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ORIGINAL RESEARCH

Associations of maternal sedentary behavior and physical activity levels in early to mid-pregnancy with infant outcomes: A cohort study

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Abstract

Introduction: Physical activity during pregnancy is beneficial for the woman and the fetus. However, non-objective methods are often used to measure physical activity levels during pregnancy. This study aimed to evaluate objectively measured maternal early to mid-pregnancy sedentary behavior and physical activity in relation to infant well-being.

Material and Methods: This cohort study included 1153 pregnant women and was performed at Uppsala University Hospital, Uppsala, Sweden, between 2016 and 2023. Sedentary behavior and physical activity levels were measured by accelerometers during 4–7 days in early to mid-pregnancy. Outcome measures were infant birthweight standard deviation score, small-for-gestational-age, large-for-gestational-age, preterm birth (<37 weeks' gestation), spontaneous preterm birth, iatrogenic preterm birth, Apgar <7 at 5 min of age, umbilical artery pH ≤7.05, and admission to the neonatal intensive care unit (NICU).

Results: There were no associations of sedentary behavior and physical activity levels with infant birthweight standard deviation score, small-for-gestational-age, or large-for-gestational-age. After adjustment for BMI, age, smoking, parity, maternal country of birth, and a composite of pre-pregnancy disease, the most sedentary women had higher odds of preterm birth (adjusted odds ratio (AOR) 2.47, 95% confidence interval (CI) 1.17–5.24, $p = 0.018$), and NICU admission (AOR 1.93, CI 1.11–3.37, $p = 0.021$) than the least sedentary women. The most physically active women had lower adjusted odds for NICU admission (AOR 0.45, CI 0.26–0.80, $p = 0.006$) than the least physically active women.

Conclusions: Objectively measured levels of sedentary behavior and physical activity in early to mid-pregnancy were not associated with standardized infant birth size. Sedentary behavior was associated with an increased likelihood of preterm birth and

Abbreviations: AOR, adjusted odds ratio; BMI, body mass index; BWSDS, birthweight standard deviation score; CI, confidence interval; CPM, counts per minute; LGA, large-for-gestational-age; NICU, neonatal intensive care unit; OR, odds ratio; SD, standard deviation; SGA, small-for-gestational-age.

NICU admission, while high level of physical activity was associated with a decreased likelihood of admission to NICU.

KEYWORDS

adverse neonatal outcomes, Apgar score, birthweight, large-for-gestational-age, neonatal intensive care, physical activity, pregnancy, preterm birth, sedentary behavior, small-for-gestational-age, umbilical artery pH

1 | INTRODUCTION

Physical exercise enhances positive effects on the well-being of the pregnant woman and the fetus.[1] The American College of Obstetricians and Gynecologists recommends women with uncomplicated pregnancies to participate in at least 20–30 min of aerobic and strength-conditioning exercises per day,[1] and similar recommendations are given by the World Health Organization.[2] However, many women do not meet these guidelines.[3,4] Maternal health benefits associated with physical activity include less gestational weight gain[5] and reduced risk of gestational diabetes mellitus[6] and preeclampsia.[7] Possible mechanisms behind these associations are enhanced uteroplacental blood flow and optimized blood glucose levels.[8] Conversely, sedentary behavior (defined as low-intensity behavior while lying, reclining or sitting[9]) has been linked to pre- and postpartum depression and gestational diabetes mellitus.[10]

Most previous studies use non-objective methods such as questionnaires or interviews to measure levels of physical activity during pregnancy.[10–12] Physical activity is often overestimated and sedentary behavior underestimated when questionnaires are used to monitor physical activity levels.[13]

Infant birthweight is an important marker of newborn health. Physical activity during pregnancy has been proposed to promote appropriate fetal growth and normal birthweight.[14] A recent systematic review and meta-analysis reports a negative association of physical exercise during pregnancy with macrosomia,[15] but no association with birthweight in grams, motivating further research on this topic.

