep time was <7 or ≥ 7 hours. Sedentary minutes were defined as <1.5 metabolic equivalents (METs), such as seated activities, according to the manufacturer's descriptions. In the secondary analyses, we assessed whether activity (daily steps and sedentary time) and pregnancy outcomes (total gestational weight gain, gestational weight gain categories, gestational diabetes, pregnancy associated hypertension, cesarean delivery, and birthweight) differed between women with <7 hours and women with ≥ 7 hours of sleep during the first week of ATD use with either *t*-tests or Wilcoxon's rank sum tests for continuous predictors and Chi-square or Fisher's exact tests as appropriate.

All analyses assumed a two-sided type one error rate of 0.05. Analyses were performed with SAS, version 9.4. The study was approved was the Northwestern University and the Erie Family Health Center Institutional Review Board.

Results

Of the 174 women approached at both clinical sites, 75 declined to participate and 7 were lost to follow-up, leaving 94 women with at least 1 day of ATD data available. These 94 women had a median of 24.5 sleep observations meeting inclusion criteria. The majority of the participants self-reported as belonging to a minority group (33% non-Hispanic black and 51% Hispanic), had government insurance (83%), were nulliparas (60%), and were enrolled in the second trimester (79%) (►**Table 1**). Most women also were overweight or obese prior to pregnancy (56%), felt "very comfortable using a computer or the internet" (84%), and rarely exercised every day prior to pregnancy (9.6%).

The mean sleep duration was 7.2 ± 2.4 hours with a median of 7.3 and an interquartile range (IQR) of 5.67 to 8.55 per 24 hours. ►**Fig. 1** shows the observed longitudinal trends in mean hours of sleep, averaged across women, by gestational age. There was no significant difference in sleep duration by site (p-value = 0.26), and thus, remaining analyses did not include site as a fixed effect. Mixed model analyses showed that gestational age had a significant inverse association with mean hours of sleep ($\beta = -0.02$, 95% confidence interval [CI]: −0.04 to −0.01, and p-value < 0.001, ►**Fig. 2**). After adjustment for possible confounders such as age, race–ethnicity, employment status, marital status and pre-pregnancy obesity, the association between gestational age, and sleep duration remained significant ($\beta = -0.02$, 95% CI: −0.04 to −0.01, and p-value < 0.001).

A total of 11 (12%) of the original 94 participants were excluded from further analyses of outcomes as they did not have at least two sleep records within the first 7 days of Fitbit use. A total of 30 (36.1%) women had < 7 hours and 53 (63.9%) had ≥ 7 hours of sleep during the first week of ATD use. Eligible women who had <7 hours of sleep had greater mean number of steps compared with those who had ≥ 7 hours of sleep (median: 7,122; IQR: 5,167–8,338 vs. median: 5,005; IQR: 4,115–7,059; p-value < 0.01). Conversely, there were no significant differences in other activity or pregnancy outcomes (sedentary time, median gestational weight gain, pregnancy associated hypertension, gestational diabetes, median gestational age at delivery, cesarean delivery, or mean birthweight; ►**Table 2**).

Discussion

In this study of ATD use in 94 women who were predominantly nulliparas and overweight or obese prior to pregnancy, we found that the mean duration of the main sleep episode in a 24-hour period was 7.2 ± 2.4 hours and decreased over gestational age. Our findings are similar to studies that have used actigraphy during pregnancy. In an actigraphy-based study of 80 low-income pregnant women, mean sleep duration recorded by actigraphy was 6.8 hours.[3] In another study, the mean second-trimester sleep duration was 6.6 hours.[9] In the Nulliparous Pregnancy Outcomes Study: monitoring mothers-to-be (nuMoM2b) sleep activity substudy, 782 women wore a wrist activity monitor and completed a sleep log for 7 consecutive days. Their median actigraphy-recorded sleep duration was 7.4 hours, with 27.9% having a sleep duration <7 hours. Age, race-ethnicity, BMI, insurance, and recent smoking history were significantly associated with sleep duration in multivariable models.[10]

Self-reported sleep data were not available for the current study, but our findings are also similar to data derived from sleep questionnaires or sleep logs. For example, Facco et al

