Cardiac Vagal Control in Response to Acute Stress during Pregnancy: Associations with Life Stress and Emotional Support

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Abstract

Life stressors during pregnancy can disrupt maternal stress regulation and negatively impact offspring health. Despite the important role of cardiac vagal control (e.g., heart rate variability; HRV) in stress regulation, few studies have investigated how life stressors and emotional support influence vagal control during pregnancy. This study aimed to (1) characterize patterns of cardiac vagal control in response to a stressor administered in pregnancy, and (2) examine the effects of life stress and emotional support on vagal control during rest, reactivity, and recovery. Participants included 191 pregnant women (79% Black; 21% White) living in an urban U.S. city (73% receiving public assistance). Heart rate (HR) and HRV (indexed by RMSSD) were recorded continually during the preparation, task, and recovery periods of the Trier Social Stress Task (TSST). Participants reported recent life stressors (e.g., relationship problems, financial hardship) and emotional support. Piecewise growth curve modelling was used to model rates of reactivity and recovery, adjusting for gestational age at time of assessment and recent health problems. Life stress predicted greater HR and HRV reactivity to the TSST as well as greater HRV recovery (vagal rebound). However, associations were only evident for women reporting high emotional support. Results suggest that pregnant women living with frequent life stressors may exhibit more rapid autonomic responses to acute stress, including more rapid vagal rebound after stressors, potentially reflecting physiological adaptation to anticipated high-stress environments; emotional support may enhance these responses. Studies are needed to investigate long-term health outcomes related to this stress response pattern.

Keywords

cardiac vagal control; heart rate; heart rate variability; pregnancy; prenatal stress; life stress; emotional support; trier social stress test; ECG; RMSSD; HRV

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Conflicts of Interest: None of the authors have any conflicts of interest to disclose.
1. INTRODUCTION

Exposure to frequent life stressors and dysregulation of maternal stress systems during pregnancy are known risk factors for a wide range of offspring outcomes, from adverse birth outcomes to risk for psychopathology (Glover, 2011; McGowan & Matthews, 2018). Evidence from a substantial body of work has shown that prenatal stress exposure can alter maternal stress physiology and regulation (Dunkel Schetter, 2011; Latendresse, 2009), which in turn directly influences fetal development through prenatal programming effects (Glover, 2015; Sandman et al., 2012). Women living in under-resourced environments are disproportionately impacted by recurring life stressors such as financial hardship and food and housing instability, which can increase during the perinatal period (Almeida et al., 2005; Bloom et al., 2013). Identifying risk and protective factors during pregnancy that influence maternal stress reactivity and recovery is a key step to inform early preventative interventions (Gelaye & Koenen, 2018).

1.1 Cardiac Vagal Control

Multiple physiological stress systems are involved in prenatal programming, including autonomic, neuroendocrine, and inflammatory systems (Dunkel Schetter, 2011; Glover, 2015). In the current study we focus on maternal cardiac vagal control given its key role in emotion regulation, and its relatively rapid reactivity to and recovery from acute stressors (Balzarotti et al., 2017; Perna et al., 2020; Souza et al., 2007). According to polyvagal theory (Porges, 2007), the ‘vagal brake’ (myelinated portion of the vagus nerve) is one of the primary mechanisms involved in regulating the stress response. During perceived safety, the vagal brake slows heart rate and activates the parasympathetic nervous system. Resting level of vagal control (‘vagal tone’) can be indexed noninvasively by heart rate variability (HRV; i.e., variation in time between heart beats), with higher HRV representing higher vagal tone (Laborde et al., 2017; Smith et al., 2020). When individuals face an acute stressor, the vagal brake rapidly withdraws to increase activation of the sympathetic system for adaptive ‘fight-or-flight’ responses (i.e., vagal reactivity), resulting in a rapid decrease in HRV (Laborde et al., 2018). Once the perceived threat is over, the vagal brake inhibits the sympathetic system and increases activation of the parasympathetic system to promote relaxation and recovery (i.e., ‘vagal rebound’), leading HRV levels to increase and return to resting levels (Laborde et al., 2018). Thus, through rapid inhibition and disinhibition of vagal tone to the heart, the vagal brake enables individuals to adaptively respond to stressors (Porges, 2001, 2007).

The efficient release and re-application of the vagal brake in response to demands of situational stressors has been referred to as ‘vagal flexibility’ (Muhtadie et al., 2015) and is implicated in stress resilience (Perna et al., 2020; Smeets, 2010). In general, higher vagal tone (HRV) at rest, faster reactivity to threat (decrease in HRV), and faster recovery (increase in HRV) after a stressor are thought to reflect greater flexibility and correlated with better mental health outcomes (Laborde et al., 2018; Smith et al., 2020; Souza et al., 2007), although associations between reactivity and specific outcomes like depression are somewhat mixed (Hamilton & Alloy, 2016). In addition, anticipatory responses to stressors have received some attention, with studies indicating a need to distinguish between vagal
withdrawal during the anticipation of a stressor versus more acute responses when faced with immediate threat (Engert et al., 2013; Taylor et al., 2018). Relatively few studies have examined individual differences in vagal recovery (Laborde et al., 2017; 2018), despite its implication for emotion regulation and stress resilience (Cui et al., 2015). Characterizing components of cardiac vagal control during pregnancy is the first step to identifying psychosocial factors that may influence patterns of reactivity and recovery.

