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Comparing prenatal and postpartum stress among women with previous adverse pregnancy outcomes and normal obstetric histories: A longitudinal cohort study

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ABSTRACT

Objective: The aim of this study was to compare subjectively and objectively measured stress during pregnancy and the three months postpartum in women with previous adverse pregnancy outcomes and women with normal obstetric histories.

Methods: We recruited two cohorts in southwestern Finland for this longitudinal study: (1) pregnant women (n = 32) with histories of preterm births or late miscarriages January–December 2019 and (2) pregnant women (n = 30) with histories of full-term births October 2019–March 2020. We continuously measured heart rate variability (HRV) using a smartwatch from 12 to 15 weeks of pregnancy until three months postpartum, and subjective stress was assessed with a smartphone application.

Results: We recruited the women in both cohorts at a median of 14.2 weeks of pregnancy. The women with previous adverse pregnancy outcomes delivered earlier and more often through Caesarean section compared with the women with normal obstetric histories. We found differences in subjective stress between the cohorts in pregnancy weeks 29 and 34. The cohort of women with previous adverse pregnancy outcomes had a higher root mean square of successive differences between normal heartbeats (RMSSD), a well-known HRV parameter, compared with the other cohort in pregnancy weeks 26 (64.9 vs 55.0, p = 0.04) and 32 (63.0 vs 52.3, p = 0.04). Subjective stress did not correlate with HRV parameters.

Conclusions: Women with previous adverse pregnancy outcomes do not suffer from stress in subsequent pregnancies more than women with normal obstetric histories. Healthcare professionals need to be aware that interindividual variation in stress during pregnancy is considerable.

Introduction

Many pregnant women experience stress at some point in pregnancy, a major event in a woman's life [1]. During stress, environmental demands exceed the individual resources available to cope; however, stress is a multidimensional concept [2]. Stress can be caused by major life events, daily hassles, work, or relationship issues [3]. Pregnancy-specific stress may arise from bodily changes and symptoms during pregnancy or from concerns about childbirth and the health of the unborn baby [4].

Stress activates the sympathetic nervous system and achieves different physiological responses in a human body. In general, a body recovers from stressful situations by normalizing the physiological responses. However, extended periods of stress may keep the body's responses to stress elevated and lead to pathological conditions such as fatigue or depression [5]. Frequent sources of stress may lead to some level of adaptation to highly stressful environments [6]. One hypothesis is that maternal stress may program a stress response in the foetus [7]. In some studies, maternal stress during pregnancy is associated with

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preterm birth, a low-birth-weight infant, pregnancy-induced hypertension, and mental and behavioural disorders in children [8]. A recent *meta*-analysis suggested a link between high maternal prenatal stress and a child's autism spectrum disorder, obesity, and infantile colic [7]. Thus, relieving stress may benefit both maternal and infant health.

The level and experience of stress is subjective. It could be assumed that women with previous adverse outcomes in pregnancy (other than normal live birth) experience more psychological stress during subsequent pregnancies compared to women with previous uncomplicated pregnancies. However, few studies are available on this subject. Previous adverse pregnancy outcomes, such as miscarriages or preterm births, have been associated with poorer quality of life and more symptoms of anxiety and depression during subsequent pregnancies [9,10]. However, these studies include many other adverse outcomes, such as stillbirth and early neonatal death. Qualitative studies have shown that women appreciate being treated in specialist care after a previous preterm birth [11], and although they may be scared or nervous about their pregnancies, they are pleased with the extra care provided [12].

Measuring stress is challenging due to individual variations and the multifaceted nature of stressful experiences [13]. In maternity care, researchers recommend that the level of psychological stress be examined at every antenatal appointment [7,13]. Previous studies mainly have used self-reporting to assess stress [7]. However, objective measures to assess stress in pregnant and postpartum women could help healthcare professionals provide timely support.

Heart rate variability (HRV) reflects changes in autonomic nervous control and, therefore, represents physiological responses to various psychological and environmental stimuli [5]. HRV can be used to estimate psychological stress in adults [14] as well as pregnant women [15]. Pregnancy itself has an impact on HRV because of changes in the autonomic nervous and cardiovascular systems [16,17]. HRV is traditionally measured using electrocardiography (ECG) in laboratory circumstances, but it can also be measured reliably with photoplethysmography (PPG) [18], which is a non-invasive optical method and can be applied in normal daily life.

Our research group has developed a monitoring system using the Internet of Things platform (IoT), consisting of a smartphone application for subjective measures of stress and a smartwatch equipped with a PPG sensor measuring HRV as an estimate of psychological stress [19]. As high-level prenatal stress may have severe adverse effects on both the mother and her baby, and long-term objective measurement of prenatal stress has not been conducted; applying this monitoring system to pregnant women is justified. The aim of this study was to compare subjectively and objectively measured stress during pregnancy and three months postpartum in women with previous adverse pregnancy outcomes (preterm births or late miscarriages) and women with normal obstetric histories (full-term births and no pregnancy losses).