Table 1 Maternal demographics and characteristics

Variable	Response
Age (y) (mean ± SD)	26.2 ± 5.2
Race-ethnicity, *n* (%)	
Asian American	2 (2.1)
Black/African American	31 (33.0)
Hispanic/Latino	48 (51.1)
White or European American	4 (4.3)
Other/unknown	9 (9.6)
Education, *n* (%)	
Grades 9–11	3 (3.2)
High school graduate/GED	26 (27.7)
Some college/technical school	40 (42.6)
Four year college degree or more	14 (14.9)
Unknown	11 (11.7)
Health insurance, *n* (%)	
Medicaid or Medicare	73 (77.7)
Private insurance	5 (5.3)
Other/unknown	16 (17.0)
Employed outside of the home for a salary, *n* (%)	
Yes	45 (47.9)
No	38 (40.4)
Unknown	11 (11.7)
Marital status, *n* (%)	
Married	22 (23.4)
Single	30 (31.9)
Living with partner, but not married	31 (33.0)
Unknown	11 (11.7)
Nullipara, *n* (%)	57 (60.6)
Gestational age at enrollment (wk) (mean ± SD)	17.5 ± 5.4
Trimester at enrollment, *n* (%)	
First	14 (14.9)
Second	74 (78.7)
Third	6 (6.4)
Pre-pregnancy BMI kg/m^2 (mean ± SD)	28.3 ± 7.4
Pre-pregnancy BMI, *n* (%)	
Underweight: BMI < 18.5 kg/m^2	12 (12.8)
Normal: 18.5 ≤ BMI < 25 kg/m^2	29 (30.9)
Overweight: 25 ≤ BMI < 30 kg/m^2	24 (25.5)
Obese: BMI ≥ 30 kg/m^2	29 (30.9)
History of regular cigarette use, *n* (%)	
Yes	12 (12.8)
No	73 (77.7)
Unknown	9 (9.6)
Self-reported daily internet use, *n* (%)	76 (80.9)

(*Continued*)

Table 1 (*Continued*)

Variable	Response
Self-reported "very comfortable" using a computer and/or the internet, *n* (%)	79 (84.0)
Type of smartphone owned, *n* (%)	
iPhone	55 (58.5)
Android	29 (30.9)
Other/unknown	10 (10.6)
"Before pregnancy, how much did you exercise?," *n* (%)	
Not at all	16 (17.0)
Occasionally	27 (28.7)
Once a month	5 (5.3)
Once a week	9 (9.6)
More than 1 time a week	20 (21.3)
Everyday	9 (9.6)
Unknown	8 (8.5)

Abbreviations: BMI, body mass index; GED, general equivalency development; SD, standard deviation.

evaluated 189 nulliparous women with several sleep questionnaires and compared differences in baseline and third trimester sleep characteristics.[11] Mean sleep duration was significantly shorter in the third trimester compared with baseline (7.0 ± 1.3 vs. 7.4 ± 1.2 hours, p-value < 0.001). Overall poor sleep quality, as defined by a Pittsburgh Sleep Quality Index score greater than 5, also was more common as pregnancy progressed (39.0 vs. 53.5%, p-value = 0.001).

In nonpregnant populations, poor sleep quality and quantity is associated with significant morbidities including obesity, diabetes, pregnancy associated hypertension, as well as mortality.[12–15] We found no differences in maternal and neonatal outcomes between women with < 7 and ≥ 7 mean hours of sleep in the first week of ATD use, but we also realize the low frequency of several outcomes such as hypertensive disorders of pregnancy and gestational diabetes which limits the power to detect differences between the groups.

The gold standard for documenting sleep is PSG. The correlation between actigraphy and PSG in measuring sleep duration is high (0.7–0.97), and the American Academy for Sleep Medicine considers actigraphy to be a valid method to measure sleep patterns in healthy adults.[8] The mechanism for how the Fitbit ATD measures activity and sleep is proprietary and not available for a commercial user; however, most ATD use a three-axis microelectromechanical systems (MEMS) accelerometer that measures acceleration caused by movement of the accelerometer unit along three axes.[16] The Fitbit Flex device has been validated for measuring sleep against PSG in a healthy adult population, with a correlation of $r = 0.96$ for total sleep time.[17] However, other studies have reported differences in sleep measures between PSG, actigraphy, and Fitbits. In one study evaluating the accuracy of Fitbit in determining various sleep parameters, Montgomery-Downs et al compared Fitbit against PSG and actigraphy in 24 healthy adults (mean age = 26.1; range = 19–41 years) with no history or symptoms of sleep disorders. Fitbit and actigraphy differed significantly from PSG and from each other (p-value < 0.001; d = 1.6). Fitbit overestimated total sleep time by 67.1 ± 51.3 minutes compared with PSG. Fitbit also overestimated total sleep time compared

