Pilot and Feasibility Studies

RESEARCH

Open Access

# Feasibility and tolerability of physiologic monitoring among pregnant nurses and nursing teams

Isha Agarwal[1,2*], Madeleine Puissant[1,2], Irit Altman[1], Alexandra Hinton[2], Tania D. Strout[1] and Erika L. Sabbath[3,4]

**Background** Most studies of stress during pregnancy have relied on self-reported and recalled measures, leaving a knowledge gap about the impact of acute, or momentary, stressors. Heart rate, blood pressure, and cortisol are physiologic measures known to increase acutely in response to acute stress. The feasibility of collecting these measures has not been widely reported among pregnant workers outside of a controlled laboratory setting.

**Methods** This pilot study assessed the feasibility and tolerability of measuring ambulatory heart rate, blood pressure, and diurnal urine cortisol during periods of work and rest among pregnant nurses, nursing assistants, and clinical technicians.

**Results** Over a 9-month enrollment period, we received 31 inquiries from potential candidates, of whom 18 met our eligibility criteria and 12 accepted enrollment (67% acceptance rate). Over the study period, 4 enrollees withdrew their participation, and 8 were retained until the end of the study (67% completion rate). Our feasibility threshold was the acquisition of ≥ 80% of expected measurements for heart rate, blood pressure, and urine cortisol among retained participants. We achieved our feasibility target for blood pressure recordings (acquiring 84% of expected measures) but not for heart rate recordings (acquiring 60% of expected measures). Urine cortisol levels were successfully obtained 97% of the time. Through qualitative analysis of comments provided by study participants, we identified three major themes surrounding barriers to completing physiological monitoring: (1) personal discomfort and technical issues with study equipment, (2) work or activity interference, and (3) concerns about study design.

**Conclusions** While physiologic monitoring of pregnant workers is important for learning about how work might impact pregnancy outcomes, equipment challenges pose a significant barrier to study participation. Future studies should allow for a significant withdrawal rate or explore alternative equipment options.

**Keywords** Stress, Pregnancy, Physiology, Monitoring

## Key messages regarding feasibility

- The feasibility of measuring physiologic markers of acute stress has not been widely reported among pregnant workers outside of a controlled laboratory setting.
- Equipment challenges pose a significant barrier to study participation in ambulatory heart rate and blood pressure monitoring of pregnant shift workers.

*Correspondence:
Isha Agarwal
Isha.Agarwal@mainehealth.org
Full list of author information is available at the end of the article

- Future studies should allow for a significant withdrawal rate or explore alternative equipment options.

## Introduction

Over 4.9 million nurses are employed in the USA, and approximately half of them are women of reproductive age [1]. Nurses practice in a unique occupational environment that can require night shift work, long working hours, prolonged standing, and heavy lifting. In the Nurses' Worklife and Health study [2], one-third of nurses worked more than 40 h per week, and 17% reported having to participate in mandatory overtime. Additionally, many nurses work in high-acuity settings, such as the emergency department or intensive care unit, where they must routinely navigate stressful situations like resuscitating critically ill patients, de-escalating patients or families with emotional upset, and taking care of patients with altered mental status, under the influence of illicit drugs, or who have severe psychiatric illness [3]. These occupational exposures also impact those who work in parallel to nurses, often in supporting roles, such as certified nursing assistants (CNAs) and clinical technicians (hereafter referred to as nursing teams).

Stress during pregnancy is a clinically important exposure associated with adverse pregnancy outcomes [4]. Existing studies have demonstrated associations between chronic stressors (such as night shift work [4], long working hours [4], and financial stress [5]) and multiple adverse pregnancy outcomes [4], including spontaneous abortion [6], preterm delivery [7], and hypertensive disorders of pregnancy [8]. Potential physiological mechanisms include disruption of normal circadian behavioral and physiologic pathways, shortened sleep duration, and neuroendocrine dysregulation [9].

Most studies of stress during pregnancy have relied on self-reported and recalled measures of chronic stress, usually at a single timepoint prior to gestation or during pregnancy [10]. However, in addition to chronic stress, most individuals, particularly those working in high-acuity environments, experience acute or momentary stressors—e.g., short-term events that may lead to acute subjective and physiologic stress responses [11]. During an acute stress response, the body activates the sympathetic nervous system and withdraws the parasympathetic nervous system, signaling the adrenal glands to release epinephrine and cortisol and stimulating increases in heart rate and blood pressure [11]. Human experiments in controlled laboratory settings have demonstrated increases in the cortisol, heart rate, and blood pressure in response to acute psychosocial stressors, among both pregnant [12] and non-pregnant [13] populations. Sustained increases in the heart rate and blood pressure after an acute stressor suggest low autonomic nervous system plasticity and unhealthy functioning [11, 14]. Over time, repeated exposures to acute stress may lead to blunted reactivity of the autonomic nervous system, resulting in decreased heart rate variability, blunted blood pressure dipping during nighttime hours, chronic hypertension, and higher risk for cardiovascular disease [13–15].

In recent years, ecological momentary assessment (EMA) approaches, which collect repeated data in a subject's natural environment, have been increasingly applied to study real-world physiologic responses to short-term stress during daily life [13]. Wearable blood pressure and heart rate monitoring devices can assess the magnitude and duration of increases in the heart rate and blood pressure in response to acute stress and capture measures of autonomic reactivity such as heart rate variability [14] and blood pressure dipping [16]. EMA approaches are superior to traditional laboratory-based methods as they capture the variety, severity, and duration of stressors that individuals face in their daily lives and measure the body's response to these stressors. Wearable devices used in EMA research enable longitudinal data collection that may not be feasible with lab or clinic-based measurements. However, most EMA studies have been conducted in non-pregnant populations, with sparse and limited data available on how daily exposure to acute stressors may impact pregnant individuals, as well as whether pregnancy poses specific challenges to the collection of EMA data [17–19].