Historically, there was a concern that physical activity during pregnancy increased the risk of preterm labor.[16] These concerns are however motiveless; higher leisure time activity during pregnancy is associated with a reduced risk of preterm delivery according to a systematic review.[17] Of note, none of the 21 cohort studies included in this review[17] measured physical activity levels objectively. Moreover, few studies evaluate subtypes of preterm birth (spontaneous and iatrogenic) in relation to maternal physical activity. Furthermore, the influence of objectively measured maternal physical activity levels on other infant outcomes, such as Apgar score, umbilical artery pH, and neonatal intensive care unit (NICU) admission, is poorly understood.[8]

We hypothesize that maternal sedentary behavior and physical activity levels are associated with infant birth size, preterm birth, and adverse infant outcomes. This study aimed to investigate the associations of objectively measured sedentary behavior and physical activity levels during early to mid-pregnancy with infant birthweight standard deviation score (BWSDS), small-for-gestational-age (SGA), large-for-gestational-age (LGA), preterm birth (including subtypes spontaneous and iatrogenic), Apgar <7 at 5 min of age, umbilical artery pH ≤7.05, and admission to NICU.

Key message

Objectively assessed sedentary behavior in early to mid-pregnancy was associated with an increased likelihood of preterm birth and NICU admission. A high level of physical activity was instead associated with a decreased likelihood of admission to NICU.

2 | MATERIAL AND METHODS

2.1 | Study design

This cohort study was performed at Uppsala University Hospital, Uppsala, Sweden, between 2016 and 2023. During this period, 1525 pregnant women were recruited to the study in conjunction with either an early ultrasound scan or the second-trimester ultrasound examination. To be eligible for participation in this study, the woman had to be 18 years or older, Swedish speaking, have an uncomplicated pregnancy at recruitment, and the ability to use a wrist watch during work hours. Study participation involved wearing an accelerometer for assessment of sedentary behavior and physical activity levels for 7 days. A core outcome set was not used in this research.

2.2 | Data collection

Maternal weight was measured at the first antenatal visit. Body mass index (BMI) was calculated as the weight in kilograms divided by the square of the height in meters. Data on maternal characteristics were obtained by a questionnaire filled in by the woman at inclusion and supplemented by information from the standardized antenatal and delivery medical records. Information on Apgar score, umbilical artery pH, and admission to NICU was extracted

from the standardized pediatric electronic medical records. The BWSDS was calculated by the use of national reference standards for birthweight with respect to sex and gestational age.[18] We defined SGA as birthweight standard deviation score < 10th percentile and LGA as birthweight standard deviation score >90th percentile.

2.3 | Sedentary behavior and physical activity measurement

Sedentary behavior and physical activity were objectively measured by the use of an accelerometer, either Actiwatch 2 or Actiwatch Spectrum Plus (Philips Respironics, Eindhoven, Netherlands). The Actiwatch is a monitor worn as a wristwatch that detects anteroposterior, mediolateral, and vertical movements. Accelerometers are commonly used to assess physical activity in pregnant women,[19] and the Actiwatch 2 has been validated against a waist-worn reference physical activity monitor (ActiGraph GT3X) as well as oxygen consumption (metabolic equivalent) with acceptable correlations.[20] The study participants were instructed to wear the accelerometer on the non-dominant wrist without interruption for seven continuous days during all waking hours, except during water-based activities. They were instructed to live their daily lives as usual. We only included women who had four or more days of physical activity recordings, where each day was required to include at least 10 h of recordings. Movements were collected in 30-s epochs and reported as counts per minute (cpm)[21] after processing by the use of Philips Actiware software. Based on the cpm, we classified the physical activity in four categories (sedentary, light, moderate, and vigorous) and recorded the time spent in each category.[21] We employed the following cut-off points to define the physical intensity categories: sedentary activity: ≤256 cpm, moderate activity: 418–720 cpm, and vigorous activity: ≥721 cpm, as per Kemp et al.[20] Due to low sensitivity and specificity of the accelerometer to characterize light activity (257–417 cpm),[20] this activity intensity was not included in the analyses.

2.4 | Outcomes

Outcomes were BWSDS, SGA, LGA, preterm birth (<37 weeks' gestation), spontaneous preterm birth (defined as preterm birth with a spontaneous onset of labor), iatrogenic preterm birth (defined as preterm birth with an induced vaginal onset of labor or a cesarean section before onset of labor), Apgar <7 at 5 min of age, umbilical artery pH ≤7.05, and admission to NICU.

