PHYSIOLOGIC RESPONSIVENESS TO SOCIAL INTERACTION IN MOTHERS WITH AND WITHOUT A HISTORY OF DEPRESSION

by

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Maternal depression is associated with child psychiatric illness, especially in adolescent girls. Depressed mothers have difficulty regulating their own emotions and display diminished emotional reactivity when interacting with their children. In order to better understand the role that such interpersonal difficulties may play in the intergenerational transmission of depression, the present study examined vagal responsiveness, a physiologic indictor of emotion regulation, via measurement of high-frequency heart rate variability (HF-HRV) in pairs of mothers and adolescent daughters during interaction tasks in which they discussed pleasant events and disagreements. Participants included 23 mother-daughter pairs in which both mother and daughter had a history of depression and 23 non-psychiatric control pairs in which neither mother nor daughter had a history of psychiatric illness. Separate piecewise linear growth models were used to compare slopes of HF-HRV between groups of mothers and daughters. Results showed that control mothers and daughters displayed positive slopes in HF-HRV during both pleasant events and disagreement discussions, and negative slopes during rest periods following the discussions. In contrast, mothers and daughters with a history of depression showed minimal vagal responsiveness during discussion and rest periods. These results suggest that while control mothers and daughters displayed vagal flexibility and activation during both discussion tasks—which may facilitate positive socio-emotional engagement and development—depressed individuals exhibited a lack of flexible and sensitive vagal responsiveness. Finally, exploratory analyses examined the covariation of vagal responsiveness between mother-daughter pairs. During the pleasant events discussion, a strong positive correlation was obtained among control dyads and no association was found for controls during the disagreement discussion. In contrast, during both discussions, a negative association between mothers' and daughters' patterns of responsiveness was obtained among dyads with a history of depression. The inverse correlations found in dyads with a history of depression suggest that in these individual dyads, mothers and daughters experienced the discussions in different ways, whereas the positive correlation found for control dyads suggests that control mothers and daughters experienced the pleasant events discussion similarly. Treatment strategies aimed at eliciting and sustaining mutual positive emotional interactions may be beneficial for depressed dyads.

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1.0 INTRODUCTION

Impairment in maternal interpersonal functioning has been implicated as a risk factor for child psychiatric illness (Hammen, Shih, & Brennan, 2004). An abundance of evidence has shown that depressed mothers have difficulty regulating their own emotions and display less positive engagement behaviors when interacting with their children (Gross & Muñoz, 1995; Lovejoy, Graczyk, O'Hare, & Neuman, 2000). Vagal function has been suggested as a physiologic mechanism that may support the ability to self-regulate and engage socially (Appelhans & Luecken, 2006; Beauchaine, 2001; Porges, 2003). An important aspect of the vagal pathway is its flexible responsiveness to environmental demand, supporting responses to acute threat or stress, and facilitating social affiliation. While the literature contains mixed findings, research has generally shown that depressed adults display blunted or dysregulated patterns of vagal function when exposed to positive and negative stimuli (Rottenberg, Clift, Bolden, & Salomon, 2007). However, vagal function in depression has typically been assessed individually, rather than within interpersonal contexts. Examination of vagal function in the context of social interactions between mothers and their children may inform our understanding of impaired interpersonal functioning in depressed dyads.

The present study will examine the vagal responsiveness of mother-daughter pairs with and without a history of depression during interactive tasks designed to elicit positive and negative affect. Given the novelty of the proposed paradigm and the critical importance of mothers in the intergenerational transmission of depression, the primary focus of the present study will be on the vagal responsiveness of mothers. In addition, as a secondary study aim, we will examine vagal responsiveness of daughters during the dyadic task. Finally, we will conduct a preliminary set of exploratory analyses to examine the covariation of vagal responsiveness between mothers and daughters.

