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Longitudinal Observation of Sleep and Physical Activity Behavior among Pregnant Women

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ABSTRACT

Background: Sleep and physical activity play critical roles in maternal and fetal health during pregnancy. However, longitudinal changes in these behaviours remain understudied. This study aimed to investigate sleep and physical activity behaviours across pregnancy using objective measures.

Subjects and Method: A longitudinal observational study was conducted in Australia from January 2019 to November 2020. Pregnant women in their first trimester (≤14 weeks gestation) were recruited via Facebook using convenience sampling. Fourteen participants were continuously monitored throughout all three trimesters using wrist-worn Fitbit Charge 2 devices. Sleep outcomes included total sleep duration (hours/night) and number of nightly awakenings after sleep onset, while physical activity was measured as total daily minutes. Gestational progression (trimester and day of pregnancy) served as the independent variable. Data were analyzed using linear regression and linear mixed-effects models.

Results: Sleep duration significantly declined across pregnancy ($p<0.001$). No significant difference was observed between the first (Mean= 6.93 hours; SD= 2.22) and second trimesters (Mean= 6.73 hours; SD= 1.94), but a marked decrease occurred in the third trimester (Mean= 4.95 hours; SD= 2.56), with an average reduction of 1.5 hours per night compared to the first trimester ($p<0.001$). Regression analysis confirmed a progressive daily decline in sleep duration ($\beta=-0.013$, $p<0.001$). Nightly awakenings averaged (Mean= 18.6; SD= 15.3) and decreased over time ($\beta=-0.051$, $p<0.001$). Mean daily physical activity was 114.84 minutes, predominantly light intensity (94.5%), with minimal moderate (3.78%) and vigorous activity (1.72%). Physical activity increased modestly across trimesters ($p=0.046$), with a significant difference of approximately 16.7 minutes per day between the first and third trimesters ($p=0.040$).

Conclusion: Sleep duration declines progressively during pregnancy, particularly in the third trimester. Although overall physical activity increases, it is largely dominated by light-intensity activity, with low participation in moderate and vigorous levels. Given the importance of adequate sleep and appropriate physical activity for maternal and fetal health, these findings highlight the need for targeted interventions to improve sleep and promote adherence to recommended activity guidelines during pregnancy.

Keywords: pregnancy, sleep, physical activity

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BACKGROUND

Pregnancy is a transformative period marked by significant physiological adaptations that influence both maternal and fetal health (Jee and Sawal, 2024). Maintaining optimal health behaviours during this time is essential to support the well-being of both the mother and the developing fetus. Research shows pregnant women experience progressively poorer sleep as their pregnancy progresses as a result of various factors including physical and hormonal changes, frequent urination, and anxiety about the upcoming birth (Delgado and Louis, 2022, Wong et al., 2022). The implications of poor sleep during pregnancy are well-documented (Lu et al., 2021, Warland et al., 2018, Zhong et al., 2018). For instance, poor sleep during pregnancy is associated with an increased risk of preeclampsia, gestational diabetes mellitus, caesarean delivery, depression, and preterm birth (Lu et al., 2021). While the exact aetiology of poorer sleep during pregnancy remains multifaceted, evidence indicates that the physiological and hormonal changes essential for the development of the fetus may play a significant role in the poorer sleep behaviours experienced by most women during pregnancy (Lu et al., 2021).

Several pharmacological and non-pharmacological treatment options exist to improve sleep, yet pharmacological options are discouraged during pregnancy due to limited evidence regarding their impact on maternal and fetal outcomes (Hashmi et al., 2016, Tomfohr-Madsen et al., 2017, Costa and Vale, 2024). As such, non-pharmacological strategies such as sleep hygiene education, cognitive behavioural therapies and physical activity are the preferred approaches for managing poor sleep during pregnancy (Ladyman et al., 2022).