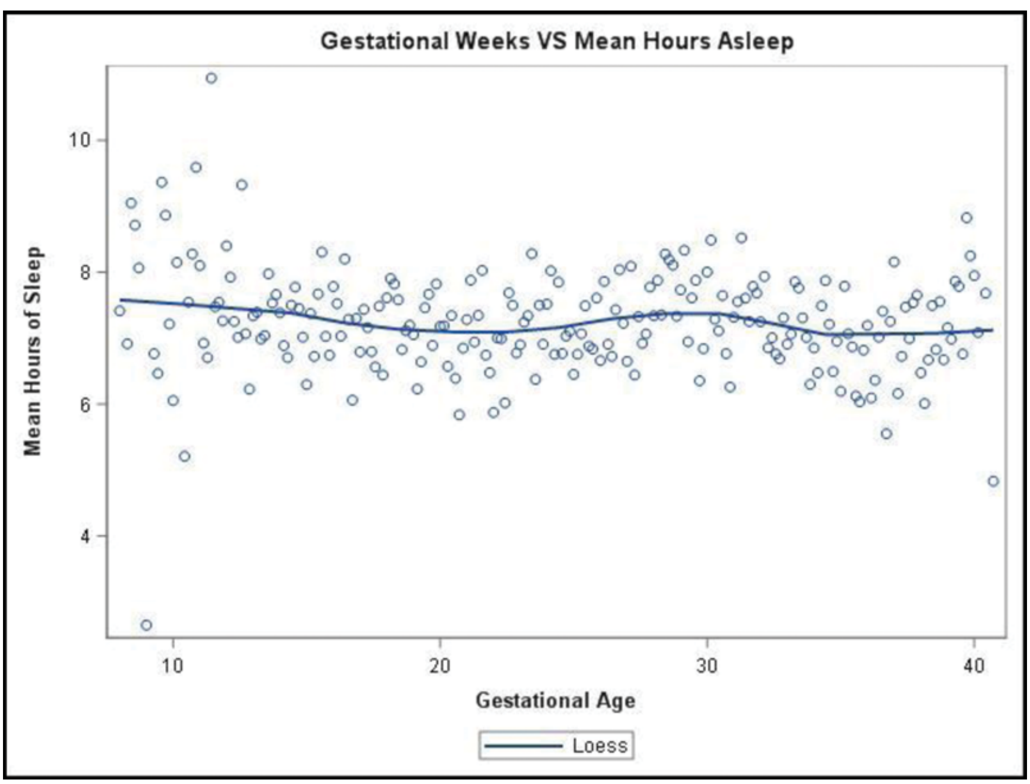

Fig. 1 Scatterplot of mean hours of sleep (across women) by gestational age, with locally weighted scatterplot smoothing curve overlaid.

