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Longitudinal changes in HRV across pregnancy and postpartum: Effect of negative partner relationship qualities

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ABSTRACT

During pregnancy, there are significant physiological changes to support a healthy fetus. Parasympathetic activity normatively decreases across pregnancy, and psychological stress can promote even further decreased heart rate variability (HRV). This study evaluated (1) changes in vagally-mediated HRV from pregnancy to postpartum, (2) changes in vagally-mediated HRV from pregnancy to postpartum based on negative partner relationship qualities, and (3) changes in depressive symptoms from pregnancy to postpartum based on negative partner relationship qualities. 78 participants in their 3rd trimester self-reported their relationship quality with their partner at the first visit. Depressive symptoms and vagally-mediated HRV were evaluated at rest at five time points from 3rd trimester to 12 months postpartum. On average, the only significant increase in vagally-mediated HRV occurred between the 3rd trimester and 4–6 weeks postpartum. However, those who reported more negative partner relationship qualities during their 3rd trimester of pregnancy maintained lower vagally-mediated HRV levels across all of the first year postpartum and significantly lower vagally-mediated HRV at both 4 and 8 months postpartum as compared to people who reported fewer negative partner relationship qualities. Across the first year postpartum, people reporting more negative partner relationship qualities experienced more severe depressive symptoms than their counterparts with fewer negative partner relationship qualities; however, there was no difference in the *rate of change* of depressive symptoms across the first year postpartum based on negative partner relationship qualities. Because lower vagally-mediated HRV is associated with depressive symptoms, future work should explore the temporal relationship between vagally-mediated HRV and depressive symptoms in the postpartum period.

1. Introduction

During pregnancy, there are significant physiological changes that occur to support a healthy fetus. These changes include normative increases in sympathetic nervous system activity and decreases in parasympathetic nervous system activity across pregnancy (Ekholm et al., 1997; Stein et al., 1999; Walther et al., 2005). Parasympathetic activity normatively decreases across pregnancy, and psychological stress can exacerbate that decrease (Mizuno et al., 2017). In both pregnant and non-pregnant adults, reduced parasympathetic activity has been associated with adverse mental and physical health outcomes, although there is far less evidence in perinatal than among non-perinatal populations (Fischer et al., 2004; Mizuno et al., 2017; Pavlov and Tracey, 2012; Thayer and Sternberg, 2006). Immediately following childbirth is a time of emotional disruption and adjustment for new parents, characterized by significant changes in relationships with their partners, lack of sleep, and feelings of loss of control over their life (Nelson, 2003). Unfortunately, we know little about normative autonomic nervous system (ANS) adjustments during the postpartum period. In this study, we observed the patterns of parasympathetic activity from the 3rd trimester of pregnancy to 1 year postpartum. We examined how the quality of one's partner relationship may influence those patterns.

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1.1. Autonomic nervous system changes during pregnancy

To successfully adapt and support fetal development, the maternal autonomic nervous system (ANS) undergoes substantial changes, such as increased blood volume (Hytten, 1985). As stroke volume and heart rate increase, cardiac output also increases. Because the decrease in peripheral resistance outweighs the increased blood volume, blood pressure typically steadily decreases until the middle of gestation before increasing until the day of delivery to return closer to pre-pregnancy values (Matthews and Rodin, 1992; Reiss et al., 1987; van der Tuuk et al., 2017). In contrast to the increases in sympathetic nervous system activity, parasympathetic activity decreases across pregnancy (Ekholm et al., 1997; Stein et al., 1999; Walther et al., 2005).

Lack of ANS adaptation is linked to adverse pregnancy outcomes. Generally, there is elevated sympathetic and reduced parasympathetic control of heart rate in a preeclamptic pregnancy compared to a healthy pregnancy (Yang et al., 2000). Successful pregnancies are characterized by substantial, adaptive changes in the ANS, and these changes are hypothesized to serve a protective function for both the pregnant person and the fetus. In contrast to these normative changes, maternal stress responses are associated with adverse health outcomes for both the pregnant person and the fetus (Christian, 2019; Weinstock, 2005). For example, greater stress reactivity during pregnancy may predict preeclampsia's clinical manifestation (Woisetschläger et al., 2000). Maternal stress during pregnancy has also been associated with an increased likelihood of offspring developing neurodevelopmental disorders, such as schizophrenia, later in life (Khashan et al., 2008).