Physical activity, in particular, is widely recognized for its broad health benefits, including improvements in cardiovascular, metabolic, and mental health (Brown et al., 2022, Kelly et al., 2020). During pregnancy, regular physical activity is associated with a reduced risk of excessive gestational weight gain, gestational diabetes, preeclampsia, gestational hypertension, obstetric interventions (e.g., caesarean section, forceps, vacuum-assisted delivery), and postpartum depression symptoms (Mottola et al., 2018). Despite these well-documented benefits, many pregnant women fail to meet the recommended guideline of at least 150 minutes of moderate to vigorous intensity physical activity per week (Mottola et al., 2018). Given the growing body of evidence linking physical activity to improved sleep quality, understanding sleep and physical activity behaviours during pregnancy is essential for developing targeted interventions that promote maternal and fetal well-being.

While extensive research has examined physical activity and sleep in pregnancy independently, few studies have investigated these variables using objective, continuous monitoring methods. Most existing studies rely on self-reported measures, which are prone to recall and reporting biases. Therefore, this study aimed to longitudinally observe sleep and physical activity behaviours throughout pregnancy using Fitbit devices. By employing continuous, real-time tracking of sleep and physical activity, this study seeks to provide more precise and ecologically valid data to enhance our understanding of how

these behaviours change over time and inform future interventions to optimize maternal health.

SUBJECTS AND METHOD

1. Study Design

This longitudinal observational study was conducted in Australia between January 2019 and November 2020. The study tracked sleep and physical activity behavior across pregnancy using objective, continuous monitoring. Data collection occurred at three predefined time points corresponding to pregnancy trimesters: first trimester (gestational weeks 4–14), second trimester (gestational weeks 14–28), and third trimester (gestational weeks 28 to birth).

2. Populationand Sample

The target population consisted of pregnant women residing in Australia. The accessible population comprised women in their first trimester of pregnancy (≤14 weeks gestation) who were recruited via the social media platform Facebook. A convenience sampling technique was used.

Eligible participants were women aged ≥18 years who were in their first trimester of pregnancy and residing in Australia. Exclusion criteria included medical or obstetric complications such as gestational diabetes, placenta previa, low amniotic fluid, unusual bleeding, pre-eclampsia, hyperemesis gravidarum, high or low blood pressure, or other medical conditions assessed on an individual basis.

A total of 14 pregnant women met the inclusion criteria and were enrolled in the study. Informed consent was obtained from all participants prior to data collection.

3. Study Variables

The dependent variables in this study were objectively measured sleep and physical activity outcomes, including total sleep duration (hours per night), number of nightly awakenings after sleep onset, and total daily physical activity (minutes). The independent variables were gestational progression measured by trimester (first, second, and third trimester) and by day of pregnancy

4. Operational Definition of Variables

Sleep duration was defined as the total number of hours slept per night as recorded by the Fitbit device.

Nightly awakenings were defined as the total number of awakenings occurring after sleep onset during a sleep period.

Physical activity was defined as the total number of minutes per day spent in light-, moderate-, and vigorous-intensity activity.

Day of pregnancy was defined as the gestational day since conception and treated as a continuous variable. Trimester was operationalized as an ordinal variable with three levels: first trimester (4–14 weeks), second trimester (14–28 weeks), and third trimester (28 weeks to birth).

Sleep and physical activity variables recorded by the device, along with their operational definitions and cut-points, are presented in Table 1.

Table 1. Sleep and Physical Activity variables recorded by wearable Fitbit device including cut points

Sleep variables	Description
Bedtime (hh:mm)	Time recorded by device when participant got into bed to initiate sleep.
Wake time (hh:mm)	Time recorded by device when participant woke from sleep.
Sleep duration (h)	The total amount of sleep recorded during a sleep period.

Sleep variables	Description
Total time in bed (h)	The total amount of time spent in bed getting to sleep, sleeping and during awakenings after sleep onset during a sleep period
Total time awake after sleep onset (m)	Total time spent awake after sleep has been initiated during a sleep period.
Number of awakenings after sleep onset (WASO) (n)	Total number of awakenings after sleep has been initiated during a sleep period.
Physical Activity variables	
Time spent lightly active per day (mins)	Calculated by device as energy expenditure occurring at > 1.5 to < 2.7 METs.
Time spent moderately active per day (mins)	Calculated by device as activity occurring at < 4.3 METs.
Time spent vigorously active per day (mins)	Calculated by device as activity occurring at > 4.4 METS.
Total minutes sedentary per day (mins)	Calculated by device as activity occurring at < 1.5 METs.
Total time spent active per day (mins)	Total sum of minutes spent lightly, moderately and vigorously active.