Methods

Study design

We used a longitudinal cohort study design. We asked the participants to wear a smartwatch to measure HRV and to use a smartphone application to collect subjective stress levels. We performed the data collection from gestational week (gwk) 12 to 15 and for three months following delivery.

Participants

We recruited two cohorts of pregnant women for the study via social media advertisements or maternity clinics in southwestern Finland. Regarding social media, we used different pregnancy-related groups on Facebook. All eligible participants had to have singleton pregnancies currently in gwk 12–15. Furthermore, they had to be Finnish-speaking and have an Android or iOS smartphone. The sample size was chosen in order to complete data collection in a reasonable amount of time. The first cohort of pregnant women (n = 32) with histories of preterm births (22–36 gwks) or late miscarriages (12–21 gwks) was recruited between January and December 2019. The second cohort of pregnant women (n = 30) with histories of full-term births (gwks 37–42) and no pregnancy losses was recruited between October 2019 and March 2020.

Based on the advertisement or preliminary information provided from the maternity clinic, pregnant women contacted the researchers by email, and/or the researcher phoned the interested women. After this initial contact, we arranged a meeting to sign a written informed consent and provide the study equipment.

Measurements

HRV was measured using a smartwatch equipped with PPG sensors. The standard deviation of normal-to-normal interbeat intervals (SDNN) and the root mean square of successive differences between normal heartbeats (RMSSD) as time-domain HRV metrics were calculated [14]. We used only night-time data to avoid motion artefacts due to hand movements and to capture HRV at resting heart rate. We assessed subjective stress via a smartphone application [19]. The application included a question about the level of stress during the past week, asked every-seven days. The participant was able to answer the question any time that day. The question was developed for this study and not validated before data collection. The wording of the question was similar each week: "How would you rate your stress level in the last week?" The participants rated their stress levels numerically from 0 (no stress) to 100 (very high). Different levels of stress were not indicated in the question or based on numerical responses.

Data collection

A cross-platform mobile application was developed and installed on participants' smartphones to collect subjective and self-reported data. We delivered a Samsung Gear Sport smartwatch to each participant and asked them to wear the watch continuously from their recruitment until three months postpartum.

The Samsung Gear Sport smartwatch is a lightweight open-source smartwatch equipped with adequate internal memory, a processing unit, and a PPG sensor. The open-source platform enabled us to develop customized data collection and data transmission applications on the watch. Our customized smartwatch application collected 12 min of PPG signals every second hour. The setup enabled us to collect a sufficient amount of data and, at the same time, ensure a satisfactory smartwatch battery life (i.e., two to three days after a full charge). The sampling frequency of the PPG signals was 20 Hz (Hz), and the data were stored on the watch's internal memory. A smartwatch application was developed to send the collected data to a cloud server through a Wi-Fi connection. We instructed the participants to upload their data regularly (once a week) to the cloud server. They were notified via text messages or emails if they forgot to upload the data.

Data analysis

We analysed the PPG signals using short-term HRV analysis, a standard analysis that uses five-minute segments of PPG signals to extract HR and HRV parameters [20]. We performed the data analysis in the cloud server. Our data analysis pipeline took five-minute segments of PPG signals as input and consisted of several steps.

First, we extracted reliable PPG signals. PPG signals can be distorted due to environmental noise and motion artefacts. Such noise is inevitable in everyday life and impacts the quality of the signals and, subsequently, the accuracy of extracted parameters [21]. Therefore, unreliable PPG signals should be detected and discarded. For this purpose, we exploited a support vector machine for classification and programmed it using several morphological features extracted from the PPG signal. The PPG signal features used for classification were skewness, kurtosis, approximate entropy, Shannon entropy, and spectral entropy.

Second, we performed peak detection and interbeat interval (IBI) extraction. We used a bandpass filter with cut-off frequencies of 0.7 Hz to 3.5 Hz to filter frequencies not in the range of human heart rates. Then, we used a moving average method with adaptive thresholds to detect all the peaks and remove false peaks. The output consisted of systolic peaks and normal IBIs. We implemented the peak detection and IBI extraction method using the HeartPy library in Python.

Third, we extracted the heart rate and HRV parameters from the IBI signals. The heart rate was calculated as the average number of peaks per minute in each segment. The HRV parameters indicated the variation of IBIs in each segment. We used IBIs in five-minute segments of reliable signals to extract the SDNN and RMSSD.

HRV parameters significantly correlate with the average heart rate, which increases during pregnancy [22]. Therefore, we used normalized HRV parameters to control for the change in baseline heart rate during pregnancy. For normalization, we divided IBIs by average IBI values in each segment of the PPG signal [23]. Then, we extracted the normalized SDNN (nSDNN) and the normalized RMSSD (nRMSSD) using normalized IBIs per each five-minute segment.