1.2 Psychosocial Influences on Vagal Control During Pregnancy

Investigations of vagal control during pregnancy have primarily focused on resting vagal tone, with a few studies additionally examining vagal reactivity to stress (Christian, 2012). In general, these studies report reductions in vagal tone and vagal reactivity as pregnancy progresses (Braeken et al., 2015; DiPietro et al., 2005; Walther et al., 2005), although little is known about social or contextual factors (such as exposure to life stressors or social support) that account for individual differences in these components of vagal control. In nonpregnancy studies, exposure to psychosocial stressors such as negative life events has been linked to lower vagal tone across the lifespan (Michels et al., 2013; Ockenburg et al., 2015; Propper, 2012). Pregnant women living in under-resourced environments experience frequent life stressors such as food and housing instability, job instability, and interpersonal difficulties (Bloom et al., 2013). Some evidence suggests that these stressors may increase as pregnancy progresses (Braveman et al., 2010). Thus, differential exposure to life stressors may partially explain individual differences in cardiac vagal control during pregnancy.

Beyond risk factors, few studies have focused on identifying protective factors that could help to promote vagal flexibility and stress regulation during pregnancy. One such factor that has been broadly linked to stress resilience and effective coping is perceived emotional support (Panagioti et al., 2014; Sim et al., 2019; Webb Hooper et al., 2013), with some evidence suggesting that protective/positive effects may be magnified for individuals exposed to chronic adversity (Coulon & Wilson, 2015). Emerging studies suggest that emotional support directly influences some physiological stress systems (e.g., HPA-axis functioning) during pregnancy and may additionally buffer the negative effects of prenatal stressors on health outcomes (Coburn et al., 2016; Dunkel Schetter, 2011; Nierop et al., 2008). To the best of our knowledge, the role of emotional support in relation to cardiac vagal control has only been examined in non-pregnant samples, and is associated with higher resting vagal tone (Smith et al., 2020) as well as increases in vagal tone in experimental and intervention studies (Kok & Fredrickson, 2010; Smith et al., 2011). Together, this evidence supports the plausibility that perceived emotional support may enhance vagal flexibility and help to buffer the negative effects of life stressors during pregnancy.

1.3 The Present Study

The current study had two primary goals: First, we aimed to characterize individual differences in vagal responses to acute stress in a community sample of pregnant women, the majority of whom reside in low-resourced neighborhoods. We used a standardized laboratory stressor to measure several distinct components of vagal control (indexed by HRV), including resting vagal tone, anticipation of stress, acute stress reactivity, and
recovery. We employed piecewise growth curve models to analyze minute-by-minute changes in vagal control to characterize individual differences in vagal withdrawal (decrease in HRV) in preparation for and during the stressor and vagal rebound (increase in HRV) following the stressor. Based on prior studies in nonpregnant samples (Park et al., 2014; Smith et al., 2020), we hypothesized that higher resting vagal tone would be associated with greater vagal withdrawal during the anticipation and stressor periods followed by greater vagal rebound during the recovery period.

Second, we aimed to test the impact of life stressors and perceived emotional support during pregnancy on individual differences in vagal tone, reactivity, and recovery. We hypothesized that current exposure to frequent life stressors would be associated with lower resting vagal tone, attenuated reactivity to the acute stressor, and attenuated recovery after the stressor (indicating less vagal flexibility). In contrast, we hypothesized emotional support to predict higher resting vagal tone and greater reactivity and recovery from the stressor. In addition, we expected that emotional support would buffer (i.e., moderate) the association between life stressors and these components of vagal flexibility during pregnancy.

Finally, although a number of noninvasive HRV indices have been validated as metrics of parasympathetically-mediated cardiac vagal control (Berntson et al., 2005; Hill & Siebenbrock, 2009; Penttilä et al., 2001), there is debate as to the extent to which these indices can be influenced by predominantly sympathetically mediated factors such as increases in heart rate (Berntson et al., 2005). In particular, the bivariate autonomic space model emphasizes that in addition to varying reciprocally, the sympathetic and parasympathetic branches of the autonomic nervous system can vary independently as well as coactively (Berntson et al., 1993). Given that sympathetic effects cannot be inferred from measures of HRV alone, studies that examine cardiac vagal control while including parallel measures of possible sympathetic influence are needed when interpreting findings in relation to cardiac vagal control (de Geus et al., 2019). Thus, to increase specificity of our models to vagal control, we tested a parallel set of models that analyzed changes in heart rate (HR) in response to the experimental stressor. These secondary models were conducted to investigate potential parallel cardiac sympathetic effects and to highlight potential interactions between HR and HRV (de Geus et al., 2019).

2. METHOD

2.1 Participants and Procedures

Participants for the present analysis were drawn from a sub-study of the Pittsburgh Girls Study (PGS). The PGS is an ongoing longitudinal study of 2,450 women who were originally recruited in childhood in 1999-2000 based on a stratified, random sampling of 103,238 households in Pittsburgh, PA; homes in low-income neighborhoods were oversampled (Hipwell et al., 2002; Keenan et al., 2010). Participants have been assessed annually for the past 20 years with high retention (86% on completion of wave 19). Starting in 2018, all PGS participants who became pregnant were invited to participate in a study of prenatal stress, as part of the NIH Environmental influences on Child Health Outcomes (ECHO) consortium. PGS-ECHO participants completed a standardized experimental stress test (described below) and a comprehensive interview battery covering a range of domains.
(e.g., life stressors, social support) during pregnancy. Study visits were scheduled between 1:00 to 5:00 PM to control for differences in stress physiology based on time of day. All study procedures were approved by the university’s Institutional Review Board (IRB); all participants provided written consent prior to any data collection.

The present study included 191 PGS-ECHO participants (age 22-28) who completed the lab stressor and had data on cardiac vagal control. Approximately 33% were in the first trimester (1-12 weeks), 46% in the second trimester (13-26 weeks), and 21% in the third trimester of pregnancy (27+ weeks). Most participants (72.7%) were receiving public assistance. Most identified as Black American (74.9%), 21.5% identified as White American and 3.7% identified as Black and another race (multiracial).