1.1 LITERATURE REVIEW

This review will focus on individual and dyadic processes of vagal function. First, research on vagal function in depressed adults will be reviewed and related to maternal depression. Next, a brief overview of vagal function during mother-child interaction studies will be presented to provide an evidence base for the present study's examination of vagal responsiveness in mother-daughter dyads. Finally, to address the exploratory aim of this study, research evaluating physiological covariation between mother-child dyads will be briefly reviewed.

1.1.1 Maternal Depression and Intergenerational Transmission of Depression

Major depressive disorder affects about 8% of mothers at a given time (Weissman, Leaf, & Bruce, 1987) and research has shown that offspring of depressed parents have a two to five fold increased risk for the development of a psychiatric illness (Goodman & Gotlib, 1999; Weissman et al., 2006). Therefore, understanding the mechanisms by which this intergenerational transmission occurs is of great social significance. Along with other risk factors (Goodman & Gotlib, 1999), impairment in maternal interpersonal functioning has been shown to contribute to negative outcomes in children of depressed mothers (Hammen &

Brennan, 2001). Specifically, depression may interfere with mothers' abilities to interact with their children in a sensitive and warm manner. Mother-child interaction studies have supported this idea in showing that depressed mothers exhibit less affective expression overall and respond to their children less positively and with higher rates of hostility and negative affect compared to non-depressed mothers (Lovejoy et al., 2000). Major theories suggest that the functioning of physiologic systems related to social engagement and stress reactivity may support maternal abilities to positively engage with one's child and to flexibly respond to the dynamic demands of parenting (Porges, 2007; Thayer & Lane, 2000). In contrast, impairments in interpersonal functioning of depressed mothers may reflect an inability to flexibly adjust one's level of physiological arousal needed to sensitively identify and respond to changing parental demands (Gross, 1998).

1.1.2 The Role of the Vagal System in Social Interactions

1.1.2.1 Vagus nerve

A key system involved in the regulation of physiological arousal is the autonomic nervous system, which is composed of the sympathetic nervous system and the parasympathetic nervous system (PNS). While the sympathetic nervous system functions to produce physiological arousal during times of threat or stress, the PNS functions to modulate arousal during times of rest or perceived safety. A major component of the PNS, the vagus nerve is a cranial nerve that projects from the brainstem to peripheral organs, providing parasympathetic output from the brain and carrying information from peripheral organs back to the brain (Silverthorn, Ober, Garrison, Silverthorn, & Johnson, 2009). As the vagus nerve terminates on the sinoatrial node of the heart, also known as the heart's pacemaker, its activity influences heart rate variability (HRV), defined as the beat-to-beat variations in heart rate. The vagus functions as a “brake” on the heart that, when activated, slows the heart rate in favor of energy conservation and parasympathetic dominance during times of rest and perceived safety (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). It does so by increasing parasympathetic input and actively inhibiting sympathetic input. In contrast, during times of perceived threat or stress, the vagal brake is withdrawn and the inhibition on the heart’s pacemaker is rapidly reduced, allowing for an increase in heart rate and sympathetic dominance (Porges et al., 1996).

1.1.2.2 Measurement

The influence of the vagus on the heart is indexed by non-invasively measuring HRV via continuous electrocardiogram signals (ECG) and can be calculated using spectral analyses. Parasympathetic effects on the heart occur relatively fast; therefore, vagal activity is detected within the high-frequency range of HRV (HF-HRV; 0.15 Hz - 0.50 Hz), which is closely linked to the respiratory cycle (Berntson et al., 1997). Increases in HF-HRV indicate activation of vagal influence on the heart and decreases indicate withdrawal of vagal influence on the heart.

1.1.2.3 Major theories

Two major theories, polyvagal theory and the model of neurovisceral integration, have provided models of neural control of HRV which highlight the critical role of the PNS in supporting aspects of interpersonal functioning. Polyvagal theory (Porges, 1995) points to the neural connections between the vagus nerve and other cranial nerves that facilitate the behavioral expression of emotions, and the model of neurovisceral integration (Thayer & Lane, 2000) is centered on the neuroanatomical links between the autonomic nervous system and brain regions associated with emotional responding. While there has been controversy over interpretation of vagal function according to these theories (e.g., Grossman & Taylor, 2007), the theories are more complementary than contradictory and are used in the present study to generate hypotheses about the role of the vagal system in social interactions (Appelhans & Luecken, 2006).