The background characteristics of the participants were described using median, range, frequencies, and percentages. The characteristics between the cohorts were compared using a chi-square test or a two-sample *t*-test (or a Mann–Whitney *U* test for non-normal data). Linear mixed models were used for modelling the change within the cohorts and the difference in the change for the subjectively assessed stress levels, nSDNN, and nRMSSD. Gwk 14 was used as a baseline because gwks 12 and 13 had too few participants. To detect possible differences between the cohorts, we performed *t*-tests for subjectively assessed stress and HRV parameters each week. We calculated weekly correlations between subjectively assessed stress and objectively measured HRV parameters for both cohorts using the Pearson correlation coefficient. For all analyses, we used the mean of the weekly nSDNN and nRMSSD for each participant. Statistical analysis was performed using R version 4.0.2.

Ethical issues

The Ethics Committee of the Hospital District of Southwest Finland evaluated the study proposal and provided a favourable statement (Dnro: 1/1801/2018) before data collection was initiated. A written informed consent was obtained from each participant.

Results

Participants

A total of 32 women with previous adverse pregnancy outcomes and 30 women with normal obstetric histories participated in the study. In both cohorts, we recruited women at a median 14.2 gwks with a range of 10.1–16.6 gwks in the cohort of women with previous adverse pregnancy outcomes and a range of 12.4–15.7 gwks in the cohort of women with normal obstetric histories. Four participants from the cohort of women with previous adverse pregnancy outcomes withdrew from the study before the end of the follow-up, but the data collected by then were included in the analyses.

Data from the women was tracked approximately-six–seven months during pregnancy and three months following birth. The background characteristics of the participants in both cohorts were similar. The participants' subjectively assessed stress before pregnancy and at recruitment greatly varied at an individual level; however, we found no differences between the cohorts (Table 1).

Table 1
Characteristics of the participants in both cohorts.

	Women with previous adverse pregnancy outcomes n = 32	Women with normal obstetric histories n = 30	P value
Age, years median (range)	32.5 (24–43)	31.5 (23–39)	0.746
BMI, median (range)	24.7 (18.0–40.4)	25.1 (17.8–45.9)	0.592
Married/cohabiting	31 (97 %)	30 (100 %)	0.516
Smoking during pregnancy	1 (3 %)	0 (0 %)	0.516
Pregnancy planned, n(%)	30 (94 %)	27 (90 %)	0.667
University level education, n(%)	10 (31 %)	8 (27 %)	0.102
Employed/full-time student	26 (81 %)	28 (93 %)	0.205
Gestational age at recruitment, median (range)	14.2 (10.1–16.6)	14.2 (12.4–15.7)	0.778
Subjective stress level before pregnancy (0–100), median (range)	45.5 (10–80)	41.5 (1–90)	0.500
Subjective stress level at recruitment (0–100), median (range)	53.5 (9–100)	42.5 (3–100)	0.314

The pregnancy outcomes of the cohorts differed significantly. The women with previous adverse pregnancy outcomes had more caesarean sections, a shorter gestational time, and by implication, a lower median birth weight of their infants (Table 2). In the cohort of women with previous adverse pregnancy outcomes, six women delivered prematurely (<37 gwks), whereas in the cohort of women with normal obstetric histories, one woman had a preterm infant.

Subjectively assessed stress levels

We found significant differences between the cohorts at 29 gwks when the cohort of women with previous adverse pregnancy outcomes displayed lower stress and at 34 gwks when the same cohort had higher stress. The weekly mean values of stress during pregnancy varied between 29 and 53 in the cohort of women with previous adverse pregnancy outcomes and between 38 and 55 in the cohort of women with normal obstetric histories.

We found no significant differences between the cohorts in the postpartum period. The weekly mean values varied between 28 and 50 in the cohort of women with previous adverse pregnancy outcomes and 33–48 in the cohort of women with normal obstetric histories (Fig. 1).

Regarding the changes in time, no trends in subjectively assessed stress levels were detected during pregnancy or after birth in either of the cohorts.

Table 2
Pregnancy outcomes in both cohorts.

	Women with previous adverse pregnancy outcomes n = 25*	Women with normal obstetric histories n = 29*	P value
Vaginal birth, n (%)	18 (69 %)	27 (93 %)	0.025
Gestational age at delivery, median (range)	38.4 (32.6–41.9)	40.1 (36.6–41.9)	<0.001
Infant birth weight, g, median (range)	3316 (2052–4154)	3800 (3152–4630)	<0.001

*Missing data, n = 7 in a cohort of women with previous adverse pregnancy outcomes and n = 1 in a cohort of women with normal obstetric history.