2.2 Measures

2.2.1 Cardiac vagal control and heart rate during experimental stress test.—Cardiac vagal control was measured before, during, and after the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), a widely-used, experimental stress task in which participants give a timed speech in front of a panel of ‘judges’ and perform mental arithmetic. To measure cardiac responses to the TSST, we collected continuous electrocardiogram (ECG) data to index heart rate variability (HRV) and heart rate (HR) across four consecutive periods: 15-minutes of acclimation (resting), 3-minutes of preparing for stress test alone (anticipation), 7-minutes of speech/mental arithmetic stressor (reactivity), and 5-minutes post-stressor (recovery). The ECG signal was amplified and digitized with a sampling rate of 500 Hz using BioLab acquisition software. All subsequent processing and HRV analyses were conducted using Mindware HRV software. Mindware’s multi-pass algorithm was used for R-wave detection, and then the ECG signal was visually inspected to edit artifacts following standard guidelines (Laborde et al., 2017). Minute-to-minute changes in HRV were indexed by RMSSD in inter-beat intervals (IBI), a reliable indicator of vagal activity in the parasympathetic nervous system (Camm et al., 1996). RMSSD was log-transformed for analysis to adjust for skewness. The first 10 minutes of the acclimation period were used to allow participants to adjust to the laboratory environment and recording device. After this initial period, RMSSD and HR data from the final 5 minutes of the acclimation monitoring period were used to index ‘resting vagal tone’ and ‘resting HR,’ respectively. Subsequent minute-by-minute changes in RMSSD and HR were examined across the 3-min preparation (anticipatory) period, 7-minute stress test (reactivity period), and 5 minutes post stressor (recovery period) to derive latent slopes that represent rates of anticipatory reactivity, reactivity to the stressor, and recovery, respectively (see Data Analytic Plan).

2.2.2 Life stress.—Participants completed the Difficult Life Circumstances Scale (DLC; Barnard, 1988, 1994), a 28-item scale designed to assess the current number of stressors in an individual’s life. The scale was developed for families living in under-resourced environments and includes items assessing arguments in the home, inadequate housing, financial problems, and exposure to violence in the home and community, each scored as 1=Yes or 0=No. Items are summed for a total score representing number of life stressors. The DLC has shown acceptable test-retest reliability ($r=0.70$; Barnard, 1988) and internal
consistency in other samples (α=.70; Shernoff et al., 2014), and demonstrated similar internal consistency in the present sample (α=.69). In studies of pregnant women, the DLC has demonstrated predictive validity with adverse offspring outcomes (Curry et al., 1994).

### 2.2.3 Emotional support.—The Patient-Reported Outcomes Measurement Information System (PROMIS, 2016) Emotional Support Short-Form assessed perceived feelings of being cared for, valued, and having social support during pregnancy. A total of four items are each rated on a 5-point Likert-scale (1=Never to 5=Always). The total raw score (α=.97) is converted to a T-score following PROMIS guidelines for standardized scoring (T-score of 50 = normed population average). The PROMIS has shown convergent validity with similar measures of perceived emotional support (Fredericksen et al., 2019). Similar to other measures of social support, raw scores in this sample were skewed (i.e., participants tended to report high perceived emotional support, with 61% of participants reporting ‘always’ for all items). Thus, we used the normed PROMIS T-scores to dichotomize the variable into 0=low emotional support (T-score < 50; mean=44.49, SD=5.71, range=25-49) and 1=high emotional support (T-score > 50; mean=61.10, SD=2.63, range=51-62).

### 2.2.4 Covariates.—We evaluated several potential covariates. Participants self-reported their week of pregnancy or gestational age at time of assessment, and data were confirmed from medical record data when available (71%). Race data were collected from families as part of the original longitudinal study. Current receipt of public assistance status was recorded during the pregnancy assessment and coded as 1=receiving assistance from sources such as WIC and Medicaid, 0=not receiving assistance. Given that prior studies have observed lower resting HRV among pregnant women with depression (Shea et al., 2008) and anxiety (Chalmers et al., 2014), these were assessed as covariates. Participants used a 4-point Likert scale to rate the frequency of experiencing DSM symptoms of major depressive and generalized anxiety disorder symptoms in the past year as part of the Adult Self-Report Inventory-4 (ASRI-4; Gadow et al., 2004). Anxiety and depression were strongly correlated (r=.78, p<.01) and summed to represent recent history of mental health problems. Similarly, lower HRV has been associated with a range of physical health problems (Benichou et al., 2018; Cygankiewicz & Zareba, 2013). Recent physical health problems were assessed by a single global rating of health (Bethell et al., 2001) in which participants rated their overall health quality over the past year on a 5-point Likert scale (1=Excellent to 5=Poor).

### 2.3 Data Analytic Plan
Descriptive analyses were conducted using SPSS version 23. To visualize patterns of HRV change in response to the lab stress task, we first plotted minute-to-minute changes in RMSSD (log-transformed for analysis) across time (Figure 1). Next, we used piecewise growth curve modeling (PGCM), a special form of the latent growth model that can be used to (1) simultaneously model resting, anticipatory, reactivity, and recovery slopes while controlling for the correlations among the components, and (2) examine predictors of each of these components in a single model to reduce error from multiple testing. PGCM has been successfully used to investigate individual differences in vagal control in child clinical psychology (Obradović & Finch, 2017), but has not yet been applied to study prenatal stress. We conducted unconditional PGCMs in Mplus 6.12 (Muthén & Muthén, 2010), starting...
from a single curve and then adding additional slopes (‘pieces’) to the growth model in a stepwise procedure based on expected task-related change points. Specifically, we separated time into four segments: ‘resting vagal tone’ (final 5 minutes of acclimation), ‘anticipatory reactivity’ (3-min speech preparation alone), ‘acute stress reactivity’ (7-minute performance stressor in front of judges) and ‘recovery’ (5-minute recovery period) (Birkett, 2011). We used the minute-to-minute plot of RMSSD to empirically guide the addition of other linear or quadratic slopes. We used standard goodness of fit indices to identify the best fitting model, including the Akaike information criterion (AIC), Bayesian information criterion (BIC), sample-adjusted BIC, root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), and the Comparative Fit Index (CFI). Lower AIC, BIC, and adjusted-BIC values indicate better fit, whereas RMSEA ≤ .08, SRMR ≤ .08, and CFI ≥ .90 indicate good fit (Hooper et al., 2008).