To fill this knowledge gap, we conducted an EMA pilot study to measure physiologic parameters of acute stress (diurnal urine cortisol and continuously monitored heart rate and blood pressure) among pregnant individuals belonging to nursing teams. The main objectives of our pilot were to (1) determine the feasibility [20] of recruitment and longitudinal retention of study participants, including both process feasibility and scientific feasibility, and (2) to determine the tolerability of study activities. Our primary goal was to assess the feasibility and tolerability of participation in ongoing physiological monitoring among pregnant participants, to inform the approach and design of future work.

## Methods

This pilot study was approved by the Institutional Review Board (IRB) at Maine Medical Center (MMC), where the study was performed. MMC is a 700-bed, level 1 trauma center and tertiary care referral center and the state's largest medical center, employing nearly 2000 nurses.

### Sample size

Our target sample size of 16 participants was based on our a priori estimation of the number of pregnant

nurses we expected to be eligible for our study during our 9-month recruitment period. Across clinical departments at MMC, there are ~600 nurses who work exclusively day shifts or exclusively night shifts. Applying a pregnancy rate of 5% among reproductive-aged women, we estimated 30 pregnant nurses (600 ×0.05) at any given time period during the study. Given that pregnancy lasts ~10 months and assuming an equal distribution of women at each gestational age of pregnancy, we anticipated ~3 new pregnancies per month. Over a 9-month recruitment period, this would lead to 27 new pregnancies available for participation in our study. Applying a recruitment rate of 60%, we anticipated we would be able to recruit and enroll 16 participants. Because our aim was to establish the feasibility of study procedures and not to estimate quantitative differences between study groups, we did not base our target sample size on the ability to ensure differences in quantitative parameters.

Study recruitment occurred over a 9-month period (Nov 2022 through July 2023) using direct and indirect recruitment methods, including the posting of IRB-approved recruitment flyers throughout the hospital in clinician-focused spaces (e.g., breakrooms and staff locker rooms), notifying potential candidates about the study via nursing team leadership, and in-person engagement with clinical staff throughout the hospital during both day shift and night shift hours. Candidates were directed to express their interest via a study-designated email to the research team. Once an inquiry was received, potential candidates were screened by study team members for eligibility using a detailed study questionnaire (Supplement Appendix A). Inclusion criteria included female nursing team members of reproductive age (18–49 years) who were actively working clinical shifts (either exclusively night shifts or exclusively day shifts) during pregnancy, known singleton pregnancy at the time of recruitment, and no known obstetrical complications requiring specialty care. If the candidate met inclusion/exclusion criteria and expressed continued interest in the study, an in-person meeting was set up to begin the informed consent process. Once a signed consent form was obtained, a participant was considered to be enrolled in the study.

Study participants were categorized according to their gestational age at the time of enrollment into an early or late pregnancy group, defined by <20 or ≥20 weeks of gestational age, respectively (Tables 1 and 2). Quantitative and qualitative indicators of stress were measured during each category of gestational age during two matched 24-h sampling periods: one inclusive of a clinical work shift (i.e., work period) and the other occurring when no clinical work was scheduled (i.e., non-work period). Matched work and non-work sampling periods were intended to take place within a 1 week (with a maximum of 30 days) of each other in an effort to better standardize the data collected to a similar set of life conditions. Whenever possible, work and non-work data were collected in both earlier and later pregnancy. For example, if a participant was enrolled in the study at a 10-week pregnant, a total of four sampling periods would be expected: a matched work and non-work sampling period during earlier pregnancy, followed by another matched set of sampling sessions in later pregnancy. Only two sampling periods (a work and non-work period) would be expected for a participant enrolled in later pregnancy, e.g., ≥20 weeks of gestational age.

During each sampling period, we measured physiological parameters that are known biomarkers of acute stress. These included urine cortisol (one morning and one evening collection, separated by 12 h) and 24 h of continuously monitored ambulatory heart rate (via Fitbit Sense smartwatch) and blood pressure (via Oscar 2 ambulatory cuff, SunTech Medical). These were chosen based on a literature review of available options. Urine cortisol was measured from chilled urine samples transported on ice via liquid chromatograph-tandem mass spectrometry (MaineHealth NorDx lab). Participants were also asked to complete written surveys using standardized assessments of self-reported sleep and well-being. These included a sleep diary to assess sleep–wake timing and duration [21], the Patient Health Questionnaire- 9 (PHQ- 9) to measure depressive symptoms [22], Pittsburg Sleep Quality Index (PSQI) to measure sleep quality [23], and Epworth Sleepiness Scale (ESS) to measure daytime sleepiness [24], each completed at the end of each sampling period. Participants were also asked to complete an exit survey at the conclusion of the study, in which they could provide quantitative and qualitative feedback regarding the tolerability of participating in study procedures.

#### *Feasibility targets*

Evaluation of feasibility and tolerability was informed by Thabane et al., [20] with a focus on process feasibility and scientific feasibility. Targets were defined according to a priori thresholds (see measures and feasibility targets, Table 3).