5. Study Instruments

Sleep and physical activity were objectively measured using a wrist-worn Fitbit Charge 2 device (Fitbit Inc., San Francisco, CA), worn continuously on the non-dominant wrist. Fitbit devices have been validated for measuring sleep parameters, including total sleep time, wake after sleep onset, and sleep efficiency, as well as physical activity metrics such as heart rate and activity intensity, when compared with gold-standard methods such as polysomnography and accelerometry.

The device uses a MEMS 3-axis accelerometer to detect movement and an optical heart rate sensor to estimate activity intensity. Physical activity intensity was calculated using metabolic equivalent minutes (METs) and classified according to Fitbit's proprietary cut-points. Sleep and physical activity variables recorded by the device, along with their operational definitions and cut-points.

While multiple sleep and physical activity variables were recorded, only those relevant to the study objectives and statistical analyses are reported in the results. Variables not included were collected for exploratory purposes and may be analysed in future research.

6. Data Access and Account Management

Participants were provided with Fitbit accounts created and managed by the research team, who had full access to all collected data. Participants were instructed to synchronise their devices regularly to ensure continuous data capture. Data were extracted at predefined intervals throughout the study and upon study completion. At the conclusion of data collection, participants returned the devices.

7. Procedures

Participants were recruited via a Facebook advertisement that directed interested individuals to the study website. Eligible individuals received detailed information about the study, completed an eligibility questionnaire, and provided informed consent. Those who did not consent were excluded.

Eligible participants completed a baseline assessment, including demographic and health information, and were issued a Fitbit Charge 2 device. Participants were instructed to wear the device

continuously throughout pregnancy, except during charging. Technical support was provided via phone and email as required.

Data extraction occurred at predefined intervals to allow continuous monitoring of sleep and physical activity. Compliance was monitored through regular data checks to identify non-wear periods. At designated follow-up points, participants completed the Pittsburgh Sleep Quality Index (PSQI) and the International Physical Activity Questionnaire (IPAQ). Data from the PSQI and IPAQ were collected for exploratory purposes and were not included in the current analyses.

8. Data Analysis

Data analysis was conducted using SPSS Statistics (Version 29, IBM, USA). Descriptive statistics, including means, standard deviations, totals, and percentages, were calculated to summarize participant characteristics and outcome variables. Statistical significance was set at $p = 0.05$, and all data are reported as mean ± standard deviation. Nights/days with missing Fitbit data were excluded. Normality of variables was assessed using the Shapiro–Wilk test.

Linear regression analyses were performed to examine changes in sleep duration and number of nightly awakenings across the days of pregnancy. Standardized regression coefficients (β) and 95% confidence intervals were calculated.

Separate linear mixed-effects models were used to assess the effect of trimester on sleep and physical activity outcomes. Trimester (three levels) was included as a fixed effect, and participant was included as a random effect. Where significant main effects were observed, Bonferroni-adjusted post hoc comparisons were conducted. Effect sizes with 95% confidence limits were calculated and interpreted as trivial (<0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), or very large (>2.0). Effects were considered unclear when confidence limits crossed ±0.20

9. Research Ethic

Ethical approval was obtained from the Central Queensland University Human Research Ethics Committee (Approval No. 0000021397). Participants were informed of their right to withdraw at any time, and data confidentiality was strictly maintained throughout the study.

RESULTS

A convenience sample of 14 pregnant women aged over 18 years (Mean= 28.7; SD= 3.7) and residing in Australia participated in the study (Table 2). See table 2 below for further demographic characteristics.

Table 2. Participant demographic characteristics

Sample characteristics		n	%
Age	23-28	5	35.7
	29-33	9	64.3
Parity	Primiparous	6	42.8
	Multiparous	8	57.1
Marital status	Married	9	64.3
	Partnered	4	28.6
	Single	1	7.1
Education	Year 12 or equivalent	6	42.8
	TAFE/VET Qualification	3	21.4
	Bachelor degree	4	28.6
	Postgraduate degree	1	7.1
Employment status	Employed full-time	11	78.6

Sample characteristics		n	%
Annual household income	Employed part-time	2	14.2
	Full-time career of children	2	14.2
	$50,000 - $70,000	2	14.2
	$110,000 - $130,000	5	35.7
	$130,000 - $150,000	2	14.2
	>$150,000	5	35.7

*Participants were able to select more than one employment category; therefore, percentages may exceed 100%.