1.2. Heart rate variability in pregnancy and postpartum

The ANS partially mediates the stress response system with the ANS parasympathetic branch facilitating energy conservation (Thayer and Sternberg, 2006). In both pregnant and non-pregnant adults, reduced parasympathetic activity has been associated with adverse mental and physical health outcomes, although there is far less evidence in perinatal than among non-perinatal populations (Fischer et al., 2004; Mizuno et al., 2017; Pavlov and Tracey, 2012; Thayer and Sternberg, 2006). Parasympathetic activity can be indexed by measuring vagally-mediated heart rate variability. The vagus nerve directly mediates the beat-to-beat variability in a heart rate time series, which is then a marker for vagally regulated heart rate variability (referred to as vagally-mediated HRV for the remainder of this paper; Moon et al., 2013; Thayer et al., 2012).

Understanding the biological mechanisms underlying successful autonomic adaptation in the postpartum period may serve as a foundation to build future interventions for new mothers. Unfortunately, there is a lack of research on vagally-mediated HRV in the postpartum period. There is some evidence to suggest that vagally-mediated HRV returns to pre-pregnancy levels within three months (Chen et al., 1999; Yeh et al., 2009); however, the sample sizes in each of these studies were quite small (ns = 15–16) and follow up visits only extended for a maximum of three months. Thus, our primary aim was to characterize the changes in vagally-mediated HRV from the 3rd trimester to 12 months postpartum. We hypothesized that there would be reliable increases in vagally-mediated HRV over the first year postpartum (Hypothesis 1).

1.3. Psychological stress and postpartum health

Psychological stress and the negative emotions it generates may exaggerate the typically adaptive decrease in vagally-mediated HRV across pregnancy. For example, in non-pregnant adults, negative psychological factors (e.g., anxiety, depression) predict lower or less adaptive vagally-mediated HRV in response to an acute stressor (Gorman and Sloan, 2000; Kawachi et al., 1995). Similarly, pregnant women with higher trait anxiety had significantly lower vagally-mediated HRV at 30 and 36 weeks gestational age than women with lower trait anxiety levels (Mizuno et al., 2017). However, we know very little about predictors of successful autonomic adaptation during postpartum.

Romantic relationship stressors are particularly salient during pregnancy and postpartum (Cox et al., 1999). Relationship problems are predictive of postpartum mental health problems (Brown and Lumley, 2000). In non-pregnant humans, poor-quality relationships are cross-sectionally (Smith et al., 2011) and longitudinally (Donoho et al., 2015) related to lower vagally-mediated HRV. Moreover, a stable partner relationship can reduce some of the risks for both new parents by decreasing both partners' stress (Cox et al., 1999). The psychological stress from poor quality partner relationships may also affect one's postpartum ANS adjustment. However, we know little about whether partner relationship quality concurrently impairs autonomic nervous system recovery in the postpartum period. Thus, we also hypothesized that more negative partner relationship qualities during the third trimester of pregnancy would be associated with more depressive symptoms (Hypothesis 2) and lower vagally-mediated HRV (Hypothesis 3) over the first year postpartum.

2. Method

2.1. Study sample

The current investigation is part of a longitudinal observational study approved by The Ohio State University Biomedical Institutional Review Board. Participants were recruited from The Ohio State University Wexner Medical Center Prenatal Clinic and the surrounding community of central Ohio from 2016 to 2019. Inclusion criteria included current singleton pregnancy. Exclusion criteria included diagnosis of a fetal anomaly or a major immunological condition of the mother and the use of medications with implications for immune function. People who reported working a night shift were also ineligible. Written informed consent was obtained at enrollment and participants received modest compensation for each visit. Visits occurred at the following intervals: 29–34 weeks gestational age (Visit 1), 4–6 weeks postpartum (Visit 2), 4 months postpartum (Visit 3), 8 months postpartum (Visit 4), and 12 months postpartum (Visit 5).

2.2. Measures

2.2.1. Heart rate variability

Heart rate variability (HRV) was continuously measured (5 min) non-invasively at each visit using FirstBeat Bodyguard; the 1000 Hz sampling rate collects valid and reliable ECG data (Parak and Korhonen, 2013). All participants were in a sitting position. Before analyzing HRV, we preprocessed the raw interbeat intervals for artifacts using KUBIOS HRV analysis software (Tarvainen et al., 2009). KUBIOS software enabled us to calculate time- and frequency-domain indices of vagally-mediated (parasympathetic) HRV. For every visit, the KUBIOS software produced values for vagally-mediated HRV using (1) the time-domain method, root mean squared successive differences (RMSSD) between R-spikes, and (2) autoregressive methods, high-frequency power HRV (HF-HRV, 0.15–0.4 Hz) (Thayer and Sternberg, 2010). We used a natural log transformation (ln) for RMSSD and HF-HRV values to fit the assumptions of linear analyses (Ellis et al., 2008). Higher scores for both RMSSD and HF-HRV indicate higher vagally-mediated HRV.