Prior to adding the main predictors to the model, we conducted a preliminary PGCM to examine the association between demographic and health covariates and each component of vagal control. Significant or marginally significant covariates were included in subsequent analyses. Next, a conditional PGCM tested the main effects of life stress and emotional support on each component of vagal control. Finally, we added the interaction term between life stress and emotional support. Following standard guidelines for interpreting interactions (Aiken & West, 1991), significant life stress x emotional support interactions were probed by examining the association between life stress and vagal outcome when emotional support was centered at 0=low (T-score < 50) or 1=high emotional support (T-score > 50). To highlight any unique effects of life stress and emotional support on cardiac vagal control and detect possible parallel cardiac sympathetic effects, a secondary PGCM was conducted to test the effects of life stress, emotional support, and their interaction on changes in HR across the stress test (i.e., resting HR, anticipation, reactivity, recovery), which was compared to the primary PGCM results for RMSSD.

3. RESULTS

3.1 Descriptive statistics

Descriptive statistics and correlations among demographic and predictor variables appear in Table 1. Life stressors were common in this sample, with the average participant experiencing more than three recent life stressors during pregnancy. Approximately 1 in 3 women (31%) reported low emotional support (T-score < 50 on the normed scale), with women receiving public assistance more likely to be experiencing low emotional support during pregnancy. As described above, most participants identified as Black (vs. White). Race was correlated with receipt of public assistance but not with emotional support or reported life stressors. Table 2 summarizes the means and standard deviations of HRV (indexed by RMSSD) and HR across each period of the laboratory stress task and displays the inter-correlations among these indices. As expected, HRV was inversely correlated with HR across all time points.
3.2 Unconditional PGCM

The solid blue line in Figure 1 shows the average minute-to-minute changes in HRV (RMSSD) across each period of the laboratory stress task, which was used to guide the construction of the PGCM. Goodness-of-fit comparisons for unconditional PGCM models appear in Table 3. Using a piecewise model to separate resting, anticipation, reactivity, and recovery significantly improved model fit over a single growth curve. Adding a quadratic term to characterize recovery additionally improved model fit, although fit indices remained poor. Inspection of the raw RMSSD data showed that there was a steep drop in RMSSD in the first minute of the stressor followed by a more gradual and variable decrease in the subsequent minutes of the stressor period. Similarly, after the stressor, RMSSD showed a steep increase in the first minute post-stressor, followed by a gradual return to resting levels. These changes in the first minute of the stressor and post-stressor, respectively, are consistent with the rapid withdrawal of the vagal brake in response to stress (i.e., acute reactivity) and rapid vagal rebound after a stressor (i.e., acute recovery) (Jennings & Wood, 1977). Distinguishing the slopes of these acute changes in RMSSD led to significant improvements in model fit, with the final PGCM demonstrating excellent fit (Table 3).

The final PGCM closely resembled the original minute-to-minute raw data (Figure 1). As expected, RMSSD was stable during the initial 5-minute resting period (resting vagal tone), and then significantly decreased when participants prepared their speech in anticipation for the stress test ($B=-.024$, $SE=.004$, $p<.001$). RMSSD substantially decreased during the first minute of the stressor ($B=-.076$, $SE=.019$, $p<.001$) followed by a slower decline in the remainder of the stressor period ($B=-.017$, $SE=.003$, $p<.001$). After the stressor, RMSSD significantly increased in the first minute of recovery (above initial resting levels) ($B=.357$, $SE=.012$, $p<.001$), before gradually returning to baseline in a positive quadratic pattern ($B=-.052$, $SE=.012$, $p<.001$; quadratic $B=.006$, $SE=.002$, $p=.002$).

Resting vagal tone was correlated with greater anticipatory reactivity ($r=-.185$, $p=.003$), greater acute reactivity to the stressor ($r=-.500$, $p<.001$), and greater acute recovery after the stressor ($r=.605$, $p<.001$). Magnitude of the reactivity slope (i.e., decreasing HRV during stressor) was negatively associated with magnitude of the recovery slope (i.e., increasing HRV after stressor) ($r=-.655$, $p<.001$); in other words, greater reactivity was correlated with greater recovery.

3.3 Conditional PGCM

In subsequent models, we focused on predicting individual differences in resting vagal tone (intercept) and slopes of anticipatory reactivity, acute reactivity, and acute recovery (Figure 1). For comparison, a parallel model predicting changes in HR was conducted (Table 4).

3.3.1 Preliminary model.—Week of pregnancy was negatively associated with resting vagal tone ($B=-.008$, $p=.003$) and magnitude of reactivity and recovery ($B=.006$, $p=.002$ and $B=-.009$, $p<.001$, respectively). History of recent physical health problems was marginally, positively associated with anticipatory reactivity and recovery ($B=.033$, $p=.05$). Race, receipt of public assistance, and recent history of mental health problems were not associated with...
any components of vagal control (all \( p^* > .10 \)). Thus, we included week of pregnancy and recent physical health problems in subsequent predictive models.

