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Sleep in the womb: Preliminary insights into fetal activity patterns

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INTRODUCTION

Sleep-wake rhythms start developing in the womb[1]. Although the importance of sleep-wake regulation for early development is increasingly established, little is known about the diurnal rhythms of fetal behavior. Animal research has shown that a chronic photoperiod shift during pregnancy alters the maternal circadian rhythm and affects the circadian system of the offspring[2]. We thus aimed to 1) characterize fetal activity patterns across the last trimester of pregnancy and 2) quantify their relationship with maternal rhythms.

METHODS

Twenty-nine pregnant women (mean age=34 ± 4 years) were equipped with four wearable acceleration sensors (SENSmotion, SENS Innovation ApS, Copenhagen, Denmark; Figure 1) to record deflections of the abdominal wall continuously over five days with a sampling rate of 25 Hz. During two hours of daily rest, participants kept a minute-by-minute diary of their own and their child's movements. For analysis, we excluded intervals that participants marked as involving their own movement to minimize contamination of fetal signals. Additionally, we used one acceleration sensor placed above the heart to eliminate maternal movement from the abdominal sensor data. In line with a previously published procedure to detect fetal movement[3], we filtered the abdominal signals and calculated the integral amplitude for 100-millisecond windows. The algorithm developed by Oakley[4] was applied to classify these signals into rest and activity in 1-second intervals. The longest period of rest for each fetus was normalized by the total duration of maternal rest periods analyzed.

To track maternal activity and rhythm, we employed a wrist actimeter at a sampling rate of 30 Hz (GENEActiv, Activinsights Ltd, Kimbolton, UK; Figure 1B) and a temperature sensor at a sampling rate of 60 seconds placed below the right clavicle (iButton, Maxim Integrated, San Jose, USA; Figure 1B) during the same time period. Two measures were extracted:

1) **Circadian function index (CFI)** from wrist actimetry data to characterize maternal rhythm robustness ranging from 0 to 1 (maximal robustness)[5,6].
2) **Temperature offset** by fitting a polynomial curve through the temperature data. We extracted and averaged the locations of troughs relative to midnight for each participant.

Linear regression was applied to quantify the effect of gestational age, maternal CFI and maternal temperature offset on the **longest normalized fetal rest duration**.

RESULTS

The longest absolute fetal rest duration ranged between 0.7 and 10 minutes (mean=3 ± 2 minutes). We found a positive association between the longest normalized rest duration and gestational age (mean=34 weeks ± 19 days; Figure 2). Linear regression modelling revealed gestational age as the only significant contributor to fetal rest duration (Table 1), suggesting that older fetuses show more consolidated rest time. Maternal CFI and temperature offset showed no association with fetal rest duration.

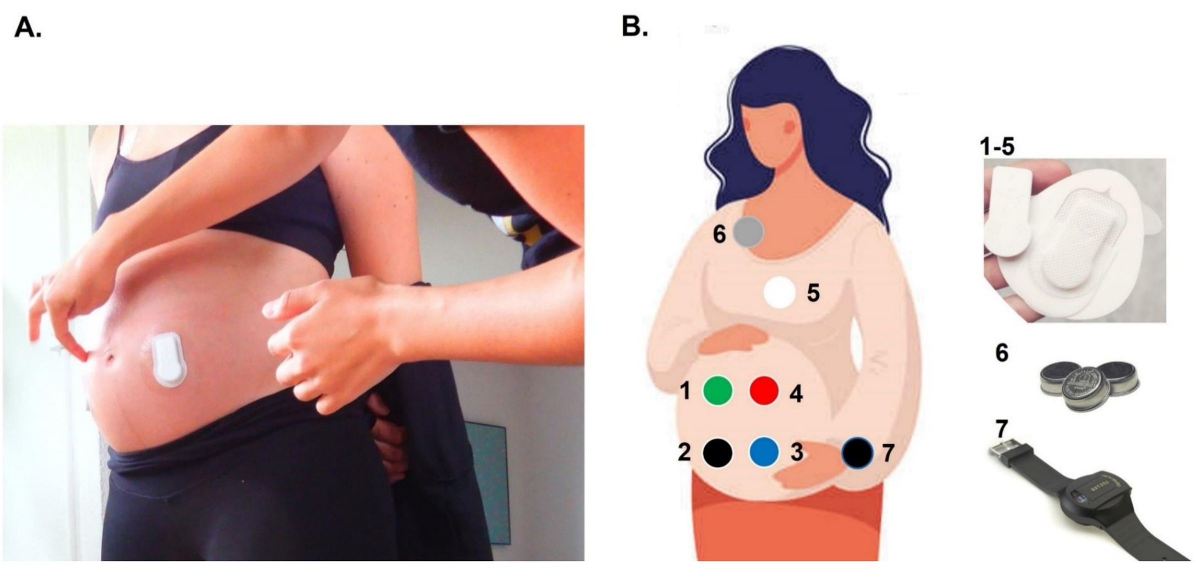

Figure 1: A. Attaching sensors during a home visit. B. Placement of sensors including four abdominal actimeters (1 to 4), one chest actimeter (5), one temperature sensor (6) and one wrist actimeter (7).