***Polyvagal Theory*.** Polyvagal theory proposes that the evolution of the mammalian autonomic nervous system provides the neurophysiological substrates for major components of social behavior (Porges, 2003). In mammals, two branches of the vagus nerve have evolved; the theory focuses on the evolutionarily newer branch which is an efferent pathway emerging from a brainstem area called the nucleus ambiguus (Porges, 2007). In addition to innervating the heart, this branch is linked to special efferent pathways originating from the brainstem that regulate several visceral organs such as the striated muscles of the face and head, the larynx, and the pharynx (Porges, 2003). These organs play a critical role in forming facial expressions, eye gaze, vocalizations, and head orientation—all implicated in the expression and receptivity of social engagement (Porges, 2003). Polyvagal theory suggests that by modulating the visceral state, the vagal brake enables mammals to flexibly adapt to the changing environment by rapidly shifting autonomic activity in response to environmental cues (Cyranowski, Hofkens, Swartz, Salomon, & Gianaros, 2011). The evolution of the vagal system is thought to have aided in survival and/or reproduction as it supports behavioral responses involved in prosocial engagement in times of perceived safety and fight-or-flight behaviors in times of threat or stress (Porges, 2007).

***The Model of Neurovisceral Integration*.** The model of neurovisceral integration uses a dynamical systems framework to relate autonomic processes to emotional responding. Crucial to the model is the central autonomic network (CAN) comprised of cortical and subcortical neural structures which function as an integrated system through which the brain controls responses to environmental demands (Thayer & Lane, 2000). It does so in part by inhibiting other potential responses through positive and negative feedback loops among system components (Appelhans & Luecken, 2006). Such inhibition is thought to be mediated synaptically in the brain and vagally in the periphery (Thayer & Friedman, 2002). The output of the CAN is directly related to HRV as it is mediated through preganglionic sympathetic and parasympathetic neurons that innervate the heart via the stellate ganglia and the vagus nerve. The model of neurovisceral integration views HRV as quantifying the ability to self-regulate through the organization of physiological resources and appropriate response selection in the service of goal-directed behavior and adaptability (Thayer & Lane, 2000).

1.1.3 The Vagal System and Maternal Depression

The above theories suggest that the activity of the vagus nerve is related to social engagement and flexible adjustment to environmental demand, two abilities that have been shown to be diminished in depressed individuals (Rottenberg, 2007). As parenting is a complex form of social interaction often requiring a mother to respond quickly and contingently to her child's needs, such deficiencies in depressed mothers may play out in interactions with their children. Mother-child interaction studies have shown that depressed mothers express little positive affect, speak less often, and respond more slowly, less contingently, and less consistently to their children (Lovejoy et al., 2000). Such difficulties in parenting may be associated with diminished emotional reactivity to both positive and negative stimuli often observed in depression (Bylsma, Morris, & Rottenberg, 2008). For example, compared with non-depressed individuals, depressed individuals have been found to exhibit lower levels of sadness and amusement in response to sad and amusing films (Rottenberg, Kasch, Gross, &

Gotlib, 2002) and blunted autonomic responding to a variety of stimuli (e.g., Dawson, Schell, & Catania, 1977). In a mother-daughter interaction study, if mothers reported experiencing depressive symptoms, the dyad showed a narrower range of emotions across positive and negative conversations compared to dyads in which mothers reported no depressive symptoms (Connell, Hughes-Scalise, Klostermann, & Azem, 2011). Given the associations between maternal depression and reduced engagement in mother-child interactions as well as inflexible responding to parenting demands, it is reasonable to speculate that depressed mothers in particular may exhibit reduced vagal function.