Process feasibility was measured across three areas: enrollment, retention, and acceptability. Enrollment was assessed based on the enrollment of the targeted number of individuals. Our target for enrollment was 16 participants, including at least 8-day shift workers and 4 night shift workers. Retention throughout the study was measured by dropout, participation in data collection, missingness in the physiologic measurements and written surveys, and reasons for missingness.

**Table 1** Sampling periods for which data collection was expected vs. initiated, among enrolled participants ($n = 12$)

| Participant category | Gestational age | Work vs. non-work | Expected number of periods | Initiated number of periods | % of expected |
|---|---|---|---|---|---|
| Day shift | Early | Work | 3 | 2 | 67% |
| | | Non-Work | 3 | 2 | 67% |
| | Late | Work | 9 | 6 | 67% |
| | | Non-Work | 9 | 5 | 56% |
| Night shift | Early | Work | 3 | 3 | 100% |
| | | Non-Work | 3 | 3 | 100% |
| | Late | Work | 3 | 3 | 100% |
| | | Non-Work | 3 | 3 | 100% |
| **Total** | | | **36** | **27** | **75%** |

Study participants were categorized according to their gestational age at the time of enrollment into an early or late pregnancy group, defined by < 20 or ≥ 20 weeks of gestational age, respectively. Whenever possible, a set of matched work + non-work sampling periods were expected at each category of gestational age

**Table 2** Demographic characteristics of eligible study participants

| | Eligible but declined to participate ($N = 6$) | Withdrawn participants ($N = 4$) | Retained participants ($N = 8$) |
|---|---|---|---|
| Age (years), *mean* (*SD*) | 28.7 (4.7) | 31.5 (3.7) | 32.0 (2.1) |
| Gestational age at enrollment (weeks), *mean* (*SD*), *n* | | | |
| < 20 weeks | 9.6 (5.0) ($n = 3$) | 12.5 (8.2) ($n = 2$) | 11.7 (3.3) ($n = 4$) |
| ≥ 20 weeks | 23.9 (2.4) ($n = 3$) | 23.6 (5.5) ($n = 2$) | 26.1 (6.0) ($n = 4$) |
| Work schedule, *n (%)* | | | |
| Day shift | 4 (67%) | 4 (100%) | 5 (63%) |
| Night shift | 2 (33%) | 0 (0%) | 3 (38%) |

Withdrawn participants were participants who agreed to participate but withdrew from the study at any time after enrollment. Retained participants participated in some or all study activities until the completion of the study protocol

Our feasibility target was a collection of 80% or more of expected data points for all study activities, including physiologic measurements (blood pressure, heart rate, cortisol) and written surveys (survey completion). Acceptability of study activities and overall participation was measured quantitatively by self-report and qualitatively by feedback throughout the study and on the exit questionnaire. Our acceptability targets were a mean score of less than 4 for self-reported difficulty of participating in study activities (0–10 scale) and 80% or more of study participants reporting that they would recommend participating in the study.

Scientific feasibility was evaluated through the ability of ambulatory heart rate and blood pressure measurements to generate meaningful variation in data, across sampling periods for each participant. Graphical data displays were created to aid in data interpretation.

Descriptive statistics were used to summarize the characteristics of the study participants. Categorical data were summarized using frequencies and percentages while continuous variables were summarized using measures of central tendency and dispersion.

Qualitative feedback from participants was analyzed using a qualitative descriptive approach [25]. Free text responses were first read by the researchers to establish a feel for the data. Following the initial reads, the researchers selected related bits of text and organized them by common themes. The research team iteratively read, re-read, coded, and re-coded bits of text as new insights about the data emerged during the process of constant comparison.

## Results

### Process feasibility

#### *Recruitment and enrollment*

Over the 9-month recruiting period (November 2022 to July 2023), our study team posted more than 50 flyers and engaged with nursing leadership across eight hospital departments to send up to three recruitment emails to

**Table 3** Feasibility measures, targets, and outcomes

| Process feasibility | Measure | Feasibility target | Outcome |
|---|---|---|---|
| Enrollment | *N* of the total enrolled participants | ≥ 16 participants | 12 participants |
| | *N* of day shift participants | ≥ 8 day shift participants | 9 participants |
| | *N* of night shift participants | ≥ 4 night shift participants | 3 participants |
| Retention | *N* of blood pressure measurements of those attempted (e.g., 1 measurement per hour, over each 24-h sampling period) | ≥ 80% expected | 84% |
| | *N* of heart rate measurements of those attempted (e.g., 1 measurement per 5 s, over each 24-h sampling period) | ≥ 80% expected | 60% |
| | *N* of urine cortisol measurements of those collected (e.g., 2 collections over each 24-h sampling period) | ≥ 80% expected | 97% |
| | *N* of the participants who completed the requested questionnaires | ≥ 80% of participants with fully completed questionnaires | Patient Health Questionnaire- 9: 96% complete (*n* = 26 complete of 27 requested; e.g., 26/27)<br>Pittsburg Sleep Quality Index (PSQI): 100% complete (27/27)<br>Epworth Sleepiness Scale (ESS): 93% complete (25/27)<br>Exit Survey: 88% complete (7/8) |
| Acceptability | Self-reported difficulty participating in ambulatory monitoring (0–10 scale), *mean (SD)* | < 4 | 6 (2.8) (among *n* = 8 respondents) |
| | Self-reported difficulty of participating in urine collection (0–10 scale), *mean (SD)* | < 4 | 1 (1.7) (among *n* = 6 respondents) |
| | Self-reported difficulty of participating in surveys (0–10 scale), *mean (SD)* | < 4 | 0 (0) (among *n* = 7 respondents) |
| | *N* of participants who would recommend participating in this study to a friend | ≥ 80% of participants | 100% (among *n* = 6 respondents) |
| **Scientific feasibility** | | | |
| Qualitative variation between sampling periods, for each participant | Heart rate monitor | > 0% variation | Yes |
| | Blood pressure monitor | > 0% variation | Yes |