2.2.2. Positive and negative quality in marriage scale

The Positive and Negative Quality in Marriage Scale (PANQIMS; Fincham and Linfield, 1997) is a brief, global measure of one's perception of the extent to which there are positive and negative qualities in their relationship. Participants responded to the 6-item scale, which includes both positive (e.g., "Considering only the positive qualities of your partner, and ignoring the negative ones, evaluate how positive these qualities are.") and negative qualities (e.g., "Considering only bad

feelings you have about your romantic relationships, and ignoring the good ones, evaluate how bad these feelings are."). Participants rated each of these items on a scale from 0 (Not at all) to 10 (Extremely). Responses for the three items corresponding to each dimension were then summed with higher scores for each dimension representing more positive and more negative qualities, respectively. The PANIQIMS has good reliability and internal consistency. Reliability coefficients are.87 and.91 for men, and.90 and.89 for women, for positive and negative qualities, respectively (Fincham and Linfield, 1997).

2.2.3. Depressive symptoms

The Center for Epidemiologic Studies Depression Scale (CES-D) was used to assess depressive symptoms. The CES-D has been used extensively to measure depressive symptomology; it is a well-validated measure that includes 20 items to determine cognitive, emotional, and somatic depressive symptoms (Radloff, 1977). The CES-D has shown excellent construct validity and acceptable test-retest reliability (Basco et al., 1997). Prior studies have also verified that the CES-D has predictive validity for both physiological processes and health outcomes during pregnancy (Christian et al., 2009, 2010).

2.2.4. Demographic variables

At the first study visit, demographic characteristics, including maternal race, age, relationship status, physical health conditions, medications, and annual household income, were assessed by self-report. Annual household income was assessed on a 6-point scale from 1 (Less than $15,000) to 6 ($100,000 and above). Education was assessed on a 9-point scale from 1 (Less than 7th grade) to 9 (Some graduate school or higher). Participants also indicated whether they were current or past smoker at the first visit. Participants' pre-pregnancy body mass index (BMI) was calculated according to pre-pregnancy self-reported weight and height as measured at the first study visit (kg/m^2).

2.3. Analytic method

There were 83 women enrolled in the study. We excluded one woman because she had no HRV data for any visits; however, no other participants were dropped from the primary analyses for missing data. Women who were not in relationships at baseline ($n = 4$; 4.8%) were excluded from analyses resulting in a final analytic sample of 78 women. Within the analytical sample, missing values for variables collected across the five study visits accounted for less than 5% of the cases. We present each analysis unadjusted and adjusted with covariates to assess the robustness of the effects of interest-based on any baseline imbalance between groups (Thabane et al., 2013).

All analyses were conducted in *R* (version 1.1.456; R. Core Team, 2019). Analyses relied on the *nlme* package (Pinheiro et al., 2020) and the *ggplot2* package for data visualization (Wickham, 2016). We also initially utilized the *dplyr* package (Wickham et al., 2020) for data wrangling.

2.4. Fitting the model

We began by testing whether there was statistically significant variability in the intercepts across groups where the level 2 grouping variable is the person. To investigate whether there was significant variability in intercepts across people, we first estimated an unconditional means model, which contained only the random intercept variance term to allow the intercepts (means) to differ across individuals. The null model partitions total variance within a dependent variable into the within- and between-persons components. Thus, the intercept for each null model represents the mean level of that variable across individuals. A substantial proportion of the variance in vagally-mediated HRV was within-individuals (RMSSD = 44%; HF-HRV = 46%), as well as the variance for depressive symptoms (56%).

Next, −2 log-likelihood results indicated whether the model, including the random effect of time, fit the data better than a model without that random effect. Akaike information criterion (AIC) assessed the relative quality between the models. We used AIC to compare the models to investigate the extent to which information is lost in each model; the more lost, the lower quality the model (Bozdogan, 1987; Vrieze, 2012). Bayesian information criterion (BIC) was also computed as estimates of posterior probability (Vrieze, 2012). The lower the AIC and BIC values, the better the model fits. The standard −2 log-likelihood was used, $[-2 \log L + kp]$, where L is the likelihood function, p is the number of parameters in the model, k is 2 for AIC, and $log(n)$ is for BIC. For each dependent variable, we identified that a model allowing the slope between time and our dependent variables to vary randomly did not fit the data better than a model that fixes the slope to a constant value for all individuals. Thus, each model presented contains a random intercept but not a random slope.