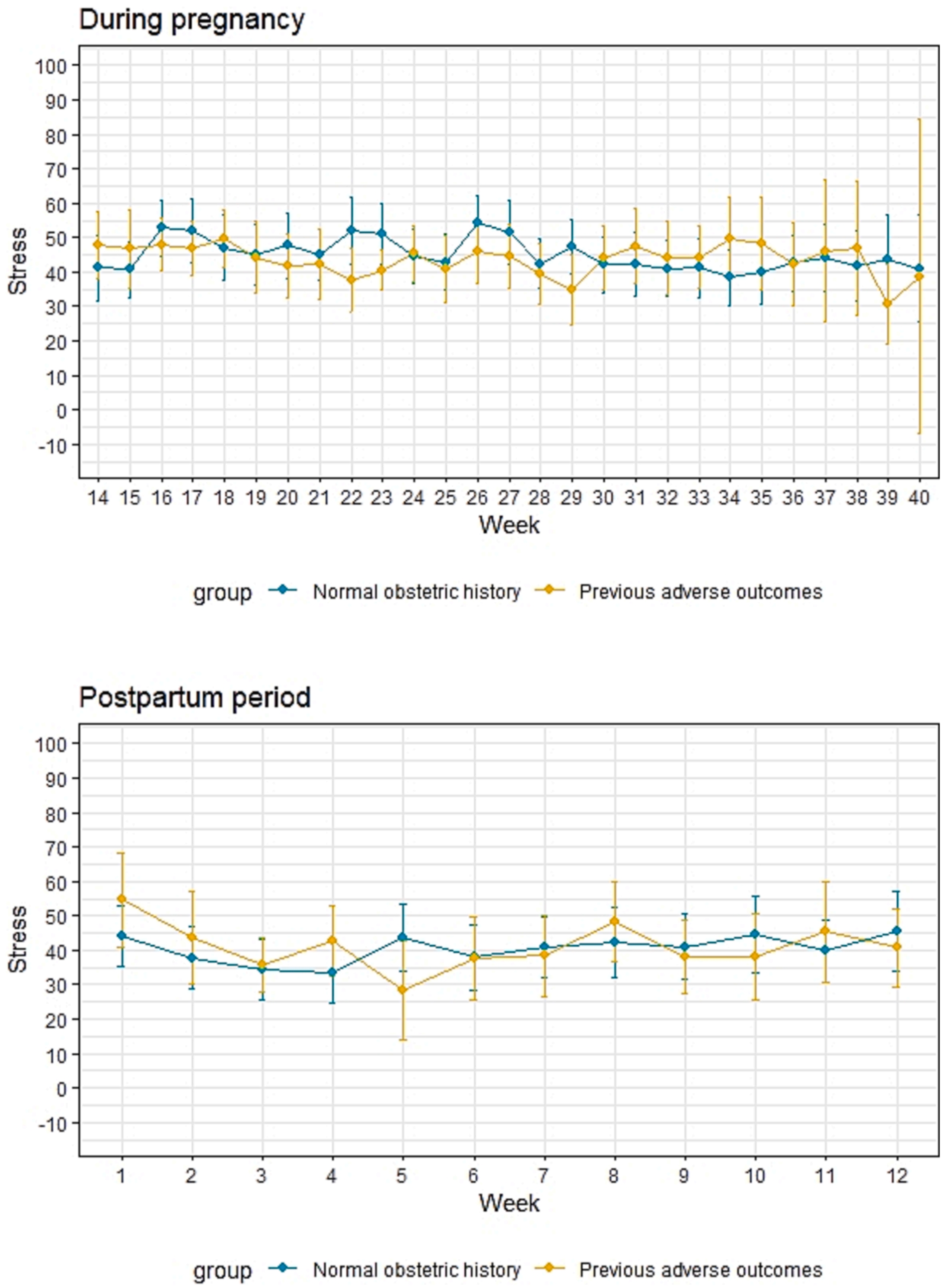

Fig. 1. The weekly subjective stress level assessments (mean and confidence intervals) in both cohorts during pregnancy and after the birth.

Objectively measured stress levels

No significant differences in the SDNN were found between the cohorts during pregnancy. Concerning the RMSSD, the cohort of women with previous adverse pregnancy outcomes had significantly higher values compared with the other cohort at 26 gwks (64.9 vs 55.0, $p = 0.04$) and 32 gwks (63.0 vs 52.3, $p = 0.04$).

Considering the cohort of women with previous adverse pregnancy outcomes, the HRV parameters remained stable during the first study weeks (14–17 gwks). Both the SDNN and RMSSD decreased at 18 gwks. The SDNN remained at a lower level compared with the initial level until 31 gwks and decreased again at 33 gwks before increasing and returning closer to the initial level at 14 gwks. The RMSSD remained at lower levels until 38 gwks and returned close to the initial level during the last weeks of pregnancy.