their clinical teams. Interested individuals were directed to reach out via the designated study email, and in total, we received 31 inquiries from potential candidates. After receiving an email inquiry, candidates were screened for eligibility. In the majority of cases, answers to all screening questions (Supplement Appendix A) were obtained from candidates; however, some partial screenings also occurred. Overall, 25 individuals were screened and a total of 18 individuals (72%) were deemed eligible to participate. The most common reason for ineligibility was that individuals did not work exclusively day or night shifts (i.e., they worked a rotating or overlapping shift schedule) with one individual found ineligible due to not being pregnant (Fig. 1). For screened individuals who provided information about their work shift ($n = 30$), inquiries were more numerous from day shift employees ($n = 16$) compared to night shift employees ($n = 7$) or those who worked rotating or evening shifts ($n = 7$). We received the greatest number of inquiries shortly after we began the study, with 77% ($n = 24$) occurring in the first 2 months of the recruitment. However, the timing of inquiries for the subset of individuals working night shift ($n = 7$) was more evenly spaced, with 4 and 3 inquiries occurring during the first and second half of the recruitment period, respectively.

Of the 18 individuals who were found eligible to participate in the study, 12 participants were enrolled over the study period, indicating an acceptance rate of 67% (Fig. 1), and an estimated enrollment rate of 1.3 participants per month of attempted enrollment. Enrolled participants worked across a broad range of clinical departments including the emergency department, labor and delivery, oncology, critical care, postoperative care, and other medical-surgical units.

*Retention.* Based on the gestational age at enrollment of study participants, we expected data to be collected from

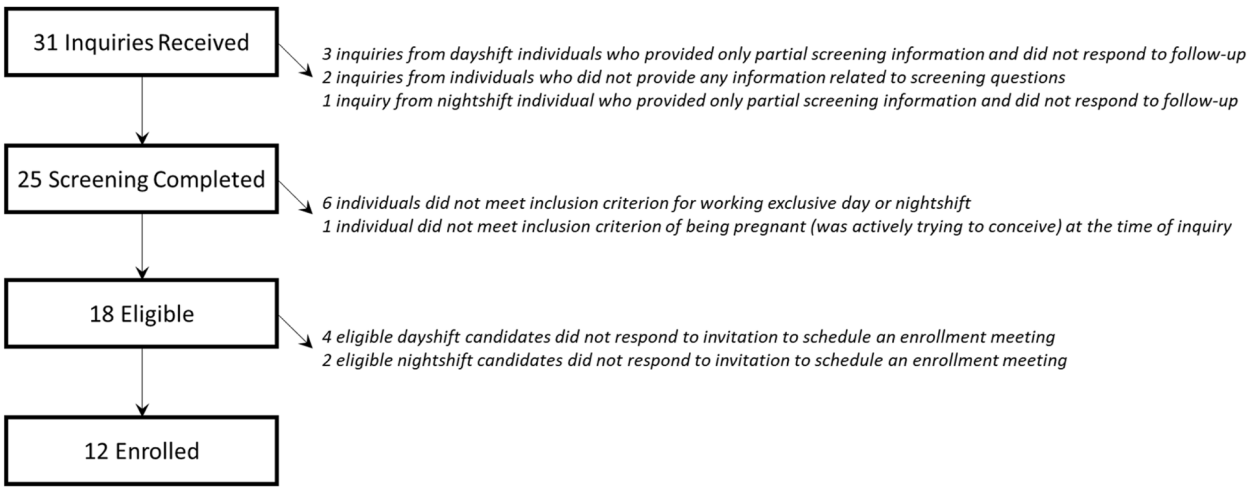


**Fig. 1** Flowchart of patient recruitment and enrollment

a total of 36 sampling periods. However, four enrollees withdrew from the study for various reasons before sampling occurred, 1-day shift enrollee did not respond to communication to schedule a sampling period, 1-day shift enrollee did not complete any sampling periods due to job relocation to a different hospital, 1-day shift enrollee completed one set of sampling activities but did not respond to follow-up communication to schedule additional, expected sampling periods, and 1-day shift enrollee completed earlier pregnancy sampling periods but then developed a pregnancy complication and could not continue with later pregnancy sampling periods. In total, data collection was initiated (e.g., some or all requested study activities were completed) for 27 of the expected 36 sampling periods (75% of expected, Table 1). Within sampling periods, heart rate and blood pressure monitoring were almost always attempted by participants.

### *Demographics*

Demographic characteristics of participants who were eligible but declined participation and enrolled participants who withdrew versus those who were retained are summarized in Table 2. Participants who were eligible but declined to participate were slightly younger (28.7 years) compared to participants who were retained in the study compared to those who withdrew (32.0 vs. 31.5 years, respectively). Gestational age at enrollment, divided into $<20$ weeks and $\geq 20$ weeks, was similar for retained participants, those who withdrew, and those who were eligible but declined to participate in the study. In comparing day shift and night shift participants, 5 of 9 (55.5%) enrolled day shift participants were retained in the study while 3 of 3 (100%) enrolled night shift participants were retained.