1. Sleep patterns during pregnancy

a. Sleep by trimester

Overall, participants exhibited a significant decrease in mean sleep duration across the trimesters of pregnancy (Figure 1). Linear mixed models identified a significant main effect of trimester on sleep duration ($F_{2, 1627}$= 87.57, p<0.001). No statistically significant differences in sleep duration were observed between the first and second trimesters. However, post-hoc comparisons indicated a significant decline in sleep duration of 1.4 hours between the second (Mean= 6.73; SD= 1.94) and third trimesters (Mean= 4.95; SD= 2.56), with p <0.001. Furthermore, participants slept an average of 1.5 hours less per night in the third trimester compared to the first trimester (Mean= 6.93; SD= 2.22 vs. Mean= 4.95; SD= 2.56, p <0 .001) (Figure 1).

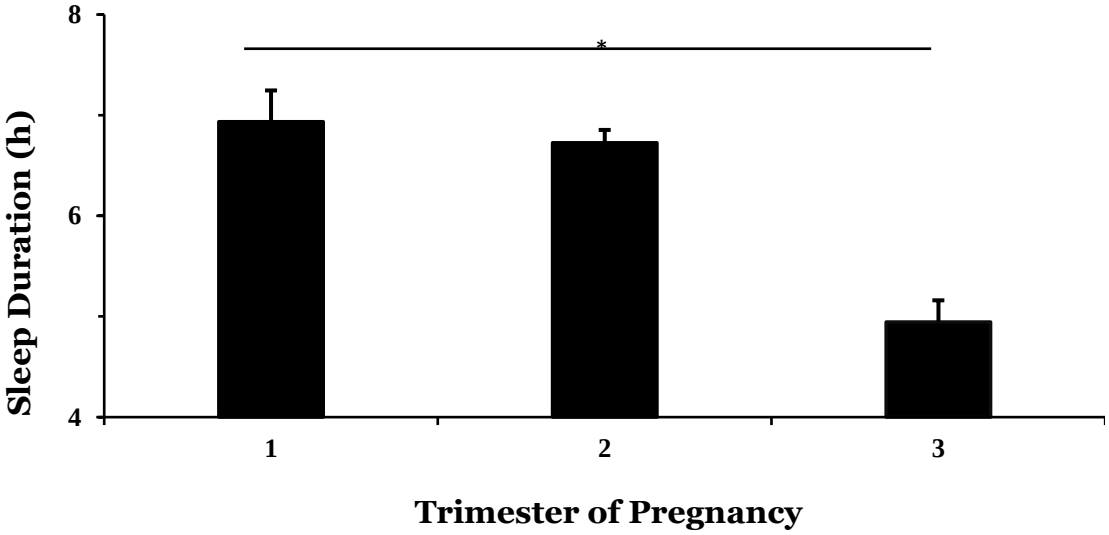

Figure 1. Mean and SD of sleep duration per day across the trimesters of pregnancy

b. Sleep across the days of pregnancy

A linear regression analysis was conducted to investigate sleep duration (h) per night across the days of pregnancy (please see Table 4 below). The linear regression analysis revealed a significant regression (p<0.001). There was a negative relationship between total sleep duration per night and the day of pregnancy. The coefficient of determination, R^2, was 0.127, which implies that 12.7% of the variance in total sleep duration can be explained by the day of pregnancy. The regression equation for predicting total sleep duration is as follows:

Predicted Hours of Sleep = 8.418 - 0.013 x Days of Pregnancy. This means that participants' total sleep duration decreased by approximately 0.013 hours (0.78 minutes or 47 seconds) for each additional day of pregnancy (β= -0.01, t= -15.41, p <0.001). Figure 2 presents a visual depiction of the relationship between total sleep duration per night and day of pregnancy.