In the cohort of women with normal obstetric histories, the HRV parameters remained stable during 14–20 gwks. The RMSSD decreased at 21 gwks, and the SDNN at 24 gwks. Both remained significantly lower compared with the initial level until 35 gwks. Thereafter, during the last weeks of pregnancy, the SDNN returned to almost the same initial level. The recovery of the RMSSD was slower, as it was again significantly lower at 37 and 38 gwks before returning close to the initial level (Fig. 2).

During the three months postpartum period, no significant differences in the HRV parameters were detected between the cohorts. Furthermore, both the SDNN and RMSSD remained stable, and we detected no significant changes compared with the third trimester at 36 gwks in either of the cohorts (Fig. 3).

Weekly mean values of nSDNN, nRMSSD, and subjective stress are presented in a supplementary table.

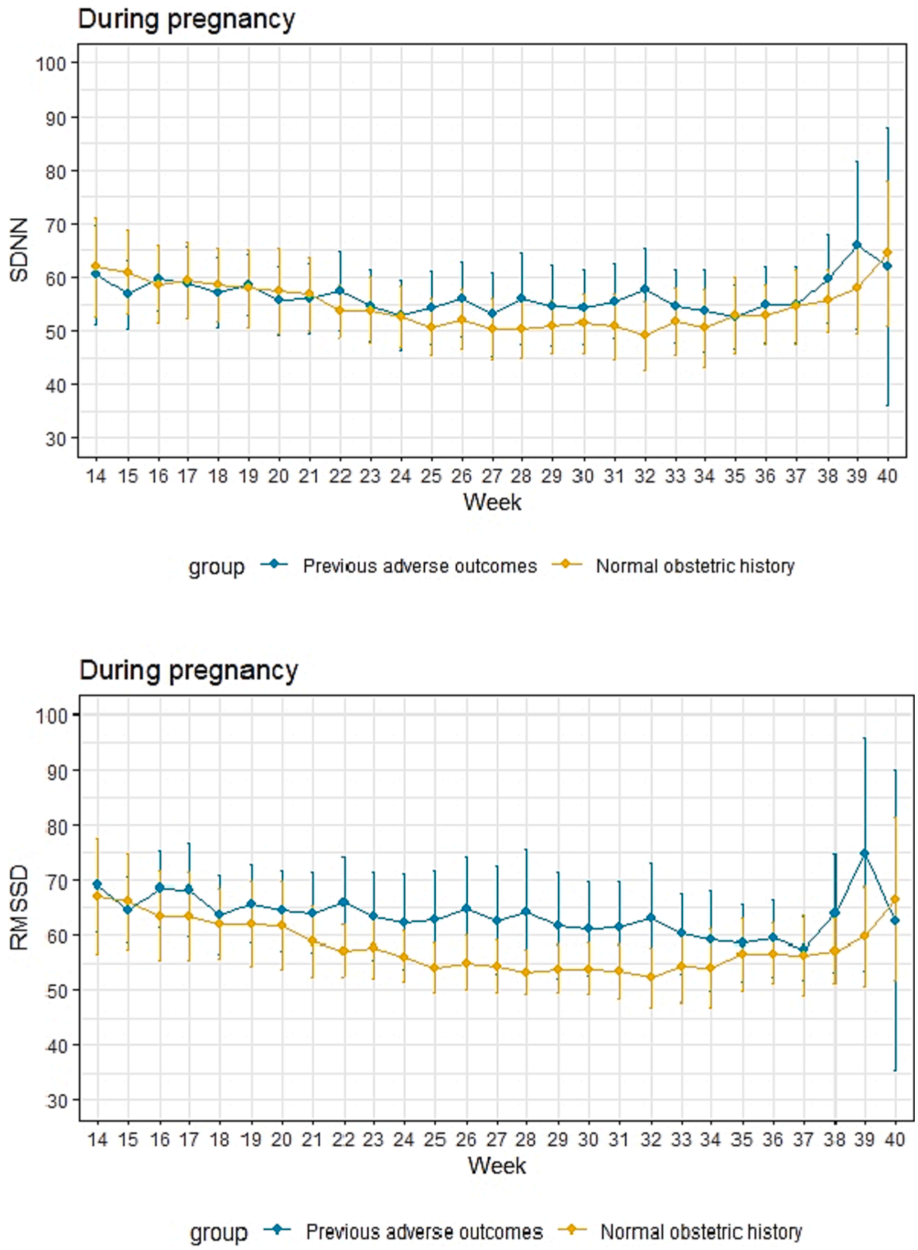

Fig. 2. The trends of HRV variables (means and confidence intervals of SDNN and RMSSD) in both cohorts during pregnancy.

Correlation between subjective and objective stress in both cohorts

Subjectively assessed stress levels did not correlate with objectively measured HRV parameters during the pregnancy or postpartum periods, and low negative and positive correlations alternated throughout the measurement period (Fig. 4).