### *Feasibility assessments*

We used our feasibility criteria as a benchmark to assess the data we collected from study participants. A summary of feasibility targets compared to outcomes is provided in Table 3. Physiologic measures included blood pressure, heart rate, and urine cortisol measurements. The blood pressure cuff was programmed to provide one measurement per hour for each 24-h sampling period, while the heart rate was assessed at a rate of 1 measurement every 5 s over each 24-h sampling period. Our feasibility threshold was the acquisition of $\geq 80\%$ of expected blood pressure or heart rate recordings. As shown in Table 3, we achieved our feasibility target for blood pressure recordings (acquiring 84% of expected measures) but not for heart rate recordings (acquiring 60% of expected measures). When completed, ambulatory heart rate and blood pressure measurements were able to generate meaningful variation in data, across sampling periods. Examples of complete vs. incomplete heart rate and blood pressure recordings from ambulatory measurements are provided in Fig. 2. In addition to missed measurements due to equipment removal, a total of 187 error messages were registered during blood pressure monitoring, most commonly related to artifact or an erratic signal ($n=63$, 34%), an air leak ($n=35$, 19%), or a blocked mechanistic valve ($n=26$, 14%). For complete tracings of heart rate and blood pressure monitoring, please refer to the Supplementary information. Urine cortisol was evaluated twice during each sampling period, with a goal of successful sample collection $\geq 80\%$ of the time. Urine cortisol levels were successfully obtained 97% of the time.

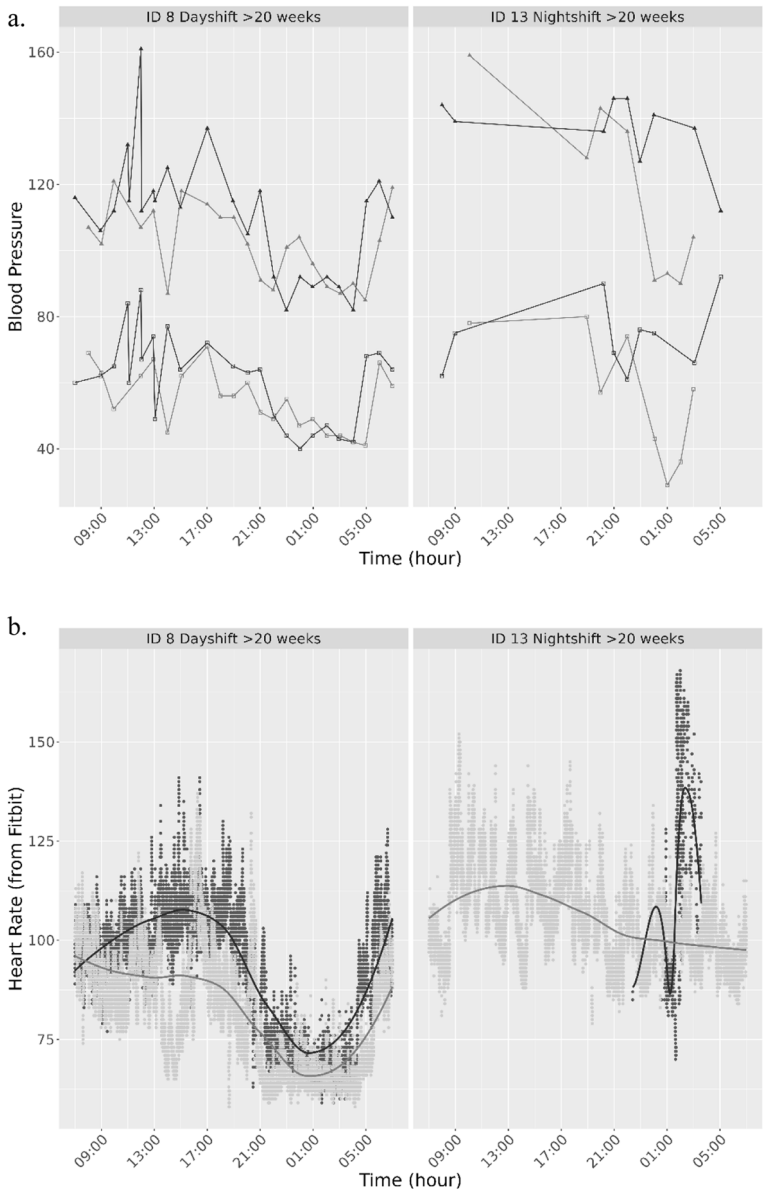


**Fig. 2** Descriptive data from heart rate and blood pressure monitors for two participants. Participant ID 8 had complete data collection, and participant ID 13 had incomplete data collection. **a** Blood pressure (mmHg) collected from blood pressure monitors over sampling periods. **b** Heart rate (beats per minute) collected from heart rate monitors over sampling periods. Dark gray represents work sampling periods, and light gray represents non-work sampling periods. Lines are plotted using locally weighted scatterplot smoothing (loess) to visualize trends in the underlying data points

We collected self-reported data on depressive symptoms, sleep–wake timing and duration, sleep quality, and daytime sleepiness, and an exit survey. Our feasibility target was to obtain fully complete assessments from ≥ 80% of participants. As noted in Table 3, there was some variation amongst instruments; however, the feasibility target was surpassed for each of the self-report measures.

### *Acceptability*

Through qualitative analysis of comments provided by study participants, we identified three major themes regarding process feasibility. These included (1) personal discomfort and technical issues with study equipment, (2) work or activity interference, and (3) concerns about study design.

