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Original Article

Sleep and physical activity from before conception to the end of pregnancy in healthy women: a longitudinal actigraphy study

Alexander Vietheer [a, b, *], Torvid Kiserud [a, b], Rolv Terje Lie [a, c, d], Øystein Ariansen Haaland [c], Jörg Kessler [a, b]

[a] Department of Obstetrics and Gynecology, Haukeland University Hospital, Bergen, Norway
[b] Department of Clinical Science, University of Bergen, Bergen, Norway
[c] Department of Global Public Health and Primary Care, University of Bergen, Bergen, Norway
[d] Norwegian Institute of Public Health, Bergen, Norway

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ABSTRACT

Background: Sleep and physical activity changes are common in pregnancy, but longitudinal data starting before conception are scarce. Our aim was to determine the changes of the daily total sleep time (TST) and physical activity duration (PAD) from before conception to end of pregnancies in respect of pregestational maternal factors.

Methods: This longitudinal observational study formed part of the CONIMPREG research project and recruited healthy women planning to become pregnant. Sleep and physical activity were recorded around-the-clock for ≥4 days via actigraphy before conception and during each trimester of pregnancy. Data were adjusted according to pregestational maternal body composition, parity and age.

Results: Among 123 women with eligible data, the unadjusted mean (95% confidence interval) TST increased from 415.3 min (405.5–425.2 min) before conception to 458.0 min (445.4–470.6 min) in the 1st trimester, remaining high through the 2nd and 3rd trimesters. Variation was substantial before conception (±2SD range: 307–523 min). The unadjusted mean PAD before conception was 363.7 min (±2SD range: 120–608 min), decreasing sharply to 262.1 min in the first trimester and more gradually thereafter. Vigorous and moderate activity decreased more than light activity. TST and PAD were significantly associated with age, parity, and pregestational body fat percentage; lean body mass was negatively correlated with TST. Results were generally unaffected by seasonal variations.

Conclusion: Marked variations were found in pregestational TST and PAD. Healthy women slept ≥30 min longer during pregnancy, while PAD decreased by ≥ 90 min in early pregnancy and continued to decrease thereafter.

1. Introduction

Sleep and physical activity are essential and interrelated modes of life [1–6]. There have been few longitudinal studies of healthy pregnant women with combined sleep and activity measurements from before conception [7]. Pregestational assessments are important since major physiological changes in pregnancy are already present during the first trimester [8].

Changes in sleep patterns are a well-known phenomenon of normal pregnancy, and are often characterized by frequent awakenings and insomnia [9,10]. This lack of sleep might be partially compensated by daytime napping, indicating the importance of performing 24-h recording of sleep [11]. While poor sleep has been associated with an increase in pregnancy complications [12–18], physical activity can prevent certain complications. This situation has resulted in several recommendations on physical activity in pregnancy being published [19–23].

The maternal body composition changes during pregnancy [24]. As early as the first trimester, overweight (body mass index [BMI] 25–29.9 kg/m^2) is associated with more frequent snoring, insomnia, excessive daytime sleepiness, and short TST, even in otherwise healthy women [25]. During the second trimester there

* Corresponding author. Department of Obstetrics and Gynecology, Haukeland University Hospital, Bergen, Norway.
E-mail address: alexander.vietheer@uib.no (A. Vietheer).

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are higher risks of obstructive sleep apnea (OSA) syndrome and poor sleep quality [26]. The higher maternal fat mass associated with gestational weight gain [27–29] may also be related to sleep and physical activity in pregnancy. Furthermore, the family situation, number of children, and maternal profession have been shown to influence the circadian rhythm, sleep, and physical activity in healthy pregnancies [30,31]. Although some sleep studies in pregnancy accounted for BMI [18], more-specific and longitudinal analyses of body composition parameters and their influence are not available. In addition, sleep and physical activity have yet to be quantified simultaneously starting from before conception.

The aim of the present study was to determine the changes of simultaneously recorded 24-h sleep and activity duration in healthy women from before conception to late gestation. We hypothesized that there are pregnancy associated changes in sleep and activity, independent of maternal body composition, parity, and age. Further, we assumed that women with a higher percentage of body fat would generally sleep more and be less active over a 24-h period, and conversely, that those with a higher lean body mass would sleep less and be more physically active.

2. Materials and methods

This longitudinal observational study of sleep and physical activity is embedded in the ongoing CONIMPREG (conception-implantation interval and later development) research program. This is a composite research program collecting the data of healthy women from before conception, through pregnancy, and until the child reaches the age of 5 years.

Participants in the present study were recruited during the period 2014–2018 with the aid of social media (targeted Facebook® advertisements) and posters. Healthy nonsmoking women aged 20–35 years and with a BMI of 18–30 kg/m^2 were eligible provided they had an uncomplicated obstetric history and no chronic diseases or fertility problems. Women with appropriate substitution therapy for hypothyroidism were eligible. The participants did not use contraceptives at study entry, including the preceding month. Any participant who did not conceive after a maximum of six sampling cycles was excluded from the study. Written informed consent was obtained from all participants. The study was approved by the Regional Committee for Medical and Health Research Ethics in Norway [REK ref. 2013/856a].