Discussion

Women with previous adverse pregnancy outcomes did not suffer from more stress than women with normal obstetric histories during subsequent pregnancies and during the three-month postpartum period. The level of stress was measured using both subjective weekly assessments and a continuous night-time HRV. In all participants, the HRV parameters, SDNN, and RMSSD decreased as the pregnancy proceeded but started to increase at the end of the pregnancy. Subjectively and objectively measured stress did not correlate.

Based on previous studies, perceived stress has either decreased [24] or increased [25] as pregnancy proceeded, but in this study, we detected no such trends. The differences between the cohorts are difficult to explain because we were not able to control all the factors influencing HRV. Many physical conditions, lifestyle choices, or medication may affect HRV results [5]. In contrast to our hypothesis, women with previous adverse pregnancy outcomes did not report considerably higher levels of subjectively assessed stress [9,10]. Women who experienced adverse, or even traumatic events during their previous pregnancies may have recovered before becoming pregnant again [26]. Secondly, the perceived emotional support of a pregnant woman may have facilitated recovery from acute stress [6]. In Finland, the care of preterm infants in the neonatal intensive care units (NICUs) is of high quality. Many NICUs follow family-centred care principles that may decrease psychological distress, such as the postnatal depression of mothers [27]. Thirdly, the experience of having already coped, despite adverse pregnancy outcomes, may decrease distress in a subsequent pregnancy.

Support in stressful situations and life events should be available. The Finnish maternity care system provides regular visits and support

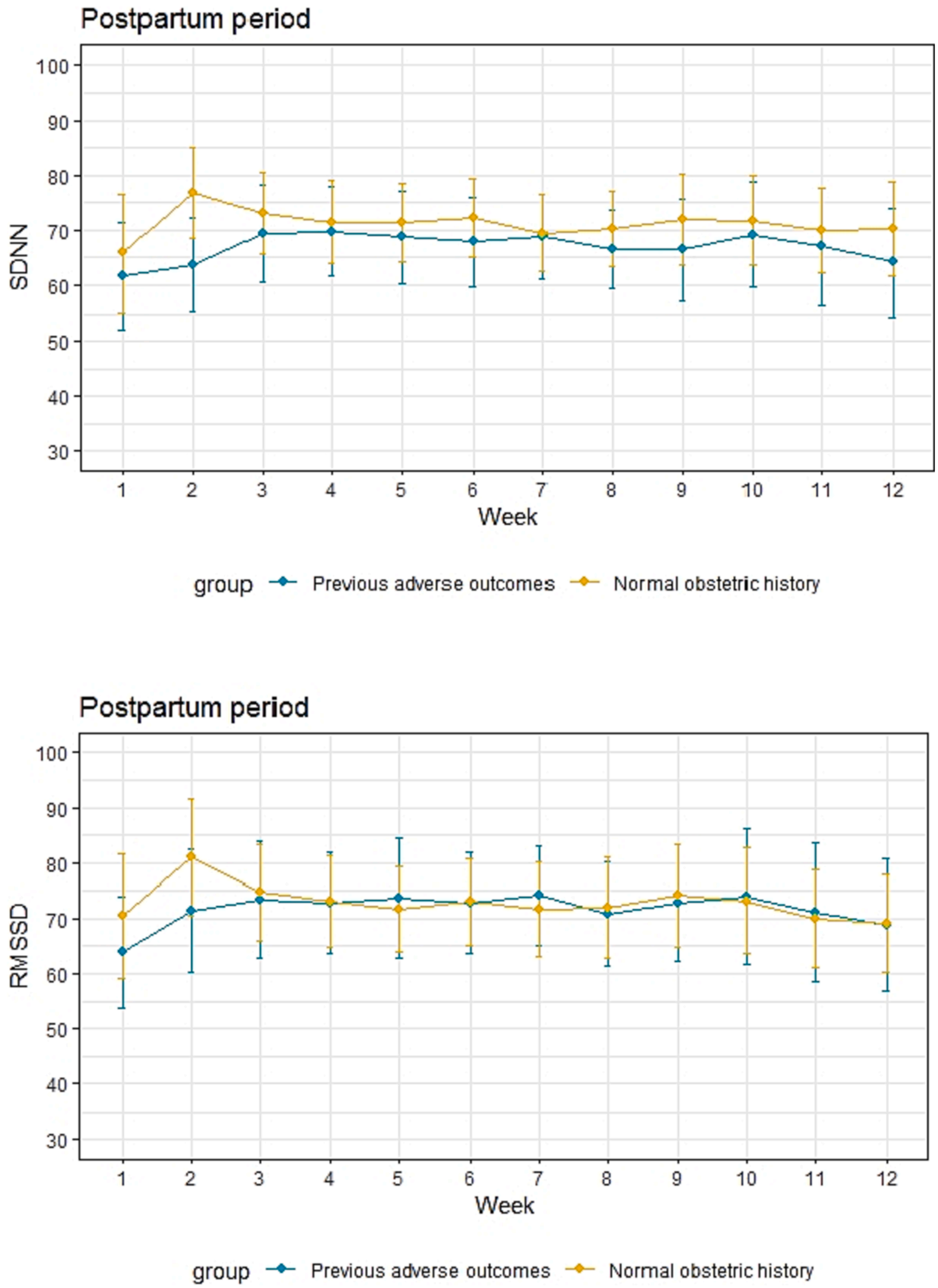

Fig. 3. The trends of HRV variables (means and confidence intervals of SDNN and RMSSD) in both cohorts during the twelve weeks postpartum period.