2.5 | Statistical methods

The statistical analyses were performed using IBM SPSS Statistics version 28. A nominal two-sided *p*-value <0.05 was considered to indicate statistical significance. The proportion of time spent being sedentary and the proportion of time spent being physically active were normally distributed. The study population was divided in tertiles with respect to proportion of time spent being sedentary. Likewise, the cohort was divided in tertiles with respect to the proportion of time spent being physically active (sum of the proportion of time spent in moderate and vigorous activity). Pearson correlation coefficients were calculated for the linear associations between early pregnancy BMI, maternal age, proportion of time being sedentary, and proportion of time being physically active. *t*-tests were used to evaluate the proportion of time spent being sedentary and physically active between groups defined by demographic and clinical parameters. Linear regression models were used to evaluate associations of sedentary behavior and physical activity with standardized birthweight. Logistic regression analyses were performed to assess the association between maternal early to mid-pregnancy physical activity and the odds of infant outcomes. A directed acyclic graph (DAG)[22] was used in the process of selecting covariates (Figure S1). Adjustments were made for early pregnancy BMI (kg/m^2), age (years), smoking at first antenatal visit (yes or no), parity (nulliparous or parous), country of birth (within EU or outside EU), and a composite of pre-pregnancy disease (yes or no). The composite of pre-pregnancy diseases included inflammatory disease, asthma, essential hypertension, hypothyroidism, diabetes mellitus, neurological disease, chronic kidney disease, rheumatic disease, mental illness, and other severe chronic disease. A sensitivity analysis restricted to nulliparous women ($n = 559$) was also performed. The covariates described above, except parity, were included in the adjusted sensitivity analysis. Associations are presented as odds ratios (OR) and adjusted odds ratios (AOR) with 95% confidence intervals (CI).

3 | RESULTS

3.1 | Study population

Of the 1525 women recruited to this study, 372 individuals were excluded from further analyses due to the following reasons: insufficient wear time ($n = 190$), technical problems with the software ($n = 31$), discontinuation due to technical/medical reasons ($n = 13$), multiple pregnancy ($n = 14$), giving birth elsewhere ($n = 67$), abortion or miscarriage ($n = 12$), lost to follow-up ($n = 2$), not yet delivered ($n = 14$), certain data missing from delivery ($n = 23$), intrauterine fetal death ($n = 5$), and physical activity measured in late pregnancy ($n = 1$). Thus, the final study population consisted of 1153 women giving birth between August 2016 and February 2023. The mean maternal age was 31.4 years (standard deviation (SD) 4.5 years), and 559 women (48.5%) were pregnant with their first child. The mean BMI of the women was 24.9 kg/m^2 (SD 4.7 kg/m^2), 310 (26.9%) were overweight (BMI 25.0–29.9 kg/m^2), and 153 (13.3%) were obese (BMI ≥30.0 kg/m^2). The study population characteristics are presented in Table 1.

TABLE 1 Study population characteristics.

	Variable	Whole cohort	Most sedentary tertile	Least sedentary tertile	Most physically active tertile	Least physically active tertile
Women	*n*	1153	385	384	384	384
	Age, years (mean ± SD)	31.4 ± 4.5	31.6 ± 4.5	31.3 ± 4.3	31.3 ± 4.3	31.6 ± 4.5
	Country of birth within EU, n (%)	1051 (91.2)	344 (89.4)	359 (93.5)	358 (93.2)	346 (90.1)
	BMI at first antenatal visit, kg/m^2 (mean ± SD)[a]	24.9 ± 4.7	25.3 ± 5.1	24.5 ± 4.4	24.5 ± 4.1	25.5 ± 5.2
	Nulliparous, *n* (%)	559 (48.5)	235 (61.0)	143 (37.2)	144 (37.5)	228 (59.4)
	Smoking at first antenatal visit, *n* (%)	85 (7.4)	27 (7.0)	30 (7.8)	29 (7.6)	25 (6.5)
	Inflammatory disease, *n* (%)	35 (3.0)	14 (3.6)	11 (2.9)	14 (3.6)	13 (3.4)
	Asthma, *n* (%)	100 (8.7)	31 (8.1)	40 (10.4)	38 (9.9)	29 (7.6)
	Hypertension, *n* (%)	15 (1.3)	5 (1.3)	5 (1.3)	6 (1.6)	5 (1.3)
	Hypothyroidism, *n* (%)	86 (7.5)	24 (6.2)	34 (8.9)	32 (8.3)	25 (6.5)
	Diabetes mellitus, *n* (%)	14 (1.2)	6 (1.6)	2 (0.5)	3 (0.8)	7 (1.8)
	Neurological disease, *n* (%)	10 (0.9)	2 (0.5)	5 (1.3)	5 (1.3)	2 (0.5)
	Chronic kidney disease, *n* (%)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Rheumatic disease, *n* (%)	15 (1.3)	3 (0.8)	6 (1.6)	7 (1.8)	4 (1.0)
	Mental illness, *n* (%)	137 (11.9)	51 (13.2)	49 (12.8)	53 (13.8)	37 (9.6)
	Other severe chronic disease, *n* (%)	33 (2.9)	7 (1.8)	14 (3.6)	13 (3.4)	10 (2.6)
	Gestational diabetes, *n* (%)	36 (3.1)	14 (3.6)	6 (1.6)	7 (1.8)	15 (3.9)
	Gestational hypertension, *n* (%)	40 (3.5)	14 (3.6)	12 (3.1)	13 (3.4)	13 (3.4)
	Preeclampsia, *n* (%)	51 (4.4)	26 (6.8)	9 (2.3)	9 (2.3)	28 (7.3)
Infants	*n*	1153	385	384	384	384
	Female, *n* (%)	571 (49.5)	187 (48.6)	193 (50.3)	186 (48.4)	192 (50.0)
	Birthweight, g (mean ± SD)	3562 ± 526	3563 ± 540	3589 ± 486	3581 ± 483	3564 ± 524
	Gestational age at birth, days (mean ± SD)	278 ± 12	279 ± 11	279 ± 10	279 ± 9	279 ± 11