At the first study visit (ie, before conception), height was measured manually using a wall-mounted stadiometer in a standardized way [32]. Weight was measured digitally using hand-to-foot multifrequency bioelectrical impedance analysis (model BC-418, Tanita, Tokyo, Japan). The percentage of body fat was estimated using the instrument's computer software, and the lean body mass was calculated by subtracting the body fat mass from the total body weight. Measurements were performed as recommended by the manufacturer [33] and immediately followed by physical activity and sleep recording.

Based on the last menstrual period, women were scheduled for a first-trimester ultrasound, and gestational age was adjusted according to crown-rump length [34]. Sleep and activity measurements were conducted using the SenseWear® Mini Armband actigraph (model MF-SW, BodyMedia, Pittsburgh, PA, USA) during the following periods (gestational age in weeks + days): 12 + 0–14 + 0, 23 + 0–25 + 0, and 35 + 0–37 + 0 (referred to here as first, second, and third trimesters, respectively; Fig. 1). The participants were instructed to wear the armband continuously on the upper posterior aspect of the nondominant arm for 4 days or more [35] and the recording of each day started at midnight. The SenseWear® actigraph is a wireless, noninvasive sleep and activity monitor that provides estimates of energy expenditure by recording daily life and lifestyle activities. It incorporates triaxial accelerometry, heat flux, galvanic skin response, skin temperature, and near-body temperature as well as demographic characteristics (sex, age, height, and weight) into propriety algorithms [36]. Sleep and wakefulness are discriminated based on motion and skin temperature. The model used in this study has a sampling rate of 32/sec in order to predict sleep versus wakefulness and physical activity with energy expenditure in 1-min epochs. In accordance with the SBRN (sedentary behavior research network) consensus [37] and ACSM (American college of sports medicine) guidelines, the activity was classified as light when the level of metabolic equivalents (MET's) was ≥1.5, moderate at ≥3.0, and vigorous at ≥6.0 [38]. SenseWear® actigraphy has shown good agreement when compared with other standard techniques such as double-labeled water or indirect calorimetry in humans of different ages [39–41]. The validity of this version of the actigraph (as well as older versions) for assessing activity during pregnancy and postpartum has been demonstrated [42–44]. SenseWear® actigraphy has also been validated for the measurement of sleep in other clinical and nonclinical, experimental settings with good agreement for estimating the total sleep time (TST) compared with polysomnography and other actigraphy sleep recordings [45–50]. The software calculated sleep efficiency (SE) as TST proportion (%) of the total duration lying down.

2.1. Statistics

The number of participants was limited by the allocated study period (2014–2018). Raw data were processed and summarized using the SenseWear® Pro analysis software (SenseWear® Professional, version 8.0.0.2903, Body Media) and exported into Excel workbooks (Microsoft Office, Excel version 2016, Redmond, WA, USA). Statistical analysis was performed using IBM SPSS® (version 24, Armonk, NY, USA), R (Foundation for Statistical Computing, version 3.6.1, Vienna, Austria), and (R-studio: Integrated development for R, Boston, MA, USA) software. Sampling days were excluded from the statistical analyses when the data loss exceeded 6% of a single day. This cutoff was chosen pragmatically as a compromise between recording quality aiming for precise 24-h sleep and activity measurements, and recording quantity with respect to the number of recorded days used for mean calculations.

Mean, standard deviation (SD), and range values were calculated for each continuous variable, and frequencies and proportions were calculated for categorical variables to describe the cohort. In addition, 95% confidence intervals (CIs) were calculated for the mean values of sleep and activity duration.

Random intercept models were used to analyze the repeated measurements of TST and physical activity duration (PAD). The pregnancy trimesters were defined as time categories and included as fixed effects in our models. The regression models were adjusted for age, parity, height, lean body mass, and fat percentage. We also tested whether the addition of a random slope by pregnancy trimester significantly improved the models.

As a measure of fit, the Akaike information criterion was calculated and compared against standard regression models using the method of least squares. Differences in the estimated model performance were tested using analysis of variance. Linearity assumptions and normal distribution of the residuals were ascertained, and calculations were carried out with and without outliers (>2SD). The variance inflation factor was calculated to identify possible problems with multicollinearity. Subanalyses were conducted using paired and unpaired Student's t-test or nonparametric tests. For all statistical analyses the criterion for statistical significance was set at $p < 0.05$.