3. Results

3.1. Sample characteristics

The study sample consisted primarily of educated women, with most participants completing some college, and earning between $50,000 and $75,000 per year (see Table 1). Most participants were married (83%) or in relationships (95%). In this sample, 76% of participants were White women, 21% were Black women, and 3% were Native American women.

3.2. Hypothesis 1: characterizing HRV over time

Unadjusted, zero-order correlations revealed a significant increase in RMSSD ($r = 0.29, p < .001$) and HF-HRV ($r = 0.22, p < 0.001$) over time (see Fig. 1 for means, boxplots, and raw data points across each time point; see Table 2 for means and standard deviations for untransformed and natural log transformed RMSSD and HF-HRV). There was a positive, linear relationship between time and RMSSD, $t(269.4) = 6.56$, $p < 0.001$, as well as a significant quadratic trend, $t(267.9) = -5.20$, $p < 0.001$. Thus, we modeled RMSSD including a quadratic term for each subsequent model. However, we only observed a reliable linear relationship between time and HF-HRV, $t(272.9) = 5.27$, $p < 0.001$.

After controlling for key participant confounds including age, pre-pregnancy body mass index, and income, we observed reliable increases in RMSSD ($b = 0.55$, *95% CI* [0.40, 0.72], $p < 0.001$) and HF-HRV ($b = 0.18$, *95% CI* [0.12, 0.25], $p < 0.001$) over time, which indicates that this is a robust effect. Post hoc comparisons using the Tukey HSD test indicated that RMSSD and HF-HRV were significantly different during the 3rd trimester as compared to any other time point (all $ps < 0.001$); however, there were no other significant differences between any other time point (all $ps > 0.29$).

3.3. Negative partner relationship qualities

3.3.1. Hypothesis 2: negative qualities in romantic relationships & depressive symptoms

First, we examined the unadjusted, zero-order correlations over time, which did not reveal a significant change in depressive symptoms over

Table 1
Demographic characteristics for study sample.

Variable	*M*	*SD*
1. Age	29.53	4.48
2. Education	7.74	1.69
3. Income	4.48	1.59
4. BMI	30.89	6.8
5. Negative Partner Relationship Qualities	7.87	6.51
6. Depressive Symptoms	9.08	7.72

Note. $N = 78$. All values as assessed during 3rd trimester. *M* and *SD* are used to represent mean and standard deviation, respectively.

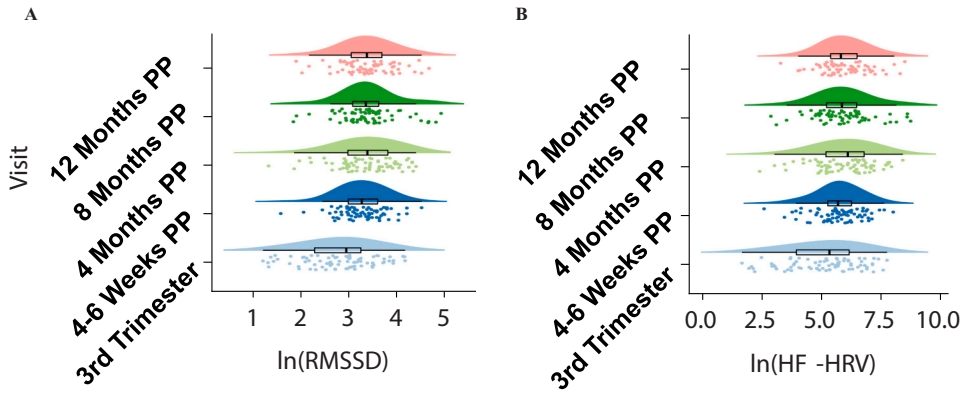

Fig. 1. Raincloud plots summarizing means, boxplots, and data points across each visit for RMSSD (Panel A) and HF-HRV (Panel B). PP = postpartum.

Table 2
Means and standard deviations for RMSSD and HF-HRV before transformation and after natural log transformation.