*Theme 1: Personal discomfort and/technical issues with study equipment* Many participants expressed frustration with using the blood pressure cuff, including noting personal discomfort, repeated cycling, and related sleep disturbances (for themselves and their sleep partners). One participant wrote, "The blood pressure cuff was very cumbersome, uncomfortable and distracting... It woke me up every hour of sleep." Another shared, "I really tried to give the blood pressure cuff a good go. But this does not seem to be working out for me. I've been having to readjust the cuff several times and it keeps pumping 2–3 times each hour and giving me error codes. I don't think I can tolerate continuing to wear it." Some participants commented that a less bulky blood pressure cuff or different blood pressure cuff sizes (particularly smaller sizes) would have improved comfort.

Feedback on the Fitbit device, designed to capture heart rate, was primarily focused on technical issues with the equipment. Several participants indicated that Fitbit displayed the wrong date and time when the study started and expressed concern that this could lead to inaccurate data analysis.

*Theme 2: Work or activity interference* Many participants felt that the blood pressure cuff limited participation in work or other activities, although others did not. One wrote, "It kept falling out of my shirt and getting stuck on things/pulled by my baby... I found it overwhelmingly frustrating at home trying to do chores and take care of my 1-year-old." Another felt it was "a bit bulky and irritating when trying to move quickly in the OR [operating room]." A third reported, "The blood pressure cuff was very cumbersome, uncomfortable, and distracting. It would only cycle if I was not moving, which was very difficult at work." However, these concerns were not universal; some participants stated that they were able to take part in daily activities during non-work sampling periods without issue, including painting walls, running errands, and walking for extended periods.

Multiple participants reported that they removed the Fitbit to shower, although they were told at the start of data collection that it was water resistant. One participant explained, "I know its immersible, but I never shower with devices on."

*Theme 3: Concerns about study design* One participant voiced global concerns about study remuneration and wondered if the $25 gift card provided for participation in each sampling period was adequate compensation. She wrote, "Honestly it was a lot to put up with/remember during pregnancy for only $25 per session, specifically, [wearing the] blood pressure monitor and [collecting] two urine samples at specific times around work." Other participants also mentioned difficulty with collecting urine at specific times of the day.

### Scientific feasibility

Examination of the heart rate and blood pressure monitor data did reveal an ability to generate valid measurements during work and non-work sampling periods. A graphical representation of the data generated from the heart rate monitor (Fitbit) is illustrated in Supplementary Fig. S1 and from the blood pressure cuffs in Supplementary Fig. S2. As stated above, data was evaluated descriptively but hypothesis testing for differences between work and non-work periods was not performed due to the limited sample size of this pilot study.

## Discussion

Pregnant shift workers are a historically understudied group [26–28] at increased risk for adverse health outcomes compared to the general population and in whom we have a limited understanding of the physiologic effects of night shift work [4, 29]. This pilot study assessed the feasibility and tolerability of an EMA study protocol designed to monitor physiologic and self-reported stress among pregnant nurses during work and non-work periods. Our methodological approach adds to the literature by considering stress as a dynamic and context-specific risk factor, with the potential to change over time.

A major aim of our pilot was to determine if we could recruit and retain pregnant nursing team members to participate in our research protocol. Over the 9-month study period, we received 31 inquiries from individuals (3.4/month) and enrolled 12 participants (1.3/month). Our recruitment efforts were more successful among day shift nurses than night shift nurses; though equal effort was made to recruit both groups via recruitment flyers, emails; and in-person engagement with study team members. Possibly, the discrepancy in recruitment success may reflect underlying differences between day shift and night shift nurses in terms of interest in research or lifestyle flexibility to accommodate research participation. Due to the small number of participants in our study, we are unable to determine if recruitment success was different across hospital departments. Based on qualitative feedback received from participants, increasing the financial remuneration for study participants could be considered to mitigate recruitment challenges in subsequent studies.

Participant retention was a significant challenge for our study, with withdrawals and incomplete participation affecting data collection. Participant concerns

included the complexity of the study design, adequacy of compensation, and personal discomfort as well as technical issues with the equipment. Previous studies demonstrate that pregnant women report mostly altruistic and personal reasons for their willingness to participate in clinical research, while barriers primarily relate to inconveniences [30]. In the future, strategies for improved retention could include greater compensation, a more streamlined study protocol, and equipment that is less burdensome to use. Additionally, given participant concerns with collecting urine at specific times of day, more flexible protocols or alternative approaches to measuring cortisol, such as via hair or saliva, could be explored.

The Oscar 2 blood pressure cuff and Fitbit device we used in our study had frequent technical issues, and participants experienced significant discomfort with the blood pressure cuff in particular. While we achieved our feasibility target for blood pressure recordings (acquiring 84% of expected measures), we did not achieve our target for heart rate recordings (acquiring 60% of expected measures). Despite these challenges, data from heart rate and blood pressure monitors overall yielded valid measurements when worn. Other pilot tests of ambulatory blood pressure cuffs among pregnant women have similarly demonstrated a rate of 15% monitor discontinuation, with sleep disturbance as the strongest predictor of patients discontinuing the monitor [31]. Future directions could include testing alternative devices in this participant population to determine if tolerability or data capture might be improved. Devices such as the Oura ring [32] may have a lower rate of user discontinuation than heart rate monitors worn on the wrist. Decreasing the frequency of blood pressure measured may also be a consideration to improve tolerability. There is a growing body of work using wrist-cuff devices that cause less discomfort and muscle compression than traditional upper arm cuffs and cuffless devices (Wearable Sensor by Shuzo, HeartGuide by Omron Corp, Blood Pressure Monitor by Echolabs); however, the validity of these methods is still controversial [33].