1.1.4 Vagal Function and Depression Findings in Adults

1.1.4.1 Resting HRV level

The literature on resting vagal function in depressed individuals has been mixed. A meta-analysis of 13 studies that included both depressed and non-depressed adults found that depression was associated with reduced cardiac vagal control (an indirect measure of vagal function); however, the overall effect size was in the small to medium range (d = 0.332; Rottenberg, 2007). Similarly, a more recent meta-analysis of 18 studies of non-medicated adults found a small overall effect size (Hedge's g = -0.293) for lower HF-HRV in depressed relative to non-depressed adults, and found that depression severity was negatively correlated with HRV (Kemp et al., 2010). The modest effect sizes reflect the variation in study findings with some studies reporting reduced vagal function in depressed compared to non-depressed adults (e.g., Agelink, Boz, Ullrich, & Andrich, 2002; Chang et al., 2012) and others reporting no association (e.g., Lehofer et al., 1997; O'Connor, Allen, & Kaszniak, 2002). Some of the inconsistent findings may be due to heterogeneity in small samples, use of different HRV measures, or confounding factors such as medications, physical health, physical activity, smoking, or psychiatric comorbidities that may suppress or magnify the effect of depression on vagal function (Chang et al., 2012; Rottenberg, 2007).

1.1.4.2 HRV response

Researchers have focused mainly on HRV level; however, theories emphasize the importance of the vagus in facilitating flexible responses to changing environmental demands. Thus, studies of vagal activity in response to various stimuli may be more informative of the impact of abnormal vagal function in depressed individuals. Although very few studies have examined HRV response to stimuli, those that have generally find that depressed individuals display blunted or dysregulated patterns of response (see also Light, Kothandapani, & Allen, 1998; Sheffield et al., 1998; Straneva-Meuse, Light, Allen, Golding, & Girdler, 2004). In tasks designed to elicit increases in HF-HRV (vagal activation), one study found that individuals with elevated levels of depressive symptoms displayed smaller increases compared to individuals with low levels of depressive symptoms (Hughes & Stoney, 2000), and another study found that while non-depressed individuals exhibited vagal activation, depressed individuals showed no significant change in vagal activity from a neutral period (Rottenberg, Wilhelm, Gross, & Gotlib, 2003). In tasks designed to elicit decreases in HF-HRV (vagal withdrawal), Rottenberg and colleagues (2007) found that compared to controls, depressed individuals displayed a lack of vagal withdrawal during the stress tasks. Similar to other studies (Bylsma, Salomon, Taylor-Clift, Morris, & Rottenberg, 2014; Rottenberg et al., 2003), they also found that depressed individuals displayed less HF-HRV fluctuation between task and recovery periods. Together, the above results suggest that depressed individuals may have blunted vagal responsiveness to both positive and stressful environments. This is consistent with the Emotion Context Insensitivity

Theory which posits that depressed individuals often exhibit a lack of flexible and sensitive emotional responses in both positive and negative contexts (Rottenberg, Gross, & Gotlib, 2005).

1.1.4.3 HF-HRV and social factors

Despite the proposed sensitivity of the vagal system to changing social environments and demands, few studies of vagal responsiveness in depressed individuals have examined or manipulated social factors. In order to address this gap in the literature, Cyranowski and colleagues (2011) examined vagal responsiveness in non-medicated depressed women and matched controls during a relationship-focused imagery task designed to elicit vagal activation. They found that depressed women displayed significantly lower HF-HRV compared to the non-depressed women when asked to relive in their memory a past experience in which they felt strong feelings of love or infatuation. This suggests that depressed individuals may be less likely to exhibit increased HF-HRV during positive daily social encounters (Cyranowski et al., 2011), such as interactions between mothers and their children. Future work should continue in this direction by examining depressed individuals in social contexts that elicit vagal activation and withdrawal. For example, Smith and colleagues (2011) examined HF-HRV in married couples during an interactive task in which they were asked to discuss a problematic topic and found that women displayed decreases in HF-HRV typical of psychological stress during the discussion when it followed a positive or neutral task. Few, if any, studies have examined HF-HRV during positive social interactions in adults. There is some evidence in children that increases in HF-HRV accompany positive mood inductions and social engagement, whereas decreases are produced by negative mood inductions and laboratory stressors (Beauchaine, 2001), however the findings have been mixed. Hence, studies of both positive and stressful social interactions are needed to contribute to a deeper understanding of vagal function in depressed and non-depressed individuals. Such studies conducted during interactions between mothers and their children may inform our understanding of physiologic systems that support adaptive interpersonal functioning during social interactions, and how these processes may become impaired in depressed individuals.