Abbreviations: BMI, body mass index; SD, standard deviation.

[a]Data missing in 3 individuals.

3.2 | Daily sedentary behavior and physical activity patterns

Sedentary behavior and physical activity levels were measured between gestational weeks 8 and 22. Two-thirds of the study population ($n = 767$) were recruited in conjunction with an early ultrasound scan (median gestational length at start of measuring period 90 days, interquartile range (IQR) 5 days). One-third ($n = 383$) was recruited at the second-trimester ultrasound examination (median gestational length at start of measuring period 133 days, IQR 7 days). The measuring period ranged 4–7 days (mean 6.6 days), and the mean waking wear time was 15.8 h (SD 1.0 h) per day.

On average, the women spent 9.3 h as being sedentary and 4.2 h as being physically active (Table S1). The proportions of time spent being sedentary and physically active across groups are displayed in Figure 1 and Figure 2. The most sedentary tertile and the least physically active tertile spent similar proportions of time being sedentary and physically active (Figure 1 and Figure 2). Likewise, the least sedentary tertile and the most physically active tertile spent similar proportions of time as sedentary and physically active (Figure 1 and Figure 2).

3.3 | Sedentary behavior and physical activity in relation to maternal characteristics

Maternal age and BMI did not correlate with sedentary behavior or levels of physical activity (Table S2). As expected, an inverse correlation was observed between time spent being sedentary and time spent being physically active (r = −0.96) (Table S2).

Women born within EU spent less time being sedentary and more time being physically active compared with women born outside EU. Parous women were less sedentary and more physically active compared with nulliparous women (Table S3).

3.4 | Sedentary behavior in relation to infant outcomes

The frequencies of infant outcomes across groups defined by levels of sedentary behavior and physical activity are presented in Table 2. The most common reason for iatrogenic preterm birth ($n = 31$) was preeclampsia ($n = 15$), followed by diabetes mellitus ($n = 3$) and gestational diabetes mellitus ($n = 3$). Infant BWSDS was not associated with sedentary behavior (Table 3). The odds of SGA and LGA did not differ between the most and least sedentary tertile (Table 4). The odds of preterm birth (<37 weeks' gestation) were 2.56 among women in the most sedentary tertile compared with those in the least sedentary tertile (OR 2.56, CI 1.25–5.23, $p = 0.010$) (Table 4). The result remained after adjustments for early pregnancy BMI, age, smoking at first antenatal visit, parity, country of birth, and a composite of pre-pregnancy disease (AOR 2.47, CI 1.17–5.24, $p = 0.018$) (Table 4). There was no difference in the odds of having an infant born spontaneously preterm between the groups (Table 4). For iatrogenic preterm birth, the odds were 3.56 (CI 1.17–11.00, $p = 0.026$) in the most compared with the least sedentary tertile (Table 4). After adjustments, the result was no longer significant (AOR 3.06, CI 0.95–9.82, $p = 0.060$) (Table 4). There was no difference in the odds of umbilical artery pH ≤7.05 between the groups (Table 4). The odds of admission to NICU were doubled in the most sedentary compared with the least sedentary tertile (OR 2.12, CI 1.25–3.62, $p = 0.006$ prior to adjustments and AOR 1.93, CI 1.11–3.37, $p = 0.021$ after adjustments) (Table 4). In the sensitivity analysis restricted to nulliparous women only, there were no significant results (Table S4).