for each pregnant woman. At antenatal visits, it is very important to screen or ask about stress from a pregnant woman, as well as her ability to cope with stress, to be able to tailor support accordingly [7]. Notably, participating women in this study were highly educated, non-smoking, and married, with planned pregnancies; thus, we could assume they had social support and good resources to cope with stress. However, interindividual variation in subjective stress scores during recruitment and across pregnancies was considerable. The subjective assessment of stress poses challenges for comparisons, as the experience of stress is very personal [13]. Furthermore, the sources of stress may have varied and were not investigated in this study. In future studies, this should be considered because the sources of stress could support the interpretation of the HRV results. For example, some of the participants may have suffered from high stress caused by major life events and nothing related to pregnancy [3].

This study suggests that previous adverse pregnancy outcomes do not increase maternal stress in subsequent pregnancies as evaluated through HRV. However, the interpretation of different HRV parameters is not straightforward. Many physical and environmental factors as well as lifestyle habits affect HRV [5]. Furthermore, the state of pregnancy is known to affect maternal HRV, also shown in the present study [17]. Although subjective and objective stress measures yielded similar results, the measures did not correlate. According to Klinkenberg et al. [15], subjective stress perception may not follow changes in HRV, whereas Shah et al. [28] found a correlation between perceived stress and HRV. Manifestation of stress varies, and the symptoms of stress can be emotional, physical, cognitive, or behavioural [29]. The individual nature of stressful experiences may partly explain the missing correlation.