1.1.5 Vagal Function in Mother-Child Interactions

The majority of studies assessing vagal function during mother-child interactions have focused on maternal interactions with infants or young children (e.g., Calkins, Graziano, Berdan, Keane, & Degnan, 2008; Field, Pickens, Fox, Nawrocki, & Gonzalez, 1995). Very few studies have evaluated maternal interactions with middle childhood or adolescent offspring, who face new social challenges in which they need to independently regulate their emotions and manage interpersonal stress. Longitudinal studies show that dyadic experiences with parents create the foundation for closer relationships later in life. Therefore, the physiologic responsiveness in adolescents during interactions with their mothers may have implications for patterns of interaction in future adult relationships.

HF-HRV responses during a conflict discussion with a parent have been examined in depressed adolescent girls (Crowell et al., 2014) and adolescent boys at risk for developing behavior problems (Morgan, Shaw, & Forbes, 2013). Examining vagal responses only during conflict discussions, however, limits generalizability to that type of interaction. In contrast, examining both negative and positive discussions would allow for a more complete picture of one's dynamic vagal functioning in everyday life. For example, Connell et al. (2011) had adolescents engage in three conversations with parents—encouragement/support, planning a fun activity, and conflict—but only reported mothers' and daughters' HF-HRV during a resting baseline period. There have been no studies to our knowledge that have reported outcomes of vagal responsiveness of mothers and adolescents during both positive and negative interactions.

While some studies examine the effects of depression in either mothers (Connell et al., 2011) or adolescents (Crowell et al., 2014), no studies have examined HF-HRV during interactions between members of dyads in which both the parent and adolescent have been diagnosed with depression. It may be particularly difficult for depressed parents to sensitively attend to their children's increased emotional needs when they are struggling to regulate their own emotions. Thus, these dyads may be especially important to study. For example, the frequency and intensity of conflicts may be increased in depressed dyads (Cyranowski, Swartz, Hofkens, & Frank, 2009); thus their vagal responses to such interactions may affect their ability to effectively negotiate conflict or to modulate their arousal levels to permit subsequent positive engagement or interactions. The present study will examine vagal responsiveness in mother-daughter dyads as the incidence for depression in offspring of depressed parents is highest for adolescent girls (Weissman et al., 1997).

1.1.6 Physiological Covariation in Mother-Child Interactions

As in all close dyadic relationships, parents and children reciprocally influence each other's emotional, behavioral, and physiological responses through interactions. Many studies have shown statistical dependencies between parents and children across a variety of domains such as eye gaze, facial expressions, speech rhythms, and autonomic physiology (Field, 1985). In mother-infant relationships this influence has been argued to provide the basis for infants' self-regulation as the mother constructs optimal emotional states and scaffolds the child's self-regulatory capacity. As children get older, the range of their self-regulatory capacities is expected to increase; however, the parent's role in shaping this process remains important. For example, mothers who are sensitive and engage in more responsive parenting have children with better vagal functioning, whereas maternal intrusiveness has been shown to undermine such functioning (Calkins, 2008). Covariation of vagal responses between mothers and their children may represent one pathway through which mothers may influence their children's interpersonal and socio-emotional functioning and development. Thus, identifying maladaptive patterns of mother-child co-variation that may occur in depressed dyads may ultimately help to develop targeted prevention and intervention strategies to mitigate negative outcomes in high risk families.