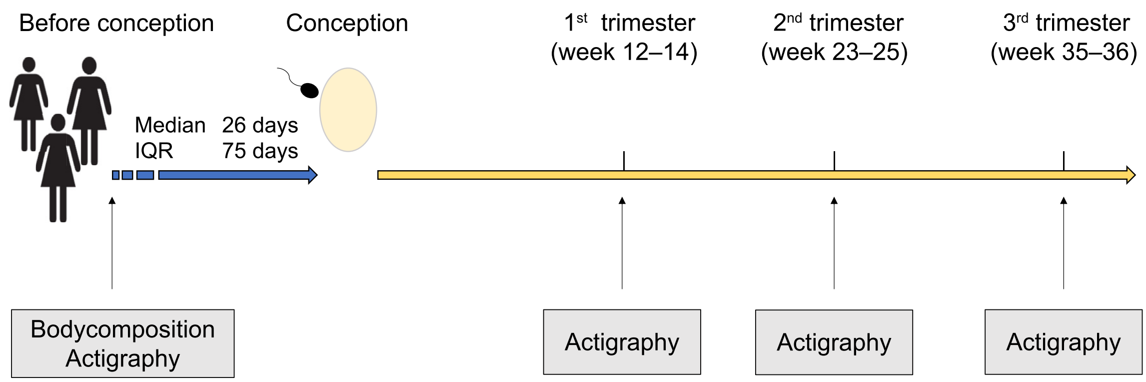

Fig. 1. Timing of sleep and physical activity measurements. The first assessment, performed before conception, was carried out at a median of 26 days before the last menstrual period.

3. Results

Of 249 eligible participants, 123 conceived with a successful pregnancy and were included in the present study (Fig. 2). Demographic information on the study cohort is provided in Table 1. All participants provided sufficient data for analysis at all measurement time points; however, due to some data loss during recording, 99 of the 1579 recorded days (5.9%) were excluded, resulting in a mean duration per recording of 3.6 days (95% CI 3.56–3.69 days). The median initial assessment was 7 weeks + 5 days prior to conception and followed up at gestational age 13 + 2, 24 + 3, and 36 + 1 (median number of weeks + days), respectively. The corresponding interquartile ranges (IQR) were 10 weeks +5 days, 5 days, 8 days, and 8 days.

3.1. Total sleep time

There was a notable normal variation in TST both before conception and during pregnancy (Appendix A), with a ±2SD span of 307–523 min before conception and 320–596 min at first trimester. The unadjusted mean daily TST increased from 415.3 min before conception (Table 2) to 458.0 min in early pregnancy, and remained increased for the remainder of the pregnancy. The same pattern was found after adjustments for maternal age, parity, and body composition factors, with an increase in TST of about 15 min over unadjusted levels at each time point (Table 2).

Compared with measurements made before conception, the adjusted mean TST (Fig. 3) was significantly longer (≥30 min) in all three trimesters ($p < 0.001$). Appendix B presents a comprehensive overview of the entire regression model with estimated effects of age, parity, and pregestational body composition parameters (height, lean body mass, and fat percentage).

3.2. Sleep efficiency

The adjusted mean 24-h sleep efficiency was before pregnancy 88.7% and significantly lower in the first and third trimesters (ie, by 1.4% and 3.1%, respectively). Apart from a negative correlation of 0.44% per 1-kg increment of lean body mass, demographic parameters and body composition variation did not affect sleep efficiency (Table 2 and Appendix C).

3.3. Physical activity duration

The unadjusted mean daily PAD, which was 363.7 min before conception, decreased to 262.1 min at the first trimester and continued to decrease during the remainder of the pregnancy (Table 2). The individual variation in PAD was large, with ±2SD ranging between 119.7 and 607.7 min before conception and between 44.7 and 479.5 min in the first trimester (Appendix A).

Adjustment for maternal age, parity, and body composition parameters did not alter this pattern (Table 2). The adjusted estimated reduction in PAD between the first and third trimester and between the second and third trimesters was 52.4 min (95% CI 73.6–31.3 min, $p < 0.001$) and 39.8 min (95% CI 61.1–18.5 min, $p < 0.001$), respectively (Fig. 3).

Comparison of the different unadjusted physical activity levels revealed that vigorous or moderate exercise constituted 27% of the total physical activity before conception, with the remainder being light activities (73%) (Table 2). In the first trimester (at gestational weeks 12–14) there was a shift toward lighter activities, with reductions in the proportions of vigorous or moderate, and light activity of 42% and 23%, respectively. The unadjusted overall duration of activity was reduced by 28%. At the end of pregnancy, the PAD had reduced by 41% compared with pregestational levels, but that of vigorous or moderate activity had reduced by 56%.

3.4. The influence of maternal pregestational characteristics

Both maternal age and parity were negatively associated with TST. For every 1-year increase in maternal age there was a reduction in daily TST of 3.1 min (95% CI 5.8–0.3 min, $p = 0.03$). Compared with nulliparous participants, those with parity ≥2 experienced a reduction in TST of 41.6 min (95% CI 70.9–12.4 min, $p = 0.01$). A positive association was found between pregestational body fat percentage and TST, with an increase of 1.9 min with each 1% increment in maternal body fat (95% CI 0.2–3.6 min, $p = 0.03$), while a negative association was found for pregestational lean body mass, with a reduction in TST of 3.7 min for every 1-kg increment in maternal lean body mass (95% CI 6.8–0.6 min, $p = 0.02$).