Variable	*M*	*SD*
RMSSD, untransformed		
1. 3rd trimester	20.29	14.66
2. 4–6 weeks postpartum	28.59	14.11
3. 4 months postpartum	32.86	18.67
4. 8 months postpartum	34.84	25.71
5. 12 months postpartum	32.10	18.29
RMSSD, natural log		
6. 3rd trimester	2.76	0.74
7. 4–6 weeks postpartum	3.24	0.48
8. 4 months postpartum	3.32	0.62
9. 8 months postpartum	3.37	0.59
10. 12 months postpartum	3.33	0.53
HF-HRV, untransformed		
11. 3rd trimester	359.59	464.13
12. 4–6 weeks postpartum	432.06	447.43
13. 4 months postpartum	649.75	781.52
14. 8 months postpartum	707.02	1208.03
15. 12 months postpartum	572.64	797.58
HF-HRV, natural log		
16. 3rd trimester	5.02	1.51
17. 4–6 weeks postpartum	5.65	0.97
18. 4 months postpartum	5.86	1.22
19. 8 months postpartum	5.82	1.17
20. 12 months postpartum	5.86	0.95

Note. $N = 78$. *M* and *SD* are used to represent mean and standard deviation, respectively.

the first year postpartum ($r = -0.06$, $p = 0.23$; see Table 3 for means, standard deviations, and correlations for each depressive symptom timepoint). In further tests taking into account the multilevel structure of the data, we confirmed that there was no significant relationship between time and depressive symptoms, $t(272.8) = -1.60$, $p = 0.11$. However, we observed a significant zero-order correlation between negative partner relationship qualities and depressive symptoms ($r = -0.29$, $p < 0.001$). In an unadjusted model accounting for time, negative partner relationship qualities did not reliably predict the slope of depressive symptoms ($b = -0.04$, *95% CI* [−0.10, 0.03], $p = 0.27$). However, there was a significant main effect for negative partner relationship qualities on depressive symptoms ($b = 0.49$, *95% CI* [0.22, 0.77], $p < 0.001$).

Table 3
Means, standard deviations, and correlations for depressive symptoms over time.

Variable	*M*	*SD*	1	2	3	4
Depressive symptoms						
1. 3rd trimester	9.49	8.13				
2. 4–6 weeks postpartum	9.32	8.37	0.55**			
3. 4 months postpartum	8.77	8.48	0.40**	0.55**		
4. 8 months postpartum	8.16	7.71	0.44**	0.61**	0.63**	
5. 12 months postpartum	7.83	8.32	0.44**	0.64**	0.52**	0.73**

Note. $N = 78$. *M* and *SD* are used to represent mean and standard deviation, respectively. *indicates $p < 0.05$. **indicates $p < 0.01$.

After controlling for maternal age, BMI, income, and the visit, the main effect of negative partner relationship qualities on depressive symptoms persisted ($b = 0.33$, *95% CI* [0.08, 0.58], $p = 0.012$); thus, although the slope of depressive symptoms was not affected by negative partner relationship qualities, those in worse quality relationships had significantly more depressive symptoms across the first year postpartum and this effect remained robust after adjusting for meaningful baseline characteristics (see Fig. 2).

3.3.2. Hypothesis 3: negative qualities in romantic relationships & HRV

We observed a significant zero-order correlation between negative partner relationship qualities and RMSSD ($r = -0.15$, $p < 0.007$), as well as between negative partner relationship qualities and HF-HRV ($r = -0.19$, $p < 0.001$). In an unadjusted model accounting for time, negative partner relationship qualities did not reliably predict the slope of RMSSD ($b = 0.00$, *95% CI* [−0.01, 0.00], $p_{RMSSD} = 0.081$) and HF-HRV ($b = -0.01$, *95% CI* [−0.02, 0.00], $p_{HF\text{-}HRV} = 0.15$).