1.2 SCOPE OF THE CURRENT STUDY

The current study aims to examine the vagal responsiveness of mother-daughter pairs in which both mother and daughter have a history of depression and mother-daughter pairs in which both mother and daughter do not have a history of depression (controls) during interactive tasks designed to elicit vagal activation and withdrawal. Specifically, the following hypotheses will be tested. It is hypothesized that compared to control mothers, mothers with a history of depression will display a pattern of diminished responsiveness to interactions with their children characterized by less vagal activation (increase in HF-HRV) during conversations designed to elicit positive affect (**Hypothesis 1a**), less vagal withdrawal (decrease in HF-HRV) during conversations designed to elicit negative affect (**Hypothesis 1b**), and less dynamic changes representing a return to baseline levels observed during post-task resting recovery periods (**Hypothesis 1c**). As a secondary set of hypotheses, it is expected that compared to control daughters, daughters with a history of depression will display the same pattern of diminished responsiveness to interactions with their mothers (**Hypotheses 2a-c**). Finally, exploratory analyses will examine the covariation of HF-HRV in mother-daughter pairs during the interaction tasks. Based on the limited amount of literature in this area, it is hypothesized that control dyads will display greater covariation than dyads with a history of depression as control dyads are likely to have greater variability in HF-HRV and better relationship quality (Helm, Sbarra, & Ferrer, 2014).

2.0 METHOD

2.1 PARTICIPANTS

Participants in this study included 46 mothers (ages 32-59) and their daughters (ages 10-18). Mothers and daughters with a history of depression (*n* = 23) were recruited from a number of sources including a randomized clinical trial designed to treat depressed mothers of psychiatrically-ill children (Swartz et al., under review), a clinic that specializes in the treatment of suicidal adolescents, and community advertisements. In order to participate in the study, both mothers and daughters had to have a current or lifetime diagnosis of Major Depressive Disorder. Mothers were excluded from the study if they were not currently living with the child, endorsed substance abuse within the preceding six months, were actively suicidal, were suffering from a psychotic disorder, had an unstable medical condition, or were taking medications that may interfere with HRV. Daughters were excluded if they had an unstable medical condition or had any cognitive impairments that may interfere with the ability to complete questionnaires. Control mothers and daughters (*n* = 23) were recruited from community advertisements and advertisements in the University of Pittsburgh Medical Center employee newsletter. In addition to the above exclusion criteria, potential control mothers and daughters were excluded from the study if they had any current or lifetime psychiatric diagnoses. All study procedures were approved by the University of Pittsburgh Institutional Review Board and informed consent was obtained from all study participants.

2.2 MEASURES

2.2.1 Interaction tasks

Mother-daughter pairs were asked to engage in three interaction tasks: two pleasant events discussions followed by a disagreement discussion (adapted from Whittle et al., 2009). Personally-relevant topics for discussions were chosen based on participants' responses to modified versions of the Pleasant Event Checklist (PEC; MacPhillamy & Lewinsohn, 1976) and the Issues Checklist (IC; Prinz, Foster, Kent, & O'Leary, 1979). The PEC includes a list of activities that families may enjoy doing together (e.g., taking a trip, having a family party, watching a favorite movie). Similarly, the IC contains a list of topics on which parents and children often disagree (e.g., household chores, talking back, grades in school). For the two three-minute pleasant events discussions, participants were asked to 1) discuss an event they enjoyed together in the past, and 2) plan a pleasant activity they would like to do together in the future. For the disagreement discussion, participants were asked to talk together for six minutes about a topic of disagreement that engendered mild to moderate conflict, why they were upset about the topic, and how they might solve the issue. These tasks are of minimal risk and have been used successfully in healthy samples (Whittle et al., 2009).