### 3.3.2 Primary model predicting vagal control (HRV).

Controlling for week of pregnancy and recent physical health problems, neither life stress nor emotional support had main effects on resting vagal tone, anticipatory reactivity, or acute reactivity. Number of life stressors was positively associated with acute recovery slope (i.e., steeper vagal rebound), and emotional support was marginally positively associated with vagal recovery. Finally, emotional support interacted with life stress to predict vagal reactivity and recovery (Figure 2). Post hoc analyses revealed that the positive associations between life stressors and vagal reactivity (decrease in HRV: \( B = -.023, SE = .009, p = .012 \)) and vagal recovery slopes (increase in HRV: \( B = .038, SE = .011, p < .001 \)) were only observed among women reporting high levels of emotional support. In contrast, life stress was unrelated to cardiac vagal control for women reporting low levels of emotional support (reactivity: \( B = .007, SE = .009, p = .467 \); recovery: \( B < .001, SE = .008, p = .952 \)).

### 3.3.3 Parallel model predicting HR for comparison.

Similar to the model for HRV, life stress significantly interacted with emotional support to predict HR reactivity. Specifically, life stress was associated with greater reactivity (i.e., steeper increase in HR) in response to the lab stressor for women reporting high levels of emotional support (\( B = .971, SE = .454, p = .032 \)), whereas life stress was unrelated to HR reactivity for women reporting low emotional support (\( B = -.398, SE = .323, p = .217 \)). In contrast, neither life stress nor its interaction with emotional support significantly predicted changes in HR during recovery. Instead, emotional support had a main effect on HR recovery regardless of life stress levels.

### 3.4 Post hoc analysis of life stress and emotional support

To help with interpreting the interactions between life stress and emotional support, we conducted additional post-hoc analyses to compare women with high vs. low emotional support on number of life stressors and the types of stressors most frequently endorsed (> 30%). On average, women with low support reported significantly more life stressors during pregnancy (mean = 4.01 stressors) than women with high support (mean = 2.87; \( t = -2.27, p = .03 \)). Both groups frequently endorsed difficulties related to a partner being away from the home more than half the time (33% of low vs. 32% of high support group). However, women with low support were also likely to reported chronic housing and financial stressors, including difficulties finding affordable housing (38% vs. 21% of high support group), lack of privacy in the home (33% vs. 18%), and frequently getting hassled by bill creditors or collection agencies (31% vs. 22%). Thus, stress related to partner absence was relatively common in the current sample, but pregnant women with low emotional support also experienced chronic housing and financial stressors.

### 4 DISCUSSION

The goal of this study was to investigate individual differences in cardiac vagal control in response to an experimental stressor administered during pregnancy, and to examine the extent to which experiences of life stress and emotional support during pregnancy influenced...
patterns of stress regulation. Participants in this study were drawn from a community-based sample of pregnant women, most of whom identified as Black American and were receiving public assistance (e.g., Medicaid) during pregnancy. We employed piecewise growth curve modeling (PGCM) to identify distinct components of vagal control, including resting vagal tone, vagal withdrawal upon stressor onset, and vagal rebound after the stressor. A six-piece growth curve model fit the data best: as expected, vagal tone was stable during the resting period and then decreased when participants prepared their speech in anticipation for the stress test. Vagal tone then rapidly decreased during the first minute of the stressor (acute reactivity), followed by a slower decline in the remainder of the stressor period. After the stressor, vagal tone significantly increased in the first minute of recovery (acute vagal rebound), followed by a gradual return to resting levels.

Consistent with our first hypothesis, higher resting vagal tone was robustly associated with greater vagal withdrawal upon stressor onset and greater vagal rebound after the stressor. Prior studies have suggested that this correlated pattern of high resting vagal tone combined with rapid reactivity and recovery represents ‘vagal flexibility’ or the capacity to calibrate physiological stress systems in response to behavioral demands of a situation (Muhtadie et al., 2015). Similar to prior pregnancy studies, we found that later stage of pregnancy predicted lower resting vagal tone and higher resting HR, as well as dampened vagal withdrawal and dampened HR reactivity to the stressor (DiPietro et al., 2005; Walther et al., 2005). In addition, we observed attenuated vagal rebound and attenuated HR recovery from the lab stressor in later weeks of pregnancy. These results are consistent with studies reporting dampened cortisol, HR, and blood pressure responses to stress in more advanced pregnancy (de Weerth & Buitelaar, 2005; Entringer et al., 2010). Together, these findings indicate that there may be attenuation in the ability to flexibly respond to and recover from acute social stress as pregnancy progresses.

We examined recent exposure to life stressors and emotional support as potential correlates of cardiac vagal control (indexed by RMSSD) during pregnancy, and we compared these results to secondary models conducted with HR to highlight any parallel cardiac sympathetic effects. For both RMSSD and HR, recent life stress predicted greater reactivity in response to the lab stressor, but only for women reporting high levels of emotional support. In contrast, when predicting recovery, the pattern of results differed between RMSSD and HR: women reporting high life stress combined with high emotional support showed more rapid vagal (RMSSD) recovery. However, neither life stress nor its interaction with emotional support significantly predicted HR recovery. This pattern of findings suggests that life stress may specifically interact with emotional support to predict parasympathetically-mediated vagal control during the recovery period. These results are consistent with theoretical models suggesting that the vagal system may be uniquely involved in adaptive responses to life stressors, and our findings highlight that this may be particularly relevant for rapid physiological recovery from acute stress.