Table 1: Unstandardized beta coefficients and the corresponding p-values resulting from a linear regression model. Significant effects on longest normalized fetal rest duration are depicted in bold.

	β	p
Intercept	-0.0355	0.062
Gestational age	**0.0001**	**0.039**
CFI	0.0115	0.477
Temperature offset	0.00002	0.303

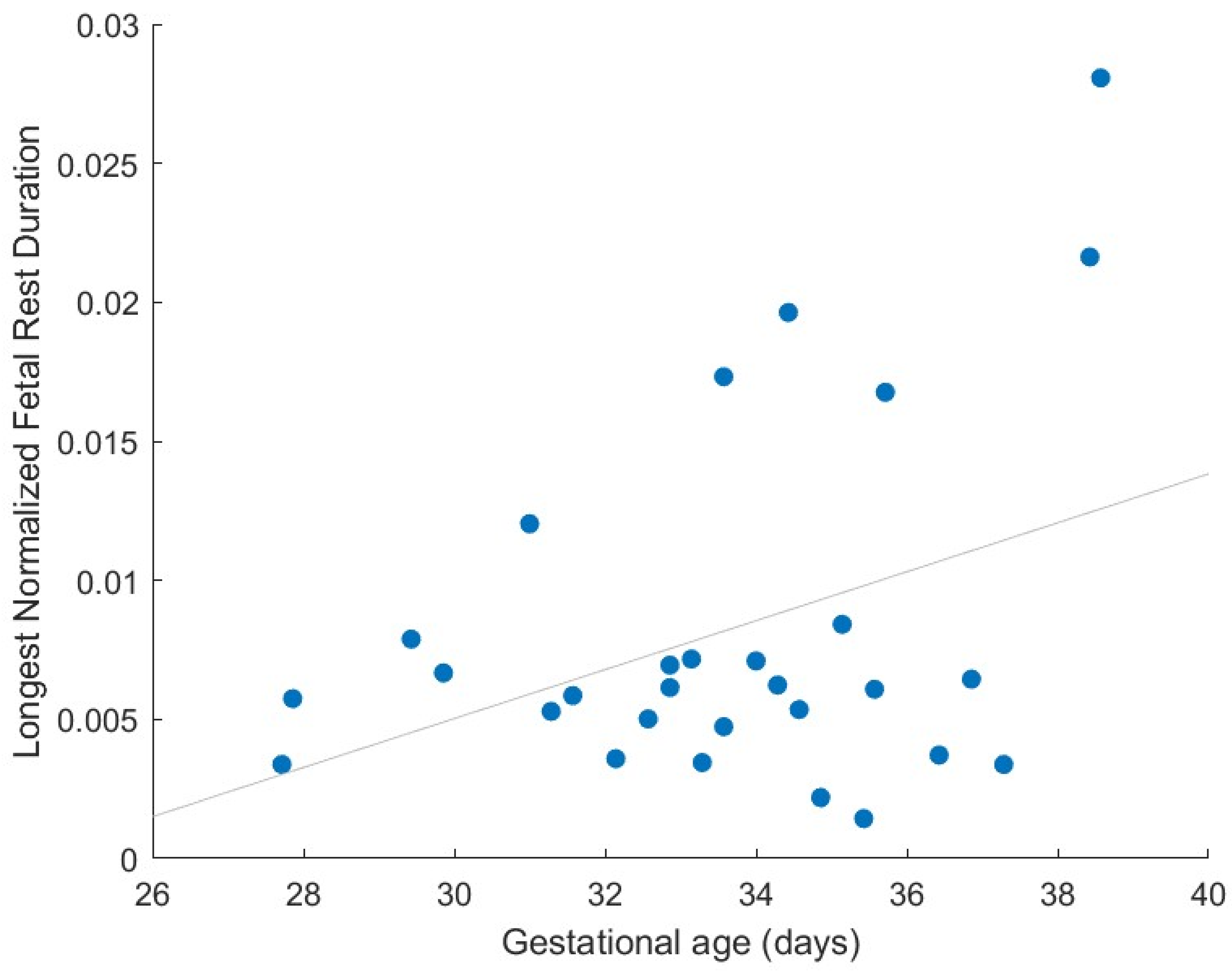

Figure 2: Relationship between gestational age and the longest fetal rest duration (in minutes) normalized by the total duration of the included time periods (in minutes). A least-squares line fit through the data is shown in grey.

CONCLUSION

This research is the first to apply wearable technology for continuous measurement of fetal sleep-wake patterns, representing an important step towards precision medicine. Our preliminary findings show that older fetuses exhibit longer periods of rest suggesting that the gradual increase in consolidated rest periods starts before birth and continues through the ontogeny of sleep observed after birth. While maternal CFI and temperature offset did not determine fetal consolidated rest, we believe that our study will help unravel other pregnancy-related factors associated with early sleep regulation and discover opportunities for interventions targeting regulatory difficulties in infants.

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