Our study had several limitations. It was conducted at a single tertiary hospital site and was based on a small sample of enrolled participants ($n = 12$). As such, we were not powered to draw statistical conclusions from our data; however, the primary objective of the study was to assess feasibility versus test hypotheses. Participant recruitment in our study relied heavily on self-selection; if participants differed fundamentally from non-participants on the tolerability of data collection, this could have introduced bias to our results. Additionally, we collected only limited demographic data from participants and did not capture information on race, ethnicity, and occupational characteristics (e.g., department, typical work responsibilities) that should be considered for larger studies. Finally, enrollment focused on pregnant nurses who worked full-time, exclusively day or night shifts, with shift lengths of at least 8 h long. Although these inclusion criteria were established to better standardize the data collected, the results may not be reflective of non-pregnant nurses, pregnant nurses who work fewer or shorter shifts per week, or those who work a rotating day/night work schedule.

## Conclusions

While physiologic monitoring of pregnant shift workers is a relatively understudied area, equipment challenges pose a significant barrier to study participation in ambulatory monitoring of pregnant shift workers. Future studies should allow for a significant withdrawal rate or explore alternative equipment options.

### Abbreviation

EMA Ecological momentary assessment

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40814-025-01647-z.

Supplementary Material 1.

### Acknowledgements

We acknowledge Charles Reynolds for his role as a senior mentor in guiding the early development of this project.

### Authors' contributions

Isha Agarwal, Madeleine Puissant, and Erika Sabbath were responsible for the conception of this work; these authors worked together with Tania Strout and Irit Altman on study design. Irit Altman and Madeleine Puissant, with Tania Strout and Isha Agarwal, led study enrollment and data acquisition. Alexandra Hinton performed the majority of data analysis. Tania Strout directed the thematic analysis of qualitative responses, with input from Isha Agarwal, Madeleine Puissant, and Irit Altman. Isha Agarwal led the drafting of this manuscript, with input and critical revisions from all study team members.

### Funding

This investigation was made possible by Grant No. T42 OH008416 from the National Institute for Occupational Safety and Health (NIOSH). Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the NIOSH. Isha Agarwal is supported by 2P20GM121301 from NIGMS (Liaw PI).

### Data availability

Due to privacy constraints, data generated as part of this study is not publicly available.

## Declarations

### Ethics approval and consent to participate

This pilot study was approved by the MaineHealth Institutional Review Board, where the study was performed (Project #1892929-6). The study was conducted in accordance with the Helsinki Declaration to promote and protect the health of participants. All participants signed a consent form before commencing the protocols.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no competing interests.

**Author details**
[1]Department of Emergency Medicine, Maine Medical Center, Portland, ME, USA. [2]Center for Interdisciplinary and Population Health Research, MaineHealth Institute for Research, Portland, ME, USA. [3]Boston College School of Social Work, Chestnut Hill, MA, USA. [4]Center for Work, Health, and Wellbeing, Harvard T.H. Chan School of Public Health, Boston, MA, USA.