The pleasant events discussions are designed to be relatively low-stress and to elicit positive affect. The disagreement discussion is designed to elicit more negative affect and conflictual behavior and may require greater emotion regulation on the part of the participants. Hence, the use of these two tasks will allow us to examine vagal responsiveness in conditions which are meant to elicit vagal activation and withdrawal, respectively.

2.2.2 Vagal function

Vagal function was measured in both mothers and daughters non-invasively via continuous ECG signals sampled at 1000 Hz with three spot electrodes placed in a 3-lead configuration using the MindWare BioNex data collection system (MindWare Technologies Ltd, Gahanna, OH). HF-HRV will be calculated using MindWare HRV 2.16 software. R-wave markers in the ECG signal will be processed with an artifact detection algorithm implemented in the MindWare software. The data will also be visually inspected and suspected artifacts will be corrected manually. Minute-by-minute estimates of HF-HRV will be determined in accordance with current guidelines (Berntson et al., 1997). For each minute, a 60-second time series of interbeat intervals (the time in milliseconds between sequential ECG R-spikes) will be created from an interpolations algorithm that has a 250-millisecond sample time. This 60-second interbeat interval time series will then be linearly detrended, mean-centered, and tapered using a Hamming window. Spectral-power values will be determined (in ms^2/Hz) with fast Fourier transformations, and the power values in the 0.15-0.50 Hz spectral bandwidth will be integrated (ms^2). Before statistical analyses, data will be inspected and transformations will be applied to correct for any distributional violations. HF-HRV values will be calculated for each one-minute epoch.

One frequent problem with measuring HF-HRV is the effect of respiration. The current study will not be able to control for respiration due to participant speech during the periods in which we are interested. While this is a limitation of the study, it is important to examine vagal function during natural interactions. Speaking and non-speaking periods are divided into separate epochs and each epoch will be evaluated individually in the statistical model.

2.2.3 Mothers' clinical and demographic characteristics

Demographic information. Information regarding mothers' age, race, marital status, level of education, household income, and tobacco use was assessed during an interview with a clinician. Mothers' height and weight were also measured to calculate body mass index.

Psychiatric diagnoses. Current and past psychiatric diagnoses were assessed by a trained clinician using the Structured Clinical Interview for DSM-IV (First, Spitzer, Gibbon, & Williams, 1995), the gold standard semi-structured assessment instrument for clinical disorders. In a mixed sample of 151 inpatients and outpatients, inter-rater reliability values for diagnoses were found to vary from 0.61 to 0.83, with a mean Kappa of 0.71 (Lobbestael, Leurgans, & Arntz, 2011). Fair inter-rater reliability was demonstrated for a diagnosis of major depression (Kappa = 0.66; Lobbestael et al., 2011).

Anxiety. The short form anxiety instrument of the Patient-Reported Outcomes Measurement Information System (PROMIS; Ader, 2007) was used to measure anxiety symptoms in mothers. The seven-item self-report measure asks how often one has experienced fear, anxious misery, hyperarousal, and somatic symptoms related to arousal in the past seven days. Each item is rated on a scale of 1 (never) to 5 (always) and total scores range from 7 (low anxiety) to 35 (high anxiety). In a sample of 788 individuals, the short form was strongly correlated (r = .96) with the full bank of 29 items, and reliability was greater than 0.89 for most of the score distribution (Cella et al., 2010). In the same sample, the measure was shown to be correlated with the general anxiety subscale of the Mood and Anxiety Symptom Questionnaire ($r = .80$; Watson, Clark, & Tellegen, 1988).

Depression. The 16-item self-report version of the Quick Inventory of Depressive Symptomatology (Rush et al., 2003) was used to assess depressive symptom severity in mothers during the prior seven days. Each item is scored on a scale of 0 to 3, with higher scores denoting greater symptom severity, and corresponds to one of the DSM-IV symptom criteria domains: sad mood, concentration, self-criticism, suicidal ideation, interest, energy/fatigue, sleep disturbance, decrease/increase in appetite/weight, and psychomotor agitation/retardation. The total score ranges from 0 to 27. In a study of 596 outpatients being treated for chronic, non-psychotic, major depressive disorder, the internal consistency of the scale was high (Cronbach's $\alpha = .86$) and high concurrent validity was demonstrated by high correlation of the total score with the longer version of the scale ($r = .96$; Rush, Gullion, Basco, Jarrett, & Trivedi, 1996) as well as the 24-item Hamilton Rating Scale for Depression ($r = .86$; Hamilton, 1960), a widely used measure of depressive symptomatology (Rush et al., 2003).