3.5 | Physical activity in relation to infant outcomes

Maternal physical activity was not associated with infant BWSDS (Table 3). There was no difference in the odds of having an infant born SGA or LGA between the most and least physically active tertiles (Table 4). Likewise, there were no difference in the odds of umbilical artery pH ≤7.05 between the groups (Table 4). There was a 56% decrease in the odds of NICU admission in the most compared with the least physically active tertile (OR 0.44, CI 0.25–0.75, $p = 0.003$) (Table 4). The result was similar after adjustments (AOR 0.45, CI 0.26–0.80, $p = 0.006$) (Table 4). There were no significant results in the sensitivity analysis restricted to nulliparous women only (Table S4).

4 | DISCUSSION

This study demonstrated that pregnant women who spent more than 64% of their waking time as being sedentary had higher odds of preterm birth and NICU admission. Furthermore, infants of women

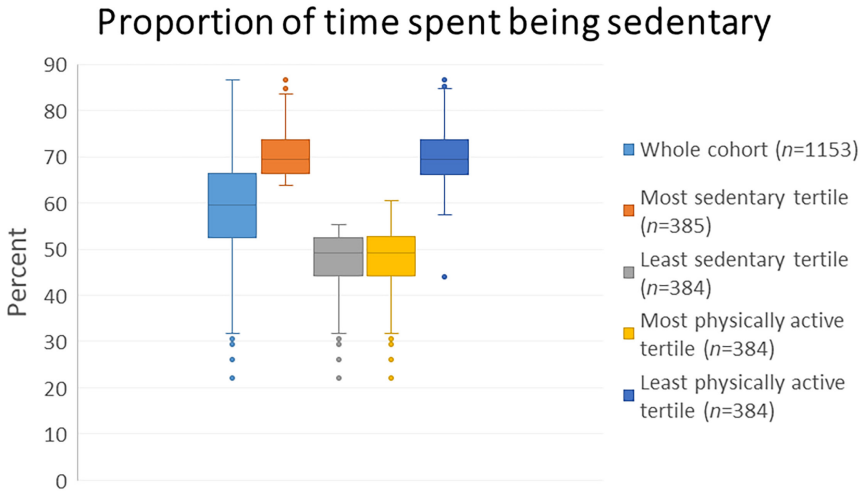

FIGURE 1 Box plots showing the proportion of time spent as being sedentary across groups.

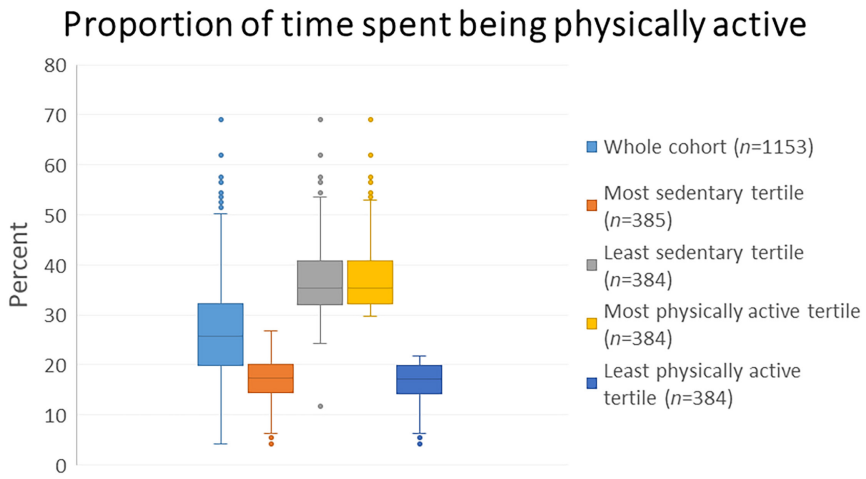

FIGURE 2 Box plots showing the proportion of time spent as being physically active across groups.