Table 3. Linear regression analysis predicting sleep duration and nightly awakenings across days of pregnancy

Outcome Variable	b	SE	β	p	R^2
Sleep duration (h)	-0.01	0.01	-0.34	<0.001	0.127
Nightly awakenings (n)	-0.05	0.01	-0.21	<0.001	0.044

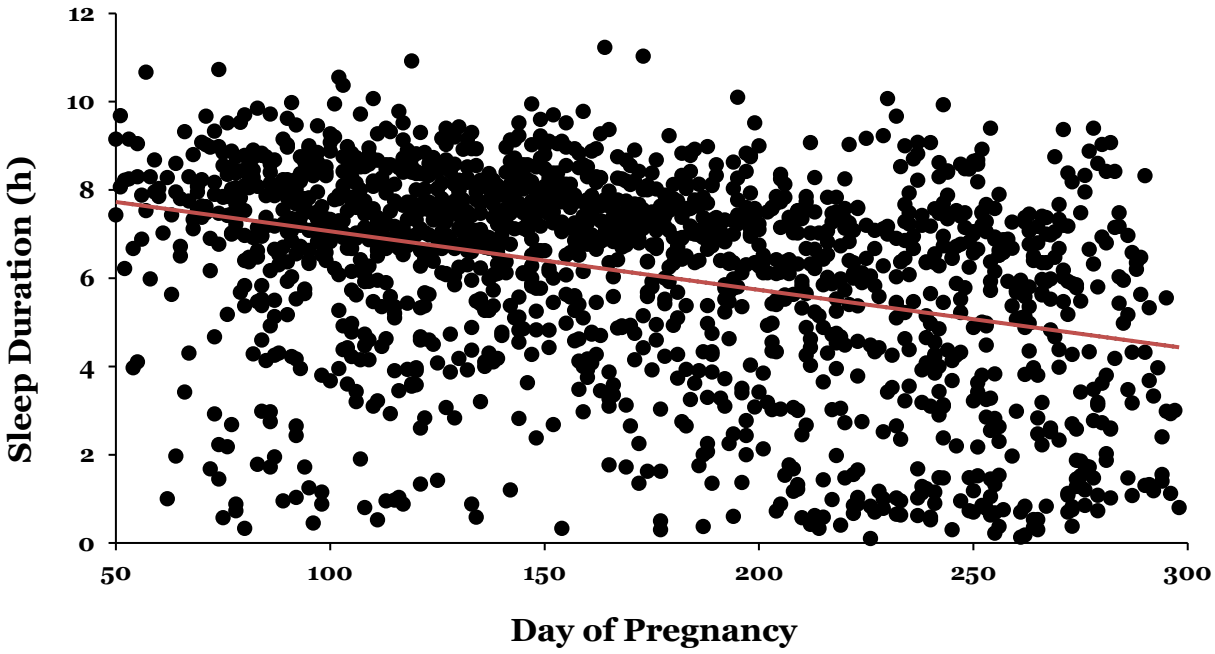

Figure 2. Scatterplot showing the negative correlation between sleep duration (hours) and day of pregnancy

On average, participants experienced (Mean= 18.6; SD= 15.3) awakenings per night after sleep onset. To predict the number of nightly awakenings, we used the regression equation: Predicted Nightly Awakenings= 27.22 + (-0.051 x Days of Pregnancy). A second linear regression analysis was conducted to examine the relationship between nightly awakenings and day of pregnancy. The analysis yielded a statistically significant regression (F1, 1886=87.50, p<0.001), indicating a strong negative relationship. The coefficient of determination, R2, was 0.044, suggesting that approximately 4.4% of the variance in nightly awakenings can be explained by the day of pregnancy. On average, participants experienced a decrease of 0.051 nightly awakenings for each additional day of pregnancy (β=-0.051, t=-9.35, p<0.001).

2. Analysis of Physical Activity Patterns During Pregnancy

a. Physical Activity by Intensity

Participants exhibited an average of 114.84 minutes of total daily physical activity (LPA+MPA+VPA). The majority of this

activity was classified as light intensity, with a mean of 108.53 minutes per day (94.50% of total activity time). Moderate activity accounted for an average of 4.34 minutes per day (3.78%), while vigorous activity was minimal, averaging 1.97 minutes per day (1.72%).

b. Physical Activity by Trimester

Total daily physical activity (minutes) was lowest in the first trimester, and progressively increased in the second and third trimesters of pregnancy (Table 4, Figure 3).