After adjusting for age, income and pre-pregnancy BMI, we did not observe a reliable difference in the overall slope of participants' postpartum vagally-mediated HRV based on negative partner relationship qualities (RMSSD: $b = -0.01$, *95% CI* [−0.01, 0.00], $p_{RMSSD} = 0.092$; HF-HRV: $b = -0.01$, *95% CI* [−0.02, 0.00], $p_{HF\text{-}HRV} = 0.17$); however, those who evaluated their partner relationships as having fewer negative qualities also had higher vagally-mediated HRV across each postpartum visit point than those who reported more negative partner relationship qualities (see Fig. 3). Post-hoc analyses revealed that those who reported fewer negative partner relationship qualities had higher vagally-mediated HRV at 4 months (RMSSD: $b = -0.03$, *95% CI* [−0.06, 0.01], $p_{RMSSD} = 0.003$; HF-HRV: $b = -0.07$, *95% CI* [−0.11, −0.03], $p_{HF\text{-}HRV} = 0.001$), and 8 months postpartum (RMSSD: $b = -0.02$, *95% CI* [−0.05, −0.00], $p_{RMSSD} = 0.028$; HF-HRV: $b = -0.04$, *95% CI* [−0.09, 0.00], $p_{HF\text{-}HRV} = 0.062$), as compared to those who reported fewer negative partner relationship qualities. By 12 months postpartum, there were no longer statistically significant differences in either measure of vagally-mediated HRV based on negative qualities in one's partner relationship (RMSSD: $b = -0.01$, *95% CI* [−0.03, 0.01], $p_{RMSSD} = 0.25$; HF-HRV: $b = -0.04$, *95% CI* [−0.07, 0.00], $p_{HF\text{-}HRV} = 0.061$).

3.4. Post-hoc analysis: depressive symptoms & HRV

In a post-hoc analysis we examined whether depressive symptoms predicted either the levels or slopes of vagally-mediated HRV. First, we examined zero-order correlations and any main effects of depressive symptoms. In this sample, there was not a significant zero-order

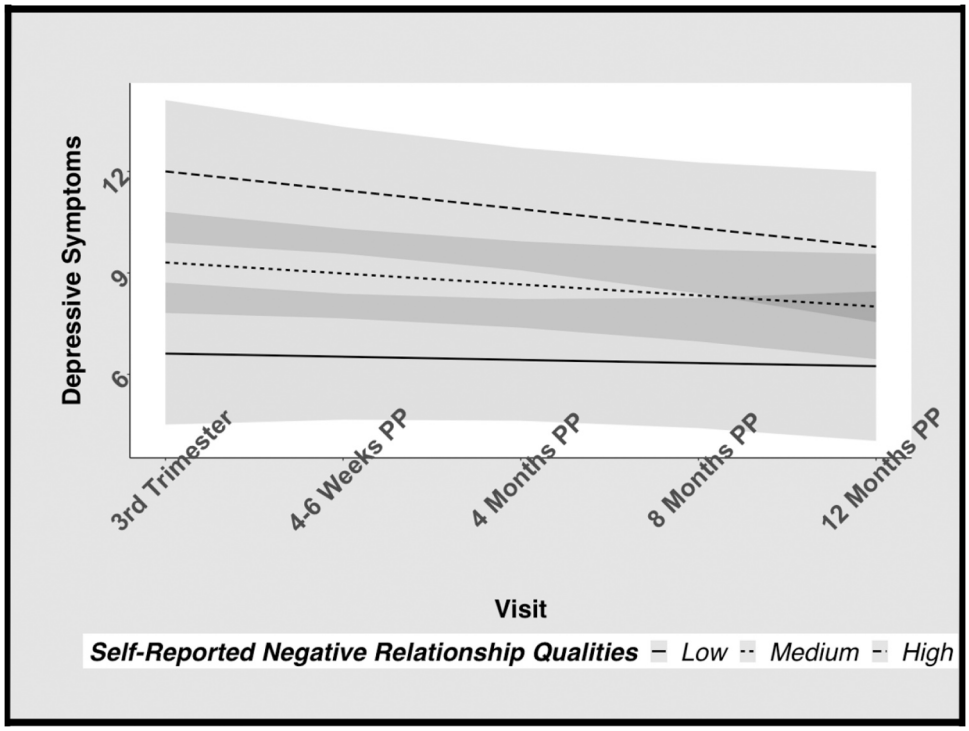

Fig. 2. The adjusted estimate of the effect of negative qualities in one's relationship across each visit for depressive symptoms.