TABLE 2 Infant outcomes in relation to sedentary behavior and physical activity measures in early to mid-pregnancy.

Outcome	Whole cohort ($n=1153$)	Most sedentary tertile ($n=385$)	Least sedentary tertile ($n=384$)	Most physically active tertile ($n=384$)	Least physically active tertile ($n=384$)
SGA, *n* (%)	80 (6.9)	34 (8.8)	24 (6.3)	24 (6.3)	28 (7.3)
LGA, *n* (%)	162 (14.1)	54 (14.0)	57 (14.8)	57 (14.8)	50 (13.0)
Preterm birth (<37 w), *n* (%)	61 (5.3)	27 (7.0)	11 (2.9)	14 (3.6)	24 (6.3)
Spontaneous preterm birth (<37 w), *n* (%)	30 (2.6)	13 (3.4)	7 (1.8)	9 (2.3)	12 (3.1)
Iatrogenic preterm birth (<37 w), *n* (%)	31 (2.7)	14 (3.6)	4 (1.0)	5 (1.3)	12 (3.1)
Apgar <7 at 5 min of age[a], *n* (%)	19 (1.7)	4 (1.0)	8 (2.1)	8 (2.1)	3 (0.8)
Umbilical artery pH ≤7.05[b], *n* (%)	21 (2.6)	5 (2.0)	5 (1.8)	4 (1.4)	6 (2.4)
Admitted to NICU[c], *n* (%)	108 (9.4)	44 (11.4)	22 (5.7)	21 (5.5)	45 (11.7)

Abbreviations: LGA, large-for-gestational-age (birthweight standard deviation score > 90th percentile); NICU, neonatal intensive care unit; SGA, small-for-gestational-age (birthweight standard deviation score < 10th percentile).

[a]Data missing in 14 individuals.

[b]Data missing in 354 individuals.

[c]Data missing in 1 individual.

TABLE 3 Associations of maternal early to mid-pregnancy sedentary behavior and physical activity levels with standardized infant birthweight.

		Unadjusted model			Adjusted model[a]		
Outcome	Physical activity type	*β*	CI	*p*	*β*	CI	*p*
Birthweight standard deviation score	Proportion of time spent being sedentary, percent	−0.00	−0.01 to 0.00	0.412	0.00	−0.00 to 0.01	0.443
	Proportion of time spent in moderate and vigorous activity, percent	0.00	−0.01 to 0.01	0.597	−0.00	−0.01 to 0.00	0.404

Note: Data are B coefficients (*β*) and 95% confidence interval (CI) for the change in birthweight standard deviation score per percent increase in physical activity level.

[a]Data were analyzed using linear regression models. Adjustments were made for early pregnancy BMI, age, smoking at first antenatal visit, parity, maternal country of birth, and pre-pregnancy disease.

who spent at least 30% of their waking time as physically active had decreased odds of being admitted to NICU.

To the best of our knowledge, the association between accelerometer measured sedentary time during early to mid-pregnancy and preterm birth has not previously been described.[23] Our findings are contrary to those of a large UK-based study reporting no association between sedentary behavior and preterm birth.[24] However, the investigators used self-reported data on physical activity, which

TABLE 4 Associations of maternal early to mid-pregnancy sedentary behavior and physical activity levels with infant outcomes.

Outcome	Most sedentary tertile vs least sedentary tertile (reference)						Most physically active tertile vs least physically active tertile (reference)					
	Unadjusted model			Adjusted model[a]			Unadjusted model			Adjusted model[a]		
	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*
Small-for-gestational-age	1.45	0.84–2.50	0.177	1.36	0.77–2.40	0.285	0.85	0.48–1.49	0.566	0.90	0.50–1.62	0.716
Large-for-gestational-age	0.94	0.63–1.40	0.747	0.99	0.64–1.51	0.948	1.16	0.77–1.75	0.466	1.15	0.74–1.77	0.539
Preterm birth (<37 w)	**2.56**	**1.25–5.23**	**0.010**	**2.47**	**1.17–5.24**	**0.018**	0.57	0.29–1.12	0.100	0.57	0.28–1.16	0.118
Spontaneous preterm birth (<37 w)	1.88	0.74–4.77	0.183	1.97	0.74–5.24	0.173	0.74	0.31–1.79	0.508	0.64	0.26–1.63	0.351
Iatrogenic preterm birth (<37 w)	**3.56**	**1.17–11.00**	**0.026**	3.06	0.95–9.82	0.060	0.41	0.14–1.17	0.096	0.49	0.16–1.49	0.208
Apgar <7 at 5 min of age	0.48	0.14–1.61	0.236	0.41	0.11–1.47	0.169	2.75	0.73–10.46	0.137	2.41	0.59–9.83	0.218
Umbilical artery pH ≤7.05	1.10	0.32–3.85	0.880	1.10	0.30–4.02	0.890	0.59	0.17–2.12	0.421	0.63	0.17–2.37	0.489
Admitted to NICU	**2.12**	**1.25–3.62**	**0.006**	**1.93**	**1.11–3.37**	**0.021**	**0.44**	**0.25–0.75**	**0.003**	**0.45**	**0.26–0.80**	**0.006**