Overall, our findings suggest that when paired with high levels of emotional support, pregnant women who have lived with more life stressors may exhibit greater flexibility in modulating autonomic control to match the behavioral demands of stress-evoking situations, as evidenced by greater vagal withdrawal and HR increase upon stressor onset and greater
vagal rebound after the stressor. According to the Adaptive Calibration Model (ACM; Del Giudice et al., 2011), an evolutionary-developmental theory of stress responsivity, a history of frequent exposure to psychosocial stress may lead to a heightened stress response, reflecting developmental adaptation of the allostatic response to anticipated psychosocial challenges. Greater vagal rebound immediately following the end of a stressor may similarly reflect rapid increases in cardiac vagal tone, reflecting the central system’s effects on vagal activity as it prepares to respond to new environmental challenges (Laborde et al., 2018). Thus, the association between life stressors and rapid reactivity/recovery from acute stress could potentially reflect a highly responsive vagal response that has physiologically adapted over time to an anticipated high-stress environment. Of note, although our findings are consistent with prior studies that reported an association between life stress and heightened stress reactivity, some prior studies (measuring HR or blood pressure) have reported an opposite pattern, in which lower or ‘blunted’ reactivity was observed among individuals living with high levels of life stress (Carroll et al., 2005; Phillips et al., 2005). According to the ACM theory, life stressors may differentially influence patterns of stress response depending on the type, timing, and chronicity of stress exposure (Del Giudice et al., 2011). Thus, studies that differentiate these components of stress exposure are needed to further elucidate the complex associations between life stress and stress response patterns during pregnancy. In addition, given that life stress may differentially influence sympathetic vs. vagal reactivity, future studies are needed to elucidate potential independent, reciprocal, and coactive patterns of sympathetic and parasympathetic responses to stress (Berntson et al., 1993).

Importantly, the associations between life stress and vagal reactivity and recovery were only observed for women who also reported high emotional support. These findings suggest that emotional support may play a critical role in facilitating flexible responding to social-environmental demands. In contrast, life stress was unrelated to vagal control for women with low emotional support. From the polyvagal perspective, emotional support may contribute to an increased sense of emotional safety, which facilitates recovery from stress (Porges, 2007). Emotional support could also increase the likelihood that an individual perceives a social stressor as a ‘challenge’ that can be overcome (vs. ‘threat’), situational appraisals that have been shown to impact cardiovascular responses to acute stressors (Seery, 2011). Thus, one potential mechanism through which emotional support may influence vagal recovery is by influencing the way women appraise stressors, a hypothesis that could be tested in future studies that incorporate measures of appraisal. In the present study, stress related to partner absence was relatively common among both groups of women, but many women with low emotional support additionally reported difficulties with chronic stressors such as financial strain and difficulties finding affordable housing. Implicit in the interaction of stress exposure and emotional support is the construct of coping. Although we did not directly measure coping, it appeared that our participants included two groups with respect to coping with stressors: one group with interpersonal stress and social coping support, and the other group with interpersonal and chronic stressors and low social coping support. Thus, vagal flexibility may be sensitive to individual differences in the availability and perceived efficacy of methods for coping with stress exposure. Such findings highlight the
need for more studies that consider both exposure and coping contexts in discerning how psychosocial stress influences cardiac vagal control during pregnancy.

Characterizing the psychosocial contexts associated with different patterns of reactivity and recovery may help to identify modifiable psychosocial factors that could be targeted to improve stress regulation during pregnancy. For example, given that emotional support was associated with recovery from acute stress, emotional support could be a modifiable factor targeted to enhance physiological recovery from acute stress particularly for pregnant women living with high levels of life stress. Follow-up studies that directly manipulate emotional support levels (e.g., intervention studies) are needed to investigate the extent to which increases in emotional support buffer the negative impact of life stress on vagal recovery and prenatal stress transmission. It will be important to further examine the extent to which changes in vagal recovery relate to observable improvements in health, which may help to inform the effectiveness of interventions focused on emotional support during pregnancy. In addition, future studies should investigate other positive contextual factors (e.g., access to prenatal care) and health behaviors (e.g., physical activity) that may influence patterns of prenatal vagal control and recovery.

In interpreting these results, it is important to acknowledge the demographic characteristics of our sample, which consisted primarily of Black women residing in low resourced environments. This differs from most studies of prenatal stress and vagal flexibility, which have typically been conducted with predominantly White women living in well-resourced environments. Although prior studies have found higher vagal tone and greater vagal flexibility to be linked with better health outcomes, it is unclear if these patterns generalize to all women. For example, although we did not observe any race differences in resting vagal tone or vagal control indices in our sample, some studies have reported higher resting vagal tone among Black individuals compared to White individuals; importantly, this difference is thought to result from repeated and prolonged down-regulation of sympathetic stress activation as a result of chronic discrimination and racism (Hill et al., 2015). Thus, although a more rapid vagal recovery from acute stressors during pregnancy may reflect an adaptive response that is protective for the developing fetus, much more longitudinal research is needed to understand the extent to which these individual differences in physiological adaptations to stress during pregnancy contribute to long-term health outcomes, such as maternal risk for later cardiovascular health problems (Geronimus et al., 2010; McEwen, 1998).

Several study limitations should be considered when interpreting our findings. First, life stressors and emotional support were assessed concurrently with cardiac vagal control, which prevents testing direction of effects. Second, most women in this sample identified as Black American and reported that they were receiving public assistance; thus, our results may not generalize to Black women with higher earnings or women who identify with other racial-ethnic groups. In addition, our life stress measure was designed to provide an overview of contextual stressors across several domains. Although we attempted to elucidate patterns of stress types in post hoc analyses, follow-up studies are needed to directly investigate the effects of different life stressors on vagal regulation during pregnancy. These future studies would benefit from including specific stressors that are salient for pregnant
women, such as pregnancy-related stress and perceived discrimination, the latter of which has been shown to increase significantly during pregnancy for Black American women (Rosenthal et al., 2014). In addition, because of the skewed distribution of scores from the emotional support scale, we used T-scores to identify women with below vs. above average support levels, which limited the ability to elucidate effects at extreme ends of low or high support. Follow-up studies are needed to investigate additional components of support (e.g., type, quality, regularity). Further, although we identified associations between emotional support and vagal control, we did not assess potential mechanisms underlying these associations (e.g., challenge/threat appraisals, coping behaviors), important next steps to further elucidate causal mechanisms. Finally, in this study’s initial design phase, we selected RMSSD as the index of vagal activity given prior literature suggesting that it is highly correlated with other vagal activity measures (e.g., pvRSA) and is less sensitive to variability in respiration than other HRV indices (Berntson et al., 2005; Penttilä et al., 2001). Nonetheless, because respiration was not directly measured in this study, in cases of major within-subject changes in respiratory rate and depth, vagal variability indices may be influenced by such respiratory changes. In addition, we note that HR is controlled by both the sympathetic and parasympathetic systems, which limits the specificity of its interpretation in relation to sympathetic activity; thus we encourage future studies to include additional psychophysiological measures that may be more uniquely mediated by the sympathetic system to further elucidate the potential interplay between sympathetic and parasympathetic responses to stress during pregnancy.