A negative association was also found between maternal age and PAD, with a reduction of 5.7 min for every 1-year increment in maternal age (95% CI 10.2–1.1 min, $p = 0.02$). In contrast to the negative association with TST, parity had a positive impact on PAD; significant effects were already seen from the first child, with an increase in PAD of 44.9 min (40.4–75.4 min, $p < 0.001$) for parity 1 and an increase of 75.0 min (95% CI 26.7–123.4 min, $p < 0.001$) for those with parity ≥2.

Pregestational body fat percentage was negatively associated with PAD, with a reduction of 4.8 min for every 1% increment in body fat (95% CI 7.6–2.0 min, $p < 0.001$). There was no relationship between lean body mass and PAD. An overview of the estimates can be found in Appendices B and C.

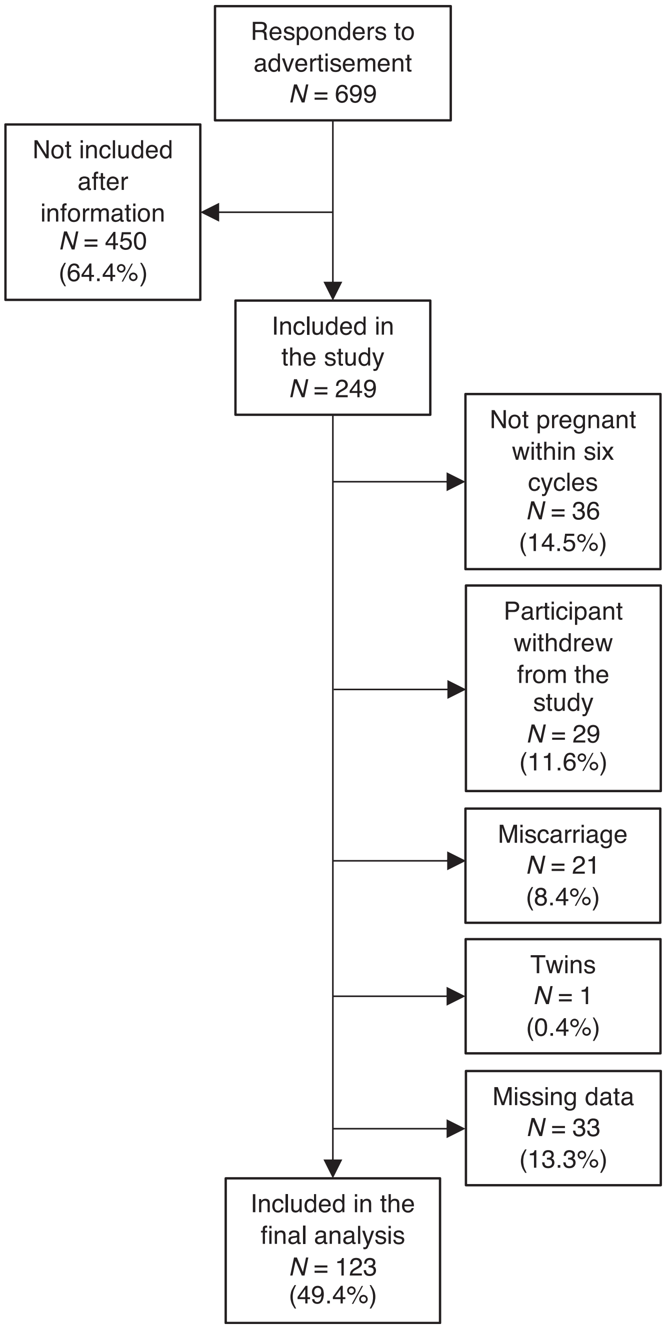

Fig. 2. Participant selection process.

3.5. Seasonal and weekday variations

Comparison of data obtained during the winter and summer seasons revealed no difference in TST at any measurement time point. Conversely, pregestational PAD was longer during the summer; however, there was no seasonal effect on PAD during pregnancy. Individual participant entry to the study was equally distributed over the year. The reduction in mean PAD was independent of season and statistically significant for both the winter and summer seasons (Appendix E).

The data were not confounded by weekday variation. Despite a slightly higher frequency of weekend recordings during the first trimester, recordings with a higher proportion of weekend days did not differ from those recordings with a lower proportion of weekdays (Appendix F).

Table 1
Demographic and anthropometric characteristics at study entry.

Characteristic	N	Mean±SD[a]	Range
Age, years	123	28.9 ± 3.3	20.0–35.0
Height, cm	123	167.9 ± 6.5	149.0–185.0
Weight, kg	123	64.7 ± 8.4	47.1–89.8
BMI[b], kg/m^2	123	22.9 ± 2.6	18.1–29.9
Lean body mass, kg	123	45.5 ± 3.7	36.0–54.9
Body fat, %	123	29.1 ± 5.4	15.9–41.9
Parity	123		
Para 0	60 (48.8%)		
Para 1	51 (41.5%)		
Para ≥2	12 (9.8%)		
Training habits[c]	123		
None	3 (2.3%)		
Effortless walking	33 (26.8%)		
<3 times/week	54 (43.9%)		
≥3 times/week	33 (26.8%)		

[a] SD, standard deviation.
[b] BMI, body mass index.
[c] Established using a non-validated questionnaire that each participant completed at study entry.