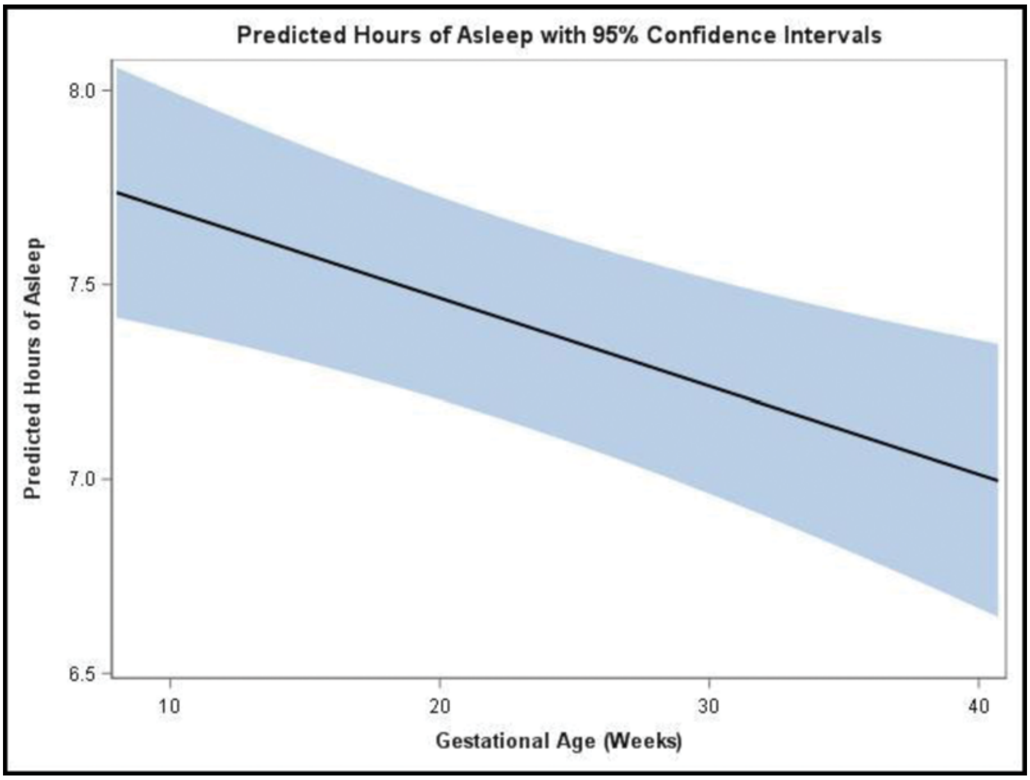

Fig. 2 Predicted hours of sleep versus gestational age in weeks with 95% confidence intervals (unadjusted model).

Table 2 Perinatal outcomes according to total sleep duration in the first 7 days of use

Variable	<7 hours of sleep $n = 30$	≥ 7 hours of sleep $n = 53$	*p*-Value
Daily steps (median, IQR)	7,122 (5,167–8,338)	5,005 (4,115–7,059)	<0.01
Sedentary time/day (h) (mean ± SD)	887 ± 157	859 ± 125	0.37
Total gestational weight gain (kg) (median, IQR)	$n = 28$ 11.4 (9.2–14.6)	$n = 46$ 14.1 (8.8–17.4)	0.40
Gestational weight gain categories, *n* (%)			
Inadequate	9 (32.1)	8 (17.4)	0.34
Adequate	8 (28.6)	15 (32.6)	
Excessive	11 (39.3)	23 (50.0)	
Gestational diabetes, *n* (%)	2 (6.9)	1 (2.1)	0.55
Gestational hypertension or preeclampsia, *n* (%)	3 (10.3)	7 (14.9)	0.73
Gestational age at delivery (wk) (median, IQR)	$n = 29$ 39.1 (37.7–39.4)	$n = 48$ 39.3 (38.4–40.2)	0.09
Preterm delivery, *n* (%)	6 (20.0)	9 (17.0)	0.73
Cesarean delivery, *n* (%)	5 (17.2)	14 (29.2)	0.29
Birthweight (g) (mean ± SD)	$n = 28$ 3,142 ± 580	$n = 46$ 3,234 ± 427	0.44

Abbreviations: IQR, interquartile range; SD, standard deviation.
Data presented as median (IQR), mean ± SD or *n* %.

with actigraphy by 24.1 minutes.[18] In another review of consumer tracking devices, Fitbit was good at detecting sleep but poor at detecting wake and tended to overestimate total sleep time.[16] In summary, the current studies of sleep measures and validity of different instruments have small numbers of participants and often use a single night of recording in a laboratory setting. In general, data to support the use of ATD in a clinical setting are limited. If our sleep data measurements are overestimated, then total sleep time would be slightly less than most studies that used either PSG or self-report during pregnancy. Further evaluation of commercially available ATD and sleep is important given their widespread use and ease of use (e.g., data accessible to participants, sleep recorded in actual sleep environment) in pregnant women.

We acknowledge several limitations to this study including the small number of participants and the number of valid sleep observations per person, especially in the context of the comparison of maternal and neonatal outcomes. We did not collect self-reported sleep or activity measures or perform PSG in this study. Participants also did not log sleep start and stop times on the ATD, as such, we opted not to evaluate other components of sleep such as sleep patterns (e.g., number of sleep periods per day, daytime, vs. nighttime sleep periods, etc.). Furthermore, we were not aware of participant's work schedules (e.g., day vs. night shifts) or prior diagnoses of sleep disorders. However, this study does add to the sleep literature among pregnant women with respect to commercially available ATD in a diverse population of women who collect the data in real-life settings and not from a laboratory.

In conclusion, sleep duration was similar to studies from self-reported or actigraphy sleep data in our study of 94 women who wore a Fitbit Flex device during pregnancy. Given the increasing ease of access to these devices, further research is required to evaluate the validity of commercially available ATD in pregnant women and how sleep duration is related to maternal and neonatal outcomes.

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Conflict of Interest
None declared.

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