In conclusion, the results of our study of pregnant women suggest that exposure to life stress may be associated greater sympathetic and vagal reactivity as well as greater vagal rebound (recovery) in response to an acute social stressor. However, associations were only evident for women reporting high levels of perceived emotional support. These findings suggest that perceived emotional support may play a critical role in facilitating vagal recovery from acute stress, particularly for pregnant women living with high levels of life stress, although further research is needed to investigate the long-term health outcomes resulting from this pattern of vagal regulation.

**Acknowledgements:**

This research was supported in part by the National Institute of Mental Health Environmental influences on Child Health Outcomes (ECHO) Program (UH3OD023244), the National Institute of Mental Health (R01MH056630), the National Heart, Lung, and Blood Institute (R01HL157787), and the National Institute of General Medical Sciences (R01GM113243). IT was supported by a postdoctoral training grant from the National Institute on Alcohol Abuse and Alcoholism (T32AA007455). Special thanks to the families of the Pittsburgh Girls Study for their participation in this research and to our dedicated research team for their continued efforts.

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*Psychophysiology. Author manuscript; available in PMC 2022 June 01.*


Psychotherapy: Author manuscript; available in PMC 2022 June 01.


Psychophysiology. Author manuscript; available in PMC 2022 June 01.


Figure 1.
Changes in HRV in response to the Trier Social Stress Test. (Note: Ln(RMSSD) = natural logarithm of the root mean square of successive differences).
Figure 2. Graphical depiction of the Life Stress x Emotional Support interaction for HRV: life stress was associated with greater acute vagal reactivity and greater acute vagal recovery in responses to the Trier Social Stress Test, but only for individuals who reported high levels of emotional support (i.e., red line). Note that life stress was analyzed continuously in the predictive models but is displayed in dichotomized form here using median split for illustrative purposes only (low stress: ≤3 stressors, high stress: >3 stressors). Emotional support was categorized using standardized, population normed T-scores (Low support: T-score < 50, High support: T-score > 50).
### Table 1

Descriptive statistics and bivariate correlations among study variables

<table>
<thead>
<tr>
<th></th>
<th>M(SD) or %</th>
<th>Range</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racial identity</td>
<td>78.5%</td>
<td>0/1</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receiving public assistance</td>
<td>72.7%</td>
<td>0/1</td>
<td>.22 **</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recent mental health problems</td>
<td>10.40 (6.50)</td>
<td>0-32</td>
<td>–.03</td>
<td>–.04</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Recent physical health problems</td>
<td>2.16 (1.01)</td>
<td>1-5</td>
<td>.02</td>
<td>.13</td>
<td>.25 **</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week of pregnancy or gestational age</td>
<td>18.45 (8.60)</td>
<td>5-38</td>
<td>.04</td>
<td>.01</td>
<td>.07</td>
<td>.06</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life stress</td>
<td>3.19 (2.69)</td>
<td>0-17</td>
<td>−.01</td>
<td>.05</td>
<td>.16 *</td>
<td>.25 **</td>
<td>.01</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Emotional support (t-score &gt; 50)</td>
<td>67.6%</td>
<td>0/1</td>
<td>−.12</td>
<td>−.17 *</td>
<td>−.16 *</td>
<td>−.25 **</td>
<td>.02</td>
<td>−.20 **</td>
<td>–</td>
</tr>
</tbody>
</table>

**Note.**

* p < .05  
** p < .01  

^1 Racial identity coded as 1=Black American (includes multiracial Black and another race) vs. 0=White American.
Table 2

Means, standard deviations, and correlations among HRV (indexed by RMSSD) and HR variables measured before, during, and after the Trier Social Stress Test

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RMSSD: resting</td>
<td>39.92 (31.02)</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. RMSSD: anticipation</td>
<td>36.06 (30.30)</td>
<td>.89**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. RMSSD: stressor</td>
<td>23.15 (14.33)</td>
<td>.63**</td>
<td>.68**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. RMSSD: recovery</td>
<td>41.66 (36.26)</td>
<td>.86**</td>
<td>.88**</td>
<td>.58**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. HR: resting</td>
<td>83.29 (10.79)</td>
<td>–.64**</td>
<td>–.56**</td>
<td>–.54**</td>
<td>–.57**</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. HR: anticipation</td>
<td>89.13 (12.31)</td>
<td>–.53**</td>
<td>–.62**</td>
<td>–.58**</td>
<td>–.53**</td>
<td>.76**</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>7. HR: stressor</td>
<td>100.85 (14.52)</td>
<td>–.33**</td>
<td>–.42**</td>
<td>–.69**</td>
<td>–.30**</td>
<td>.59**</td>
<td>.76**</td>
<td>–</td>
</tr>
<tr>
<td>8. HR: recovery</td>
<td>83.04 (11.50)</td>
<td>–.62**</td>
<td>–.60**</td>
<td>–.55**</td>
<td>–.67**</td>
<td>.90**</td>
<td>.80**</td>
<td>.60**</td>
</tr>
</tbody>
</table>
### Table 3
Comparing fit indices to select the best fitting piecewise latent growth curve model (PGCM) for HRV