4. Discussion

This study found that in healthy women, TST was ≥30 min longer in early pregnancy compared with before conception, and it remained approximately at the same level for the remainder of the pregnancy. Conversely, PAD was reduced by ≥ 90 min in early pregnancy compared with before conception, and continued to decrease for the remainder of the pregnancy, with vigorous or moderate activity being impacted more than light activity. Variations in these patterns were significantly linked to parity, age, and pregestational body composition. Given that the study included healthy women with low-risk pregnancies, we believe that these patterns of changes in sleep are likely to be physiological adaptations to pregnancy.

Increases in TST and reductions in physical activity in pregnancy have been reported before, but they have only rarely been studied longitudinally from before conception [6,9,18,51-58], and seldom in combined sleep and activity assessments (ie, simultaneous recording of sleep and physical activity over 24-h periods) [59,60]. One study conducted using that combination and starting before pregnancy did not have sufficient statistical power to show significant changes in early pregnancy [7], while other studies were based on questionnaires, which are limited by their reliance on recall ability [61–67]. The present study had the advantage of higher statistical power and utilizing a technology that allowed continuous, around-the-clock recording of both sleep and physical activity.

4.1. Sleep

A previous study using nocturnal polysomnography recording in 33 pregnant women in their homes found that TST had increased by 34 min in the first trimester compared with prepregnancy [59]. Although polysomnography is considered the standard for nocturnal sleep assessment, it is not possible to record daytime sleep (ie, napping). A Swedish study that used 24-h heart-rate recording to assess PAD and TST in 12 women found no increase in TST compared with levels recorded before conception [7]. However, analyses of questionnaire data from 23 women in the same study demonstrated a significantly (5 min) longer TST at

Table 2
Unadjusted mean total sleep time (TST), total physical activity duration (PAD), sleep efficiency (SE), and durations of vigorous or moderate and light physical activity (min/day) before conception and through the pregnancy (ie, at 12–14, 23–25, and 35–37 gestational weeks). The adjusted mean was calculated for the main outcomes (TST and total PAD) in a linear regression model with a random intercept at the participant level. Adjustments were made based on cohort medians for age, parity, and body composition parameters (ie, for a 29-year-old nulliparous woman with height 167 cm, lean body mass 45 kg, and body fat 30%).

Time point	*N*[a]	Mean±SD[b]	Range	Adj.[c] mean	Adj. 95% CI[d]
Daily total sleep time, min					
Before conception	117	415.3 ± 54.0	269.8–542.0	429.1	414.5–443.7
1st trimester	117	458.0 ± 68.8	280.7–709.3	471.6	457.0–486.2
2nd trimester	115	450.9 ± 68.2	253.2–714.7	463.4	448.7–478.1
3rd trimester	113	446.1 ± 70.4	184.7–636.8	459.8	444.9–474.6
Daily sleep efficiency, %					
Before conception	117	82.71 ± 6.34	64.87–94.30	88.69	61.22–116.15
1st trimester	117	81.17 ± 6.51	61.49–95.23	87.29	59.83–114.75
2nd trimester	115	82.44 ± 7.07	52.62–96.41	88.44	61.0–115.89
3rd trimester	113	79.73 ± 8.31	50.23–95.61	85.55	58.09–113.01
Daily total physical activity duration, min					
Before conception	117	363.7 ± 122.0	119.0–829.5	331.7	307.6–355.8
1st trimester	117	262.1 ± 108.7	7.3–568.5	231.6	207.4–255.7
2nd trimester	115	250.6 ± 114.2	17.8–772.0	218.9	194.6–243.2
3rd trimester	113	214.8 ± 95.4	38.2–509.0	179.1	154.7–203.6
Daily light activity duration, min					
Before conception	117	98.6 ± 58.4	17.2–356.2		
1st trimester	117	56.4 ± 37.5	0.0–218.8		
2nd trimester	115	54.3 ± 47.9	0.0–324.0		
3rd trimester	113	43.5 ± 29.2	0.0–123.8		
Daily vigorous or moderate activity duration, min					
Before conception	117	267.2 ± 90.6	94.3–530.8		
1st trimester	117	207.7 ± 87.0	7.2–436.0		
2nd trimester	115	197.5 ± 86.6	18.2–448.0		
3rd trimester	113	172.7 ± 81.0	33.2–439.0		

[a] Missing data were due to periods of shortness of available actigraphs, technical problems, or incompatible family plans of the participants.
[b] SD, standard deviation.
[c] Adj., adjusted.
[d] CI, confidence interval.

gestational week 14 than before conception. Although the studies differ in their methods and results, they corroborate the pattern of sleep development in early pregnancy reported herein—a notable increase in TST compared with the immediate pregestational period.

Contrary to previous research, the present actigraphy study had the power to adjust for maternal factors; this adjustment did not significantly alter the change in TST from before conception (unadjusted 42.7 min, adjusted 42.5 min; Table 2). Accounting for the specific effects of age, lean body mass, fat percentage, and parity, we believe these results represent changes that are more specifically related to pregnancy (Fig. 3 and Appendix B).