Table 4. Average Daily Sleep Duration (Hours) and Physical Activity (Minutes) Across Trimesters

Pregnancy period	Sleep (h per night)		Physical Activity (m per day)	
	Mean	SD	Mean	SD
Trimester 1	6.9	2.2	106.5	112.5
Trimester 2	6.7	1.9	125.3	125.7
Trimester 3	5.0	2.6	131.9	126.8

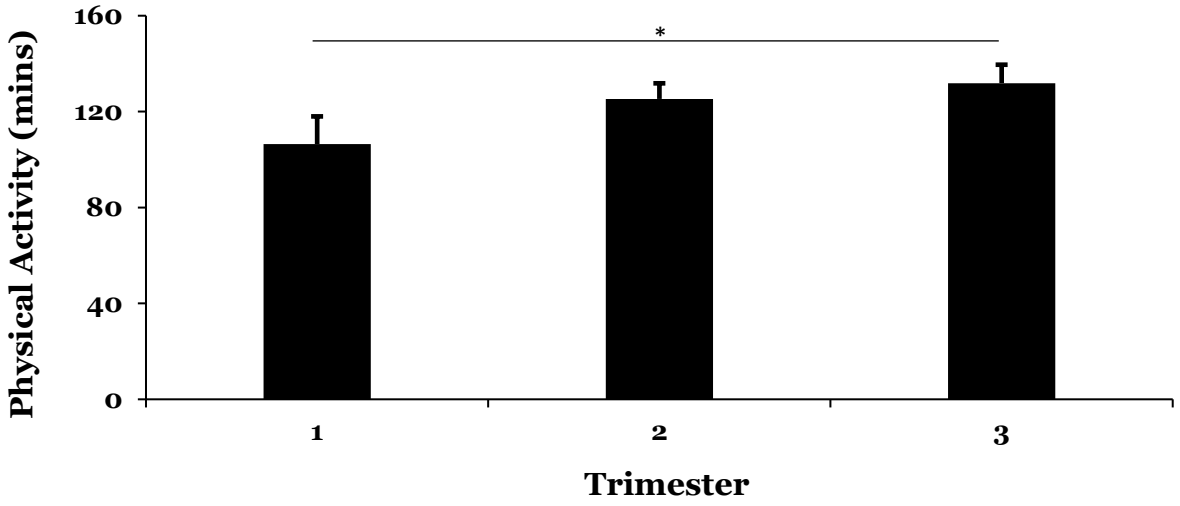

Figure 3. Mean physical activity minutes across the trimesters of pregnancy

Linear mixed models revealed a significant main effect of trimester (T1, T2, T3) on physical activity (min) ($F_{2, 2839.4} = 3.093$, $p=0.046$). No significant differences were observed between T1 and T2 or between T2 and T3. However, post-hoc comparisons indicated a significant mean difference in physical activity between T1 and T3 (-16.654 ± 6.73, $p=0.040$.

DISCUSSION

The present study aimed to longitudinally observe sleep and physical activity behaviours in pregnant women using Fitbit devices. The findings highlight significant changes in sleep patterns and physical activity levels across pregnancy, contributing to the growing body of research investigating maternal health behaviours during this critical period.

Consistent with prior research, our study found that total sleep duration significantly declined as pregnancy progressed (Liamsombut and Tantrakul, 2022). While no significant differences were observed between the first and second trimesters, a pronounced reduction occurred in the third

trimester, with participants sleeping an average of 1.5 hours less per night compared to the first trimester. This decline aligns with existing literature reporting worsening sleep quality in late pregnancy due to increased physical discomfort, hormonal fluctuations, and frequent nocturnal awakenings (Delgado and Louis, 2022, Wong et al., 2022). The decline in sleep across pregnancy was further supported by linear regression, revealing a significant negative relationship between total sleep duration and gestational day.