Note: Data are odds ratios (OR) and 95% confidence interval (CI). Bold text indicates significant results. Data were analyzed using logistic regression models. Small-for-gestational-age, birthweight standard deviation score <10th percentile and large-for-gestational-age, birthweight standard deviation score >90th percentile.

Abbreviation: NICU, neonatal intensive care unit.

[a]Adjustments in the model: early pregnancy BMI, age, smoking at first antenatal visit, parity, maternal country of birth, and pre-pregnancy disease.

is less reliable compared with objective assessment by the use of a wearable device.[25]

We found that sedentary women had increased likelihood of preterm birth, but when outcome subgroups were analyzed (spontaneous and iatrogenic preterm birth), the adjusted analyses showed no significant associations between sedentary behavior and either form of preterm birth. This makes the results less robust. However, subgroup analysis reduced the sample size, which could explain why the results were not significant.

It is important to consider that pregnant women at high risk of preterm birth may be prescribed activity restriction. A secondary analysis of data from the Short Cervix and Nulliparity trial including 646 pregnant women of which 252 had been prescribed activity restriction shows that those who were prescribed restricted activity were more likely to deliver preterm (<37 weeks' gestation).[26] The cervix screening was performed by mid-trimester ultrasound, and the activity restriction started at a median of 23.9 weeks' gestation. The analysis was adjusted for several potential confounding factors, including maternal age, ethnicity, and cervical length. The authors hypothesize that the association could be driven by stress and anxiety. Furthermore, a study evaluating physical activity in 49 pregnant women with increased risk of preterm birth due to short cervix reports an inverse association between the median number of daily steps and preterm delivery.[27] The participants received no physical activity recommendations, and the analysis was adjusted for confounding factors. The above findings, in addition to those of our present study, suggest that reduced physical activity during pregnancy may be associated with preterm birth. Although our study subjects represent a low-risk population, one could speculate that hypertensive disorders of pregnancy might underpin the increased likelihood of preterm birth among the most sedentary women as prenatal physical activity lowers the odds of gestational hypertension and preeclampsia.[7,28]

Our results showed that objectively measured moderate and vigorous physical activity was not associated with increased odds of preterm birth. This is consistent with previous findings.[29,30] Two meta-analyses demonstrate an inverse association between physical activity during pregnancy and preterm birth.[17,31] However, the results should be interpreted with caution since physical activity levels were not objectively measured in the majority of the studies included in these meta-analyses.

We found no difference in the odds of having an infant born SGA or LGA between the most and least sedentary women. Likewise, the odds of SGA and LGA did not differ between the most and least physically active women. These findings are in line with the results of a recent systematic review, which reports no association of physical activity interventions during pregnancy with SGA and LGA.[15] Of note, the methods used to measure physical activity levels varied between the studies included the review. Six of ten studies evaluating SGA and seven of ten evaluating LGA used objective methods to measure physical activity levels. Another systematic review reports associations of moderate physical activity with increased birthweight and high physical activity with decreased birthweight.[32] However, only 8 out of 54 studies

included in this review used an objective method to measure physical activity levels.

We found no differences in the odds of Apgar score <7 at 5 min of age between groups, which is in good agreement with previous findings.[33,34] Nonetheless, other investigators report positive effects of physical activity on Apgar score. Higher Apgar score at 1 and 5 min was observed among infants of mothers engaging in aerobic and strength-conditioning exercise (supervised by certified instructors) compared with controls.[35] In contrast to our study population, all women were nulliparous and had a sedentary lifestyle before the intervention, which might explain the dissimilar results.