During the second and third trimesters, neither the unadjusted nor adjusted TST changed significantly from that recorded in the first trimester, and thus remained higher than before pregnancy. The unadjusted mean TSTs of the second and third trimesters in the present study of 451 and 446 min, respectively, are longer than those reported by Tsai and colleagues in another actigraphy study: 433 min (95% CI 426–439 min) and 424 min (95% CI 417–431 min), respectively [54]. This difference may be attributable to demographic, cultural, and social differences in the study participants [68].

The negative association between TST in pregnancy and parity in the current study corroborates previous data [59]. The effect of parity persisted even after controlling for maternal age, which strengthens its significance. This is in line with another study showing that multiparous women had 10 min shorter TST than their nulliparous counterparts [58]. However, the difference was larger in the present study, 41.6 min. A larger number of participants and different parity subgrouping in the present study might explain some of the variations between the studies.

Fewer opportunities for daytime naps in parous women could be a reason for the difference in TST between women with and without children at the start of this study. It has been reported that the number of parous pregnant women having at least four naps per day is one-third of that in nulliparous women [58]. Daytime naps are common and already present in the first trimester of pregnancy, contributing to the daily TST [11,69,70]. While not necessarily influencing the duration of nighttime sleep, it has been suggested that napping compensates for the possible reduction in sleep quality during pregnancy [53]. Its importance for health during pregnancy is supported by reports on associations between napping and pregnancy outcome [71–75]. We found a reduced sleep efficiency in the first and third trimester, a possible sign of lower sleep quality, supporting an earlier questionnaire study [55]. We speculate that both the extended TST and daytime napping are part of the physiological adaptation to a normal pregnancy.

In our study, 10% more body fat before pregnancy was associated with an increase in TST of 19 min in pregnancy, while a 10-kg higher pregestational lean body mass was associated with a reduction in TST of 37 min. Intuitively, this pattern seems to fit with the notion that a physically active woman sleeps less and acquires relatively more lean mass and less fat. It is noteworthy that sleep deprivation in the general nonpregnant population is linked to an unfavorable body composition (ie, more fat and a lower lean body mass) [76–78]. This is not necessarily a contradiction since no direct comparisons can be drawn with the healthy women in the present study. However, another actigraphy study of early healthy pregnancies found no association between TST and BMI [18]. Little is known about the more-specific associations between lean body mass, body fat percentage, and sleep in healthy pregnancies. Whether or not sleep is a physiological adaption to pregnancy, it seems that women with a higher pregestational lean body mass combined with a lower body fat percentage might better tolerate the pregnancy-related changes, with a lower urge to rest or sleep during the day. Animal experiments have demonstrated