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>BIC</th>
<th>Sample adj-BIC</th>
<th>RMSEA</th>
<th>SRMR</th>
<th>CFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Single growth curve</td>
<td>−2042.716</td>
<td>−1961.409</td>
<td>−2040.600</td>
<td>0.214</td>
<td>0.326</td>
<td>0.590</td>
</tr>
<tr>
<td>B  4-piece curve: resting, prep, stressor, recovery</td>
<td>−2870.087</td>
<td>−2759.510</td>
<td>−2867.209</td>
<td>0.173</td>
<td>0.153</td>
<td>0.743</td>
</tr>
<tr>
<td>C  Add quadratic term for recovery period</td>
<td>−3378.154</td>
<td>−3248.063</td>
<td>−3374.769</td>
<td>0.142</td>
<td>0.105</td>
<td>0.832</td>
</tr>
<tr>
<td>D  Distinguish first min. of stress response ('acute reactivity')</td>
<td>−3774.975</td>
<td>−3622.118</td>
<td>−3770.997</td>
<td>0.107</td>
<td>0.083</td>
<td>0.909</td>
</tr>
<tr>
<td>E  Distinguish first min. of recovery ('acute recovery')</td>
<td>−4017.132</td>
<td>−3838.257</td>
<td>−4012.477</td>
<td>0.074</td>
<td>0.055</td>
<td>0.959</td>
</tr>
</tbody>
</table>

*Note.* Lower AIC and BIC values indicate better fit. RMSEA ≤ .08, SRMR ≤ .06, and CFI ≥ .90 indicate good fit. Best fitting model is bolded for emphasis.
Table 4

Results from the conditional PGCMs examining associations between life stress and emotional support with components of cardiac vagal control (HRV) and changes in heart rate in response to the Trier Social Stress Test.

<table>
<thead>
<tr>
<th>Primary Model: Heart Rate Variability (HRV)</th>
<th>Resting vagal tone (intercept)</th>
<th>Anticipatory reactivity (vagal withdrawal in prep)</th>
<th>Acute reactivity slope (vagal withdrawal)</th>
<th>Acute recovery slope (vagal rebound)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (SE)</td>
<td>β</td>
<td>p</td>
<td>B₁ (SE)</td>
<td>β</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------</td>
<td>---------------------------------------------------</td>
<td>------------------------------------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>Step 1 (Main effects)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week of pregnancy</td>
<td>−.007 (.003)</td>
<td>−.209 .014</td>
<td>&lt;.001 (.001)</td>
<td>.007 .937</td>
</tr>
<tr>
<td>Recent physical health problems</td>
<td>.016 (.023)</td>
<td>.056 .481</td>
<td>−.066 (.004)</td>
<td>−.103 .179</td>
</tr>
<tr>
<td>Life stress</td>
<td>−.007 (.009)</td>
<td>−.099 .451</td>
<td>&lt;.001 (.002)</td>
<td>.028 .688</td>
</tr>
<tr>
<td>Emotional support</td>
<td>−.044 (.049)</td>
<td>−.070 .365</td>
<td>−.004 (.010)</td>
<td>−.028 .729</td>
</tr>
<tr>
<td>Step 2 (Add interaction term)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life stress x Emotional support</td>
<td>.012 (.016)</td>
<td>.093 .458</td>
<td>.002 (.003)</td>
<td>.066 .590</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Secondary Model: Heart Rate (HR)</th>
<th>Resting HR (intercept)</th>
<th>Anticipatory reactivity (HR increase in prep)</th>
<th>Acute reactivity slope (HR increase to stressor)</th>
<th>Acute recovery slope (HR decrease in recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (SE)</td>
<td>β</td>
<td>p</td>
<td>B₁ (SE)</td>
<td>β</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------</td>
<td>---------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Step 1 (Main effects)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week of pregnancy</td>
<td>.345 (.105)</td>
<td>.272 .001</td>
<td>−.044 (.020)</td>
<td>−.133 .026</td>
</tr>
<tr>
<td>Recent physical health problems</td>
<td>−.231 (.790)</td>
<td>−.023 .770</td>
<td>.231 (.194)</td>
<td>.085 .234</td>
</tr>
<tr>
<td>Life stress</td>
<td>.296 (.284)</td>
<td>.076 .298</td>
<td>−.033 (.098)</td>
<td>−.624 .289</td>
</tr>
<tr>
<td>Emotional support</td>
<td>1.364 (1.804)</td>
<td>.061 .450</td>
<td>.364 (.391)</td>
<td>.062 .352</td>
</tr>
<tr>
<td>Step 2 (Add interaction term)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Life stress x Emotional support</td>
<td>.597 (.558)</td>
<td>.131 .285</td>
<td>−.179 (.138)</td>
<td>−.150 .195</td>
</tr>
</tbody>
</table>

Note. B = unstandardized coefficient; β = standardized coefficient. Significant effects (p < .05) are bolded. HRV was indexed by RMSSD.

1. As shown in Figure 2, anticipatory vagal reactivity and acute vagal reactivity were characterized by a negative linear slope, and thus negative coefficients in this table indicate that the variable was associated with a greater vagal withdrawal whereas positive coefficients indicate attenuated withdrawal.

2. Acute vagal recovery, in contrast, was characterized by a positive linear slope, and thus positive coefficients indicate greater recovery (steeper vagal rebound) whereas negative coefficients indicate attenuated recovery (less vagal rebound).

3. Anticipatory HR reactivity and acute HR reactivity were characterized by a positive linear slope, and thus positive coefficients for HR indicate that the variable was associated with a greater HR reactivity (steeper increase in HR) whereas negative coefficients indicate attenuated HR reactivity.
Acute HR recovery, in contrast, was characterized by a negative linear slope, and thus negative coefficients indicate greater recovery (steeper decrease in HR) whereas positive coefficients indicate attenuated recovery after the stressor.