We did not find any differences in the odds of umbilical artery pH ≤7.05 between groups. To the best of our knowledge, only two previous studies report on this question. Putnam et al. studied self-reported domestic activity in relation to infant outcomes and report no difference in umbilical artery pH between the groups.[36] Likewise, Perales et al. demonstrate no difference in umbilical cord pH between women who practiced regular physical exercise throughout their pregnancy compared with controls.[33] Hence, the results of our study confirm previous findings.

The pregnant women in our cohort spent on average 9.3 h per day being sedentary, which is similar to the figures reported by Barone Gibbs et al.[37] As expected, we observed a strong inverse correlation between the proportion of time being sedentary and the proportion of time being physically active. The most sedentary women were also least physically active, and vice versa. We found no correlation between early pregnancy BMI and proportion of time being sedentary or proportion of time being physically active, suggesting that early pregnancy BMI does not influence the physical activity pattern during pregnancy. Finally, our study showed that parous women were more physically active compared with nulliparous women, suggesting that already being a mother implies a more active lifestyle.

The clinical implication of the results of this study is that increased sedentary behavior in early to mid-pregnancy could indicate an increased likelihood of preterm birth as well as infant admission to NICU. The predictive value of sedentary behavior measurement in early to mid-pregnancy for risk assessment needs to be investigated by future studies.

This study had limitations and strengths. A limitation was the observational study design, which only enabled assessment of associations and not causality. It is possible that unmeasured confounders were present that could explain both high levels of sedentary behavior and poorer birth outcomes. For example, medical conditions leading to increased maternal sedentary behavior might also cause preterm delivery. However, as sedentary behavior was measured in early to mid-pregnancy, a medical condition that later caused preterm delivery must have been present and affected the woman months prior to delivery. Nonetheless, one could argue that increased sedentary behavior in early to mid-pregnancy could be a marker of increased risk of preterm delivery, even though it is not the actual cause. Besides underlying medical conditions, socioeconomic factors such as education and income could possibly influence the association. We did not have information on socioeconomic factors, but adjusted our analyses for early pregnancy BMI, smoking, and maternal country of birth as proxies for socioeconomic status. Limitations also included that the activity pattern was measured only once and that the measurement period was short in relation to the length of the pregnancy. A longer measurement period would have increased the reliability of the measures, but might instead have decreased the feasibility. Moreover, light activity was not included in the analyses due to low sensitivity and specificity of the Actiwatch to characterize it.[20] The exact levels of moderate and vigorous activity should also be interpreted with some caution, since the cut-off points suggested by Kemp et al. were determined in a lab setting.[20] Further research is needed to validate the ability of the Actiwatch to measure waking movement behavior in free-living settings. Lastly, this study might not have had enough power to detect small differences in rare outcomes. In this study, few infants had Apgar score <7 at 5 min of age and umbilical artery pH <7.05. Many children born preterm are doing well and do not necessarily have low Apgar or low umbilical artery pH. Strengths were the large study population size, and multiple infant outcomes including subtypes of preterm birth. A major strength was the use of accelerometers to objectively measure physical activity levels.[25] Lastly, the length of the measuring period (on average 6.6 days) enabled assessment of both weekday and weekend physical activity levels.

5 | CONCLUSION

Maternal sedentary behavior and physical activity levels in early to mid-pregnancy were not associated with standardized infant birth size. Sedentary behavior was associated with increased odds of preterm birth and admission to NICU, and physical activity was associated with lower odds of NICU admission. This study suggests maternal sedentary behavior and physical activity levels in early to mid-pregnancy as markers of infant well-being, implicating that sedentary behavior and physical activity should be considered more in clinical practice.

AUTHOR CONTRIBUTIONS

Emelie Lindberger: conceptualization and methodology, formal analysis, writing—original draft. **Fredrik Ahlsson**, **Inger Sundström Poromaa** and **Anna-Karin Wikström**: conceptualization and methodology, supervision, formal analysis, writing—review and editing. **Tryfonas Pitsillos** and **Anna Wikman**: investigation, formal analysis, writing—review and editing. Henrik Johansson: formal analysis, writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare that are relevant to the content of this article.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

Written informed consent was obtained from all participants at inclusion. The study was approved on April 20, 2016, by the Regional Ethical Review Board in Uppsala (Dnr: 2016/142). All research was performed in accordance with relevant national and international guidelines. There was no patient or public involvement in the development of the research.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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