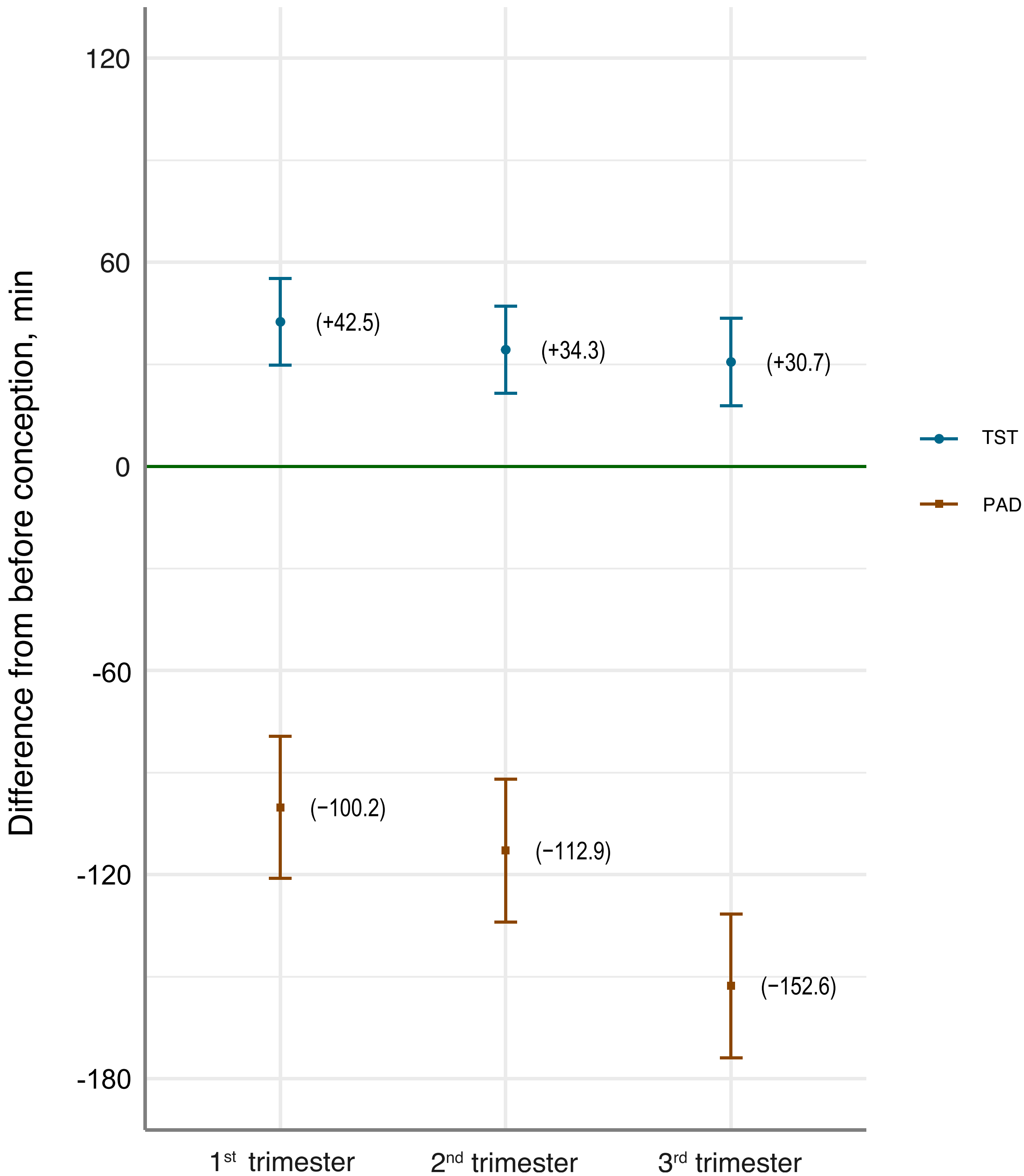

Fig. 3. Changes in mean total sleep time (TST) and total physical activity duration (PAD, min/24 h) in the first, second, and third trimesters of pregnancy over pregestational levels (set to zero in this graph). Data are mean and standard-deviation values for the increases (+) in TST and decreases (−) in PAD relative to pregestational levels, adjusted for pregestational maternal age, parity, height, lean body mass, and body fat percentage.

that gonadal steroids exert a circadian influence on sleep [79]. Conversely, the effects of sleep deprivation have structural and functional consequences for the neurodevelopment of the offspring and its viability [80]. It was shown recently that sleep deprivation in human pregnancies is associated with a higher BMI and higher diastolic blood pressure in the offspring [81], findings that should prompt further research.

4.2. Physical activity

This study assessed all levels of physical activity, including light activities such as housework and shopping. The health effects of vigorous or moderate activities are well known and included in activity guidelines for pregnancy [23,82]; however, there is also evidence supporting the health benefits of light activity [83]. In a study of adults with type 2 diabetes, light activities were more beneficial than structured exercise for glucose control and insulin sensitivity [83]. The previously reported shift from structured exercise to lighter activities during pregnancy [31,61] is confirmed by our results. This justifies the special interest in changes in PAD in our study. While previous SenseWear® actigraphy studies assessed the times spent at different activity levels in pregnancy [56,57,84,85], they neither included assessment of changes from before conception nor considered separate recordings from each trimester. One report on activity at gestational week 15 [57] corresponds well with ours at week 12–14 (Table 2). A couple of prospective studies using other actigraphy models have shown a similar trend of decreasing physical activity in low-risk pregnancies [86] and obese women [87]. However, pregestational observations remain lacking.

It has been suggested that increasing weight, cardiac load, abdominal expansion, edema, joint pain, and altered sleep pattern impair the quality of life during pregnancy [88] and contribute to the altered physical activity described herein. The 24-h TST is affected by parity and age, but physical activity is negatively correlated with age and positively correlated with parity, suggesting independent effects (Appendix B). It is known that women with children and who are older, are more likely attending to housework and caregiving with less time to exercise [89]. In another Norwegian study, Berntsen et al. found a negative correlation between parity and vigorous or moderate activity in early pregnancy for an ethnically Western subgroup of women [56]. In a subanalysis of our data restricted to vigorous or moderate exercise, the influence of parity was no longer evident suggesting that the association between parity and PAD was dependent upon the level of activity and based mainly on light activities, consistent with previous questionnaire data [67,90].

In contrast to other studies, the present study also controlled for pregestational height, lean body mass, and body fat percentage (Appendix C). Body fat percentage was lower for a higher PAD, which we believe to be plausible [91,92]. We had hypothesized that lean body mass is positively related to physical activity, as shown for nonpregnant populations [93,94]; however, we found that this was not the case for either PAD or vigorous or moderate activity. This could be due to the high contribution of light (habitual) activity and may not be associated with body composition [95].