Few studies on HRV during the postpartum period are available. In a

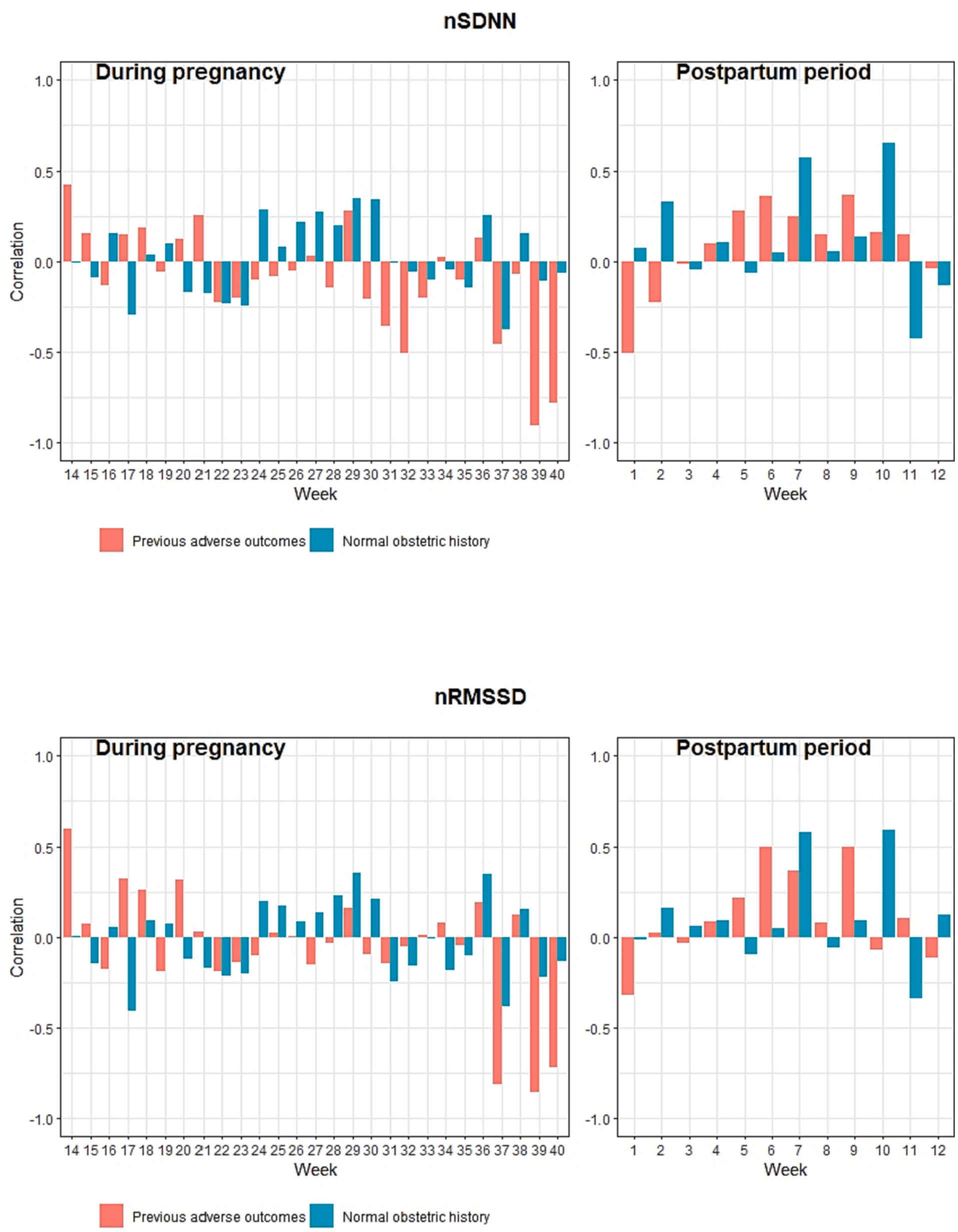

Fig. 4. Weekly correlations between subjectively assessed stress and normalised HRV parameters in both cohorts during pregnancy and postpartum period.

follow-up study, Brown et al. [30] reported an increase of the RMSSD and High-Frequency power (HF) between the third trimester and four–six weeks postpartum. In this study, no such change was detected during the three-month postpartum period, whereas the HRV started to recover already at the end of each pregnancy. Previous studies [16,17] have conducted few or no measurements of HRV during the last weeks of pregnancy; thus, the possible increase in HRV might not have been detected.

The data collection of this study was partly conducted during the COVID-19 pandemic. The results concerning the effect of the lockdown on stress in pregnant women is conflicting (e.g., [31,32]). Most of the women with previous adverse pregnancy outcomes had given birth by the time of the first wave of the pandemic in Finland, as their cohort was recruited earlier. Correspondingly, most of the women with normal obstetric histories gave birth during the pandemic. The circumstances were different as the pandemic caused many restrictions to social contact; however, in this study we detected no significant differences in the data collected. It could be speculated whether the group of women with normal obstetric histories would have had significantly lower stress levels without the pandemic. However, our previous detailed HRV analysis before and during the lockdown period suggested that pregnant women coped well with pandemic-related restrictions [32].

To our knowledge, this is the first research project in which HRV was continuously measured throughout pregnancy and the three months postpartum in a free-living environment using PPG sensors. In previous studies, HRV was measured intermittently during pregnancy using ECG in laboratory environments (e.g., [33]) or Holter monitoring [34]. PPG sensors in pregnant women have also been used to measure their resting HRV in laboratory settings [18]. Although some compromises persist regarding the quality of the data, the feasibility of continuous monitoring with smart devices using PPG sensors is promising [35].

Limitations

The sample size was rather small to draw strong conclusions. Although both preterm births and late miscarriages are traumatic experiences [9], the outcomes of these pregnancies greatly differ. Miscarriage inevitably leads to the death of a foetus, but preterm birth can result in a completely healthy baby. In future studies, investigating these groups separately would be interesting.

The low sampling rate of HRV constitutes a limitation. In ECG measurements, a sampling rate of 1 kHz is often used, and for PPG measurements conducted via smartwatches, the sampling frequency is inevitably lower. In our study, the sampling frequency was 20 Hz, which should provide reliable results based on Choi & Shin [36], where lower sampling frequencies were compared with 10 kHz ECG. We used time-domain measures (SDNN and RMSSD) in which the low sampling frequency should be sufficient [36]. PPG signals are also highly susceptible to motion artefacts, which was considered when processing the data. Furthermore, the subjective assessment of stress was based on a non-validated single question on a weekly basis. Using more detailed questions or a validated instrument could have changed the results. However, the single question was chosen to minimize the burden on the participants. For the same reason, the sources of stress were not asked. Despite the limitations, this study has provided unique long-term data of pregnant women's HRV and stress levels. Although the results as such may not be generalizable, the knowledge about PPG sensors as long-term measures of stress could be utilized more widely.

Conclusions

Women with previous adverse pregnancy outcomes, such as late miscarriages or preterm births, do not suffer from psychological stress in subsequent pregnancies more than women with normal obstetric histories. As there seems to be great interindividual variation in stress levels, pregnant women with high stress levels need to be identified to prevent any adverse effects. Therefore, the results of this study strengthen the recommendation of examining the level of psychological stress at every antenatal appointment. Further, PPG sensors seem to be a feasible method to measure continuous HRV in free-living conditions. In future studies, larger samples are needed, and the sources of stress should be measured more precisely. Continuously developing smart devices using PPG may provide even more accurate measures for stress in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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