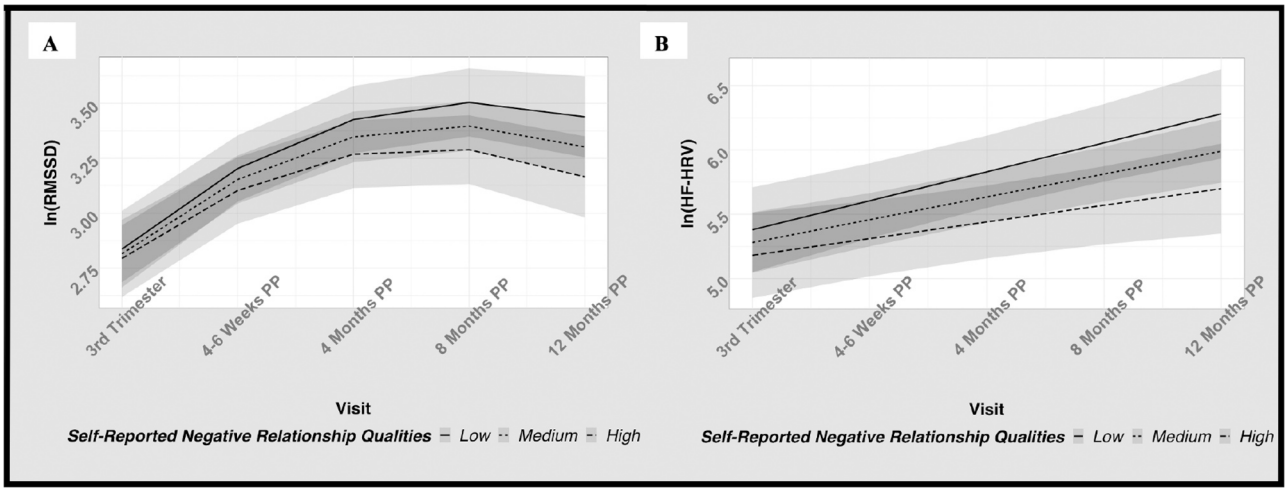

Fig. 3. The adjusted estimate of the effect of negative partner relationship qualities across each visit for RMSSD (Panel A) and HF-HRV (Panel B).

correlation between 3rd trimester depressive symptoms and RMSSD ($r = -0.06$, $p = 0.23$), nor between 3rd trimester depressive symptoms and HF-HRV ($r = -0.07$, $p = 0.17$). In an unadjusted model accounting for time, 3rd trimester depressive symptoms did not reliably predict levels of RMSSD ($b = -0.00$, *95% CI* [−0.02, 0.01], $p_{RMSSD} = 0.79$) or HF-HRV ($b = -0.01$, *95% CI* [−0.03, 0.02], $p_{HF\text{-}HRV} = 0.72$). After adjusting for age, income and pre-pregnancy BMI, there was not a reliable difference in the overall levels of postpartum vagally-mediated HRV based on 3rd trimester depressive symptoms (RMSSD: $b = -0.00$, *95% CI* [−0.01, 0.01], $p_{RMSSD} = 0.84$; HF-HRV: $b = -0.00$, *95% CI* [−0.03, 0.02], $p_{HF\text{-}HRV} = 0.87$).

Next, we examined whether depressive symptoms predicted the slopes of vagally-mediated HRV. In an unadjusted model accounting for time, 3rd trimester depressive symptoms did not reliably predict the slope of RMSSD ($b = 0.00$, *95% CI* [−0.00, 0.01], $p_{RMSSD} = 0.33$) or HF-HRV ($b = 0.01$, *95% CI* [−0.00, 0.01], $p_{HF\text{-}HRV} = 0.24$). After adjusting for age, income and pre-pregnancy BMI, there was not a reliable difference in the overall slope of postpartum vagally-mediated HRV based on 3rd trimester depressive symptoms (RMSSD: $b = 0.00$, *95% CI* [−0.00, 0.01], $p_{RMSSD} = 0.33$; HF-HRV: $b = 0.01$, *95% CI* [−0.00, 0.01], $p_{HF\text{-}HRV} = 0.24$). When analyzed by timepoint, 3rd trimester depressive symptoms were not reliably associated at any timepoint with RMSSD, *p*-value range = 0.14−0.66, or HF-HRV, *p*-value range = 0.15−0.98.

4. Discussion

We characterized the longitudinal trajectories and influence of negative partner relationship qualities on people's vagally-mediated HRV and depressive symptoms across five time points up to 12 months postpartum. On average, the only significant increase in vagally-mediated HRV occurred between the 3rd trimester and 4–6 weeks postpartum. This finding is robust and consistent with prior evidence of

pregnancy's influence on the autonomic nervous system and, specifically, vagally-mediated HRV (Chen et al., 1999; Yeh et al., 2009). However, those who reported more negative partner relationship qualities during their 3rd trimester of pregnancy had lower vagally-mediated HRV levels across all of the first year postpartum and significantly lower vagally-mediated HRV at both 4 and 8 months postpartum than people who reported fewer negative partner relationship qualities. There were no reliable differences in vagally-mediated HRV levels based on 3rd-trimester depressive symptoms.