Received: 21 May 2024 Accepted: 16 April 2025
Published online: 26 April 2025

**References**

1. Smiley RA, Ruttinger C, Oliveira CM, et al. The 2020 national nursing workforce survey. J Nurs Regul. 2021;12(1):S1–96. https://doi.org/10.1016/S2155-8256(21)00027-2.
2. Trinkoff A, Geiger-Brown J, Brady B, Lipscomb J, Muntaner C. How long and how much are nurses now working? Am J Nurs. 2006;106(4):60–71. https://doi.org/10.1097/00000446-200604000-00030. quiz 72.
3. Kostka AM, Borodzicz A, Krzemińska SA. Feelings and emotions of nurses related to dying and death of patients - a pilot study. Psychol Res Behav Manag. 2021;14:705–17. https://doi.org/10.2147/PRBM.S311996.
4. Cai C, Vandermeer B, Khurana R, et al. The impact of occupational shift work and working hours during pregnancy on health outcomes: a systematic review and meta-analysis. Am J Obstet Gynecol. 2019;221(6):563–76. https://doi.org/10.1016/j.ajog.2019.06.051.
5. Morgan N, Christensen K, Skedros G, Kim S, Schliep K. Life stressors, hypertensive disorders of pregnancy, and preterm birth. J Psychosom Obstet Gynaecol. 2022;43(1):42–50. https://doi.org/10.1080/0167482X.2020.1778666.
6. Whelan EA, Lawson CC, Grajewski B, Hibert EN, Spiegelman D, Rich-Edwards JW. Work schedule during pregnancy and spontaneous abortion. Epidemiology. 2007;18(3):350–5. https://doi.org/10.1097/01.ede.0000259988.77314.a4.
7. Lawson CC, Whelan EA, Hibert EN, Grajewski B, Spiegelman D, Rich-Edwards JW. Occupational factors and risk of preterm birth in nurses. Am J Obstet Gynecol. 2009;200(1):51.e1-518. https://doi.org/10.1016/j.ajog.2008.08.006.
8. Agarwal I, Wang S, Stuart J, et al. First-trimester occupational exposures and hypertensive disorders of pregnancy among US nurses. Occup Med (Lond). 2023;73(7):419–26. https://doi.org/10.1093/occmed/kqad089.
9. Gamble KL, Resuehr D, Johnson CH. Shift work and circadian dysregulation of reproduction. Front Endocrinol (Lausanne). 2013;4: 92. https://doi.org/10.3389/fendo.2013.00092.
10. Wadhwa PD, Entringer S, Buss C, Lu MC. The contribution of maternal stress to preterm birth: issues and considerations. Clin Perinatol. 2011;38(3):351–84. https://doi.org/10.1016/j.clp.2011.06.007.
11. Epel ES, Crosswell AD, Mayer SE, et al. More than a feeling: a unified view of stress measurement for population science. Front Neuroendocrinol. 2018;49:146–69. https://doi.org/10.1016/j.yfrne.2018.03.001.
12. De Weerth C, Gispen-De Wied CC, Jansen LMC, Buitelaar JK. Cardiovascular and cortisol responses to a psychological stressor during pregnancy. Acta Obstet Gynecol Scand. 2007;86(10):1181-1192. https://doi.org/10.1080/00016340701547442.
13. Weber J, Angerer P, Apolinário-Hagen J. Physiological reactions to acute stressors and subjective stress during daily life: a systematic review on ecological momentary assessment (EMA) studies. PLoS ONE. 2022;17(7): e0271996. https://doi.org/10.1371/journal.pone.0271996.
14. Yang J, Kershaw KN. Feasibility of using ecological momentary assessment and continuous heart rate monitoring to measure stress reactivity in natural settings. PLoS ONE. 2022;17(3): e0264200. https://doi.org/10.1371/journal.pone.0264200.
15. Mak HW, Gordon AM, Prather AA, Epel ES, Mendes WB. Acute and chronic stress associations with blood pressure: an ecological momentary assessment study on an app-based platform. Psychosom Med. 2023;85(7):585–95. https://doi.org/10.1097/PSY.0000000000001224.
16. Patterson PD, Mountz KA, Budd CT, et al. Impact of shift work on blood pressure among emergency medical services clinicians and related shift workers: a systematic review and meta-analysis. Sleep Health. 2020;6(3):387–98. https://doi.org/10.1016/j.sleh.2020.03.006.
17. de Weerth C, Buitelaar JK. Physiological stress reactivity in human pregnancy–a review. Neurosci Biobehav Rev. 2005;29(2):295–312. https://doi.org/10.1016/j.neubiorev.2004.10.005.
18. Omowale SS, Gary-Webb TL, Wallace ML, et al. Stress during pregnancy: an ecological momentary assessment of stressors among Black and White women with implications for maternal health. Womens Health (Lond). 2022;18: 17455057221126808. https://doi.org/10.1177/17455057221126808.
19. Entringer S, Buss C, Andersen J, Chicz-DeMet A, Wadhwa PD. Ecological momentary assessment of maternal cortisol profiles over a multiple-day period predict the length of human gestation. Psychosom Med. 2011;73(6):469–74. https://doi.org/10.1097/PSY.0b013e31821fbf9a.
20. Thabane L, Ma J, Chu R, et al. A tutorial on pilot studies: the what, why and how. BMC Med Res Methodol. 2010;10: 1. https://doi.org/10.1186/1471-2288-10-1.
21. Carney CE, Buysse DJ, Ancoli-Israel S, et al. The consensus sleep diary: standardizing prospective sleep self-monitoring. Sleep. 2012;35(2):287–302. https://doi.org/10.5665/sleep.1642.
22. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. 2001;16(9):606–13. https://doi.org/10.1046/j.1525-1497.2001.016009606.x.
23. Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2):193–213. https://doi.org/10.1016/0165-1781(89)90047-4.
24. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep. 1991;14(6):540–5. https://doi.org/10.1093/sleep/14.6.540.
25. Sandelowski M. Whatever happened to qualitative description? Res Nurs Health. 2000;23(4):334–40. https://doi.org/10.1002/1098-240x(200008)23:4%3c334::aid-nur9%3e3.0.co;2-g.
26. Blehar MC, Spong C, Grady C, Goldkind SF, Sahin L, Clayton JA. Enrolling pregnant women: issues in clinical research. Womens Health Issues. 2013;23(1):e39-45. https://doi.org/10.1016/j.whi.2012.10.003.
27. Biggio JR. Research in pregnant subjects: increasingly important, but challenging. Ochsner J. 2020;20(1):39–43. https://doi.org/10.31486/toj.19.0077.
28. Lyerly AD, Little MO, Faden R. The second wave: toward responsible inclusion of pregnant women in research. Int J Fem Approaches Bioeth. 2008;1(2):5–22. https://doi.org/10.1353/ijf.0.0047.
29. Nurminen T. Shift work, fetal development and course of pregnancy. Scand J Work Environ Health. 1989;15(6):395–403. https://doi.org/10.5271/sjweh.1833.
30. van der Zande ISE, van der Graaf R, Hooft L, van Delden JJM. Facilitators and barriers to pregnant women's participation in research: a systematic review. Women Birth. 2018;31(5):350–61. https://doi.org/10.1016/j.wombi.2017.12.009.
31. Walker SP, Permezel MJ, Brennecke SP, Tuttle LK, Higgins JR. Patient satisfaction with the SpaceLabs 90207 ambulatory blood pressure monitor in pregnancy. Hypertens Pregnancy. 2004;23(3):295–301. https://doi.org/10.1081/PRG-200030306.
32. Li K, Cardoso C, Moctezuma-Ramirez A, Elgalad A, Perin E. Heart rate variability measurement through a smart wearable device: another breakthrough for personal health monitoring? Int J Environ Res Public Health. 2023;20(24):7146. https://doi.org/10.3390/ijerph20247146.
33. Kario K. Management of hypertension in the digital era. Hypertension. 2020;76(3):640–50. https://doi.org/10.1161/HYPERTENSIONAHA.120.14742.

## Publisher's Note