Notably, our study found that participants experienced an average of 18.6 awakenings per night, with a gradual reduction in awakenings as pregnancy advanced. While previous research has typically reported increased sleep fragmentation in late pregnancy (Lu et al., 2021, Zhong et al., 2018), our findings suggest that sleep disturbances may peak earlier in pregnancy and decline thereafter. This discrepancy could be attributed to adaptation mechanisms, behavioural modifications or the small sample size limiting statistical power (Hashmi et al., 2016, Wong et al., 2022). The large standard deviation in nightly awakenings (Mean= 18.6; SD= 15.3) suggests substantial variability among participants. This variation may reflect individual differences in sleep quality, adaptation mechanisms, or external factors such as lifestyle and stress levels (Al-Musharaf, 2022). Future research with larger sample sizes could help clarify whether these differences represent distinct sleep patterns in pregnancy or are due to methodological variability.

Contrary to expectations, total daily physical activity increased across pregnancy, with significant differences observed between the first and third trimesters. This finding challenge prior research suggesting a general decline in physical activity as pregnancy advances due to increased fatigue, discomfort, and physical limitations (Mottola et al., 2018, Silva-Jose et al., 2022). However, the increase in activity levels was primarily driven by light intensity activity, which constituted over 94% of total daily activity, whereas moderate and vigorous activity remained minimal throughout pregnancy.

Several factors may explain the observed increase in light physical activity. Pregnant women often engage in low-impact activities, such as walking, childcare, and household tasks, as part of their daily routine, which helps maintain mobility while avoiding more intense physical activity. In the early months of pregnancy, symptoms like morning sickness and fatigue may limit physical activity, but as pregnancy progresses and these symptoms subside, women may find it easier to stay active. Additionally, increased awareness of the benefits of physical activity during pregnancy, along with healthcare recommendations, may encourage women to sustain or gradually increase their movement levels in safe and manageable ways (Sparks et al., 2023, Kianfard et al., 2022). Despite this positive trend, the minimal engagement in moderate and vigorous activity suggests that most participants did not meet recommended physical activity guidelines (Brown et al., 2022). Future interventions should emphasise strategies to safely incorporate moderate intensity physical activity into daily routines.

These findings have important implications for maternal health outcomes. The substantial decline in sleep duration in the third trimester underscores the need for targeted strategies to improve sleep hygiene and mitigate sleep disturbances. Given the well-documented associations between poor sleep and adverse pregnancy outcomes, healthcare providers should conti-

nue to prioritise sleep education and behavioural interventions tailored to pregnant women (Liamsombut and Tantrakul, 2022). Similarly, while light physical activity increased, the lack of sufficient moderate and vigorous activity highlights the need for structured physical activity programs that accommodate the unique physiological changes of pregnancy. Wearable technology, such as Fitbit devices, offer a promising avenue for real-time monitoring and personalised feedback to encourage adherence to physical activity recommendations.

A key strength of this study is the use of objective, continuous monitoring through Fitbit devices, minimizing recall bias commonly associated with self-reported data. Additionally, the longitudinal design provides valuable insights into behavioural trends across all three trimesters of pregnancy. However, several limitations should be acknowledged. The small sample size and convenience sampling limit the generalizability of findings, and factors such as individual differences in fitness levels and lifestyle were not accounted for. Future studies should employ larger, more diverse samples and consider additional variables that may influence sleep and physical activity behaviours such as pre-pregnancy fitness levels, mental health status, occupational demands, and social support.

This study provides novel insights into the longitudinal changes in sleep and physical activity during pregnancy. The findings highlight the significant decline in sleep duration in late pregnancy and the predominance of light intensity activity throughout gestation. These results underscore the need for targeted interventions to promote healthy sleep and physical activity behaviours, ultimately supporting maternal and fetal well-being. Future research should explore strategies to enhance sleep quality and increase engagement in moderate intensity physical activity among pregnant women.

AUTHOR CONTRIBUTION

Summer Cannon as the Conceptualization, Methodology, Investigation, Writing-Original Draft, Review & Editing, Data Analysis. Melanie Hayman as the Conceptualization, Methodology, Review & Editing. Michele Lastella as the Conceptualization, Methodology, Data Analysis, Review & Editing.

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