Across all time points, those who reported more negative partner relationship qualities (at the 3rd-trimester baseline visit) experienced more severe depressive symptoms than their counterparts with fewer negative attributes in their relationships. This robust effect persisted after adjusting for age, BMI, and income; however, there was no difference in the *rate of change* of depressive symptoms across the first year postpartum based on the negative qualities in one's partner relationship. Said another way, depressive symptoms declined for people across the first year postpartum (regardless of the qualities of their partner relationship). Still, people in worse relationships experienced greater depressive symptoms at each time point. That said, our sample did not report high levels of depressive symptoms overall. The cutoff score for major depression is a score of 16 on the CES-D; when collapsed, our participants hovered between an average of a 7 and 10 across all visits. However, those in the highest quartile of negative partner relationship qualities began the study 69% closer to the cutoff for major depression than people in the lower quartile (see adjusted estimates in Fig. 2). Thus, these results should be interpreted as negative partner relationship qualities being associated with people experiencing differential levels of *mild-moderate* depressive symptoms; future work can extend this to examine these relationships among those with clinical depression.

Despite the reliable decreases in vagally-mediated HRV across pregnancy, few studies have examined autonomic recovery in the postpartum period. None, to our knowledge, have investigated whether psychosocial factors influence a person's autonomic recovery following pregnancy. Our overall results are consistent with past evidence that the postpartum increase in vagally-mediated HRV disappears by approximately 3 months postpartum (Chen et al., 1999; Yeh et al., 2009). Here, we found that being in a relationship with more negative qualities predicted worse autonomic recovery at 4 and 8 months postpartum. Although we cannot rule out the possibility that these results may be attributable to a third variable influence (e.g., emotion regulation), these results are consistent with the broader relationship literature showing that poorer quality relationships are cross-sectionally (Smith et al., 2011) and longitudinally (Donoho et al., 2015) related to lower vagally-mediated HRV. Because lower vagally-mediated HRV is associated with depressive symptoms (Kemp et al., 2010; Thayer and Brosschot, 2005), future work should explore the temporal relationship between vagally-mediated HRV and depressive symptoms in the postpartum period.

Vagally-mediated HRV is a promising target for both mindfulness-based and biofeedback-based interventions during pregnancy and postpartum. Mindfulness interventions foster more attention and awareness of one's experience in the present moment (Creswell, 2017). Mindfulness-based relationship enhancement, which is derived from Jon Kabat-Zinn's highly utilized mindfulness-based stress reduction intervention, improves relationship satisfaction in adult couples (Carson et al., 2004). Carson and colleagues used daily diaries in conjunction with an 8-week mindfulness training program. They identified that mindfulness practice on the first day was associated with higher levels of lagged relationship satisfaction for the next two days. Moreover, among pregnant couples, men who participated in a "Mindful Transition to Parenthood Program" had significantly higher relationship satisfaction and less negative affect than men in a waitlist control group (Gambrel and Piercy, 2015). Because mindfulness-based stress reduction techniques can enhance one's vagally-mediated HRV (Nijjar et al., 2014), mindfulness-based relationship enhancement may be ideal for combating decrements in vagally-mediated HRV associated with negative qualities of one's partner relationship.

An important strength of our study is the prospective longitudinal design, which helps to determine the temporal relationship between variables of interest. Because relationship quality was assessed before delivery, we can be more confident in the direction of the observed effects. Moreover, our main results persisted with and without adjustment for baseline characteristics. However, our sample was predominately White, educated, in good health, and in heterosexual relationships, which are significant limitations to address in the future. We also did not have the statistical power to examine potential mediating variables for the relationships described here. That will be an important next step, primarily because vagally-mediated HRV is often associated with depressive symptoms (Jandackova et al., 2016). Despite these limitations, our study begins to elucidate the mechanisms through which poorer quality relationships can negatively influence postpartum health.

5. Conclusions

In sum, this study adds to the growing literature of psychoneuroimmunological factors underlying successful adaptation to pregnancy and recovery in the postpartum period. Future research ought to examine these relationships in larger, more diverse samples and across cultures to determine these findings' generalizability and examine potential mediators. Understanding the psychological conditions and biological mechanisms that underlie worse postpartum recovery can enable future researchers to use interventions to reduce a person's risk of autonomic dysfunction in the postpartum period.

CRediT authorship contribution statement

Ryan L. Brown: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Visualization, Writing - review & editing. **Christopher P. Fagundes:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing. **Julian F. Thayer:** Resources, Writing - review & editing. **Lisa M. Christian:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Methodology, Writing - review & editing.

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Declarations of interest

none.

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