4.3. Strengths and weaknesses

The study's strengths were the large number of subjects and its prospective longitudinal quantification of sleep and physical activity that commenced before pregnancy. This design makes it possible to measure the effects of the onset of pregnancy on sleep and physical activity and eliminates the potentially confounding impact of recall bias that commonly hampers studies that start in early pregnancy or use questionnaires. Another strength is the current regression model calculating the average of the individual difference in sleep and physical activity from before conception through the entire pregnancy (Table 2 and Fig. 3). The model took the individual variation into account and provided reliable estimates in spite of missing data [96]. TST and PAD were never included in the same regression model since their measurement was based on recordings from the same device and on movement count during the same 24-h period. In this setting, TST and PAD are highly inversely correlated. In addition to age and parity, the models were adjusted for pregestational body composition (height, lean body mass, and body fat percentage) since the body composition in a nonpregnant population is known to be related to physical activity [97] and sleep [76]. Others have shown that sleep disturbances associated with preexisting body composition can be aggravated in pregnancy [98], supporting adjustment of data for those parameters, even in healthy pregnancies. Our analysis demonstrated that those adjustments have a high impact and should be considered when the amount of daily sleep and activity is assessed.

One strength of actigraphy is the ability to measure sleep and activity both simultaneously and continuously in a natural environment for several days. The reliability and validity of actigraphy have been studied extensively using sleep diaries and polysomnography, which are standard methods for sleep assessment [99]. In healthy populations, actigraphy is considered a valid and reliable alternative for recording sleep [46,50].

A weakness of actigraphy compared with polysomnography, is its algorithm which uses motion and temperature to discriminate between sleep and awakeness [100]. This makes the sleep estimates less specific or not appropriate for assessments of other sleep qualities such as efficiency, satisfaction, or alertness [48,99,101]. Our software did not compute sleep onset latency (SOL) and wake after sleep onset (WASO). Further, our protocol did not include a sleep diary that would allow assessment of precise bedtime, wake-up, and voluntary daytime napping. Correspondingly, we do not report these classic measures. The reported sleep efficiency should be interpreted with some caution since our values are not based on exclusively nocturnal recordings, but a continuous 24-h registration over several days, as for all our measurements.

In addition to body movements, skin temperature recordings are incorporated into the SenseWear® actigraphy algorithm to distinguish between the states of sleep and awake, and the SenseWear® actigraph is not validated for sleep recording in pregnancy. The physiological temperature changes that accompany pregnancy may thus result in a systematic bias; however, this limitation is mitigated in the present study by the same technique being used consistently for all repeated measurements. The actigraph used in the present study has also been tested for sleep-time measurements under different ambient temperature conditions [50], yielding no significant difference from polysomnography under comparable conditions [50]. Further, it was found to be comparable with polysomnography for measuring TST in the setting of sleep disturbance in patients with OSA and non-OSA healthy controls [48,49]. The correlation with polysomnography in OSA and controls was high, at 0.92 and 0.91, respectively [49]. An earlier version of our actigraph was also validated for physical activity measurements in pregnancy compared with indirect calorimetry [43].

Weekday and seasonal variations are known confounders for the type of study described here [102,103]. Seasonal differences are especially important in regions where daylight hours are substantially lower during winter, such as in the present study. We found the start of pregnancy to be evenly distributed during the seasons, and with the exception of a higher level of prepregnancy physical activity during summer, there was no significant effect of season on sleep or physical activity (Appendix E). Furthermore, the varying numbers of weekend day recordings included in the statistical analyses did not significantly affect either the TST or PAD data (Appendix F).

We acknowledge that not considering sick leave, daily working hours, or working times as confounding factors may be a limitation of this study. However, the longitudinal changes in a large and healthy cohort were assessed, with recordings made over several days including weekends. None of the women were sick before conception, and sick leave or reduced weekly working hours may rather be attributable to normal pregnancy-related changes, since none of the women whose data were analyzed were admitted to a hospital due to serious pathology.

4.4. Summary

With the aid of around-the-clock actigraphy recording, this longitudinal study demonstrated that healthy women sleep for nearly 7 h per day, but with substantial variation (±2SD range >3.5 h) in the weeks before becoming pregnant. In early pregnancy, total sleep time increased by $\geq$ 30 min and remained so for the remainder of the pregnancy. Conversely, total physical activity duration decreased by < 90 min in early pregnancy, followed by a continued decrease throughout the remainder of the pregnancy.

The decrease was more pronounced for vigorous or moderate exercise than for light activity. Age, parity, body fat percentage, and lean body mass influenced the results in these healthy women during their naturally conceived pregnancies. We consider these patterns of changes in sleep and physical activity to be normal adaptations to pregnancy.

CRediT authorship contribution statement

Alexander Vietheer, MD: Methodology, investigation, software, data curation, visualization, validation, formal analysis, writing - original draft preparation, review and editing.

Torvid Kiserud, MD, Professor: Project administration, conceptualization, methodology, investigation, data curation, formal analysis, validation, visualization, writing - review & editing.

Rolv Terje Lie, Professor: Methodology, formal analysis, validation, visualization, writing - review & editing.

Øystein Ariansen Haaland, Professor: Methodology, software, formal analysis, validation, visualization, writing, review and editing.

Jörg Kessler, MD, Professor: Project administration, methodology, investigation, formal analysis, validation, visualization, writing - review & editing.

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Conflict of interest

The authors have no competing interest to declare.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2021.04.028

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2021.04.028.

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