2.2.4 Daughters' clinical and demographic characteristics

Demographic information. The age and race of daughters was assessed during an interview with a clinician.

Psychiatric diagnoses. Current and past psychiatric diagnoses were assessed by a trained clinician using the Kiddie Schedule for Affective Disorders and Schizophrenia (Kaufman et al., 1997). The instrument has been shown to have high inter-rater reliability values and excellent test-retest reliability for present or lifetime diagnoses of major depression (Kaufman et al., 1997).

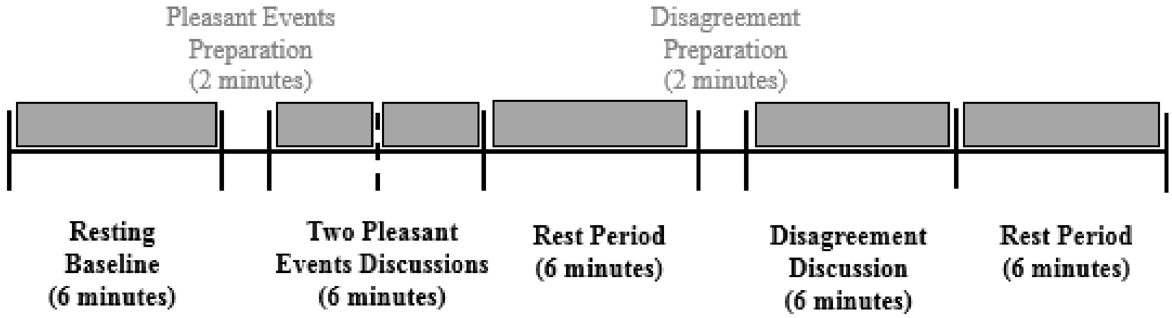
Anxiety. The pediatric, short version of the anxiety instrument of the PROMIS (Ader, 2007) was used to measure anxiety symptoms in daughters. The eight-item self-report measure was created for children ages 8-17 and assesses the same domains of anxiety as the adult version does. Each item is rated on a scale of 0 (never) to 4 (always) and total scores range from 0 (low anxiety) to 32 (high anxiety). Irwin and colleagues (2010) confirmed the scale's unidimensionality and found that its reliability was .85 for scores up to three standard deviations from the mean.

Depression. The Children's Depression Inventory (CDI; Kovacs, 1992), a 27-item self-report measure, was used to assess daughters' depressive symptom severity in several domains including affect, behavior, and cognition. The scale presents children with groups of three sentences that describe various levels of a given symptom and children are asked to choose which sentence best describes how they have been feeling in past two weeks (i.e., I am sad once in a while; I am sad many times; I am sad all the time). Each item is scored on a scale of 0 to 2, with 0 representing absence of the symptom and 2 representing greater symptom severity. Total scores range from 0 to 54, are converted to T-scores that are based on a normative sample and are calculated based on age and gender. The CDI has been extensively validated and has shown adequate internal consistency, test-retest reliability, as well as convergent and discriminant validity (Saylor, Finch, Spirito, & Bennett, 1984).

2.3 PROCEDURE

Only the procedures relevant to the present study are described. Prior to the study visit, participants refrained from caffeine and tobacco products for three hours and refrained from alcohol for 48 hours. Upon arrival, mothers and daughters met separately with clinicians for diagnostic interviews and height and weight of the mothers were measured. Dyads who were active in the treatment study did not have these assessments on the day of the experiment as this information was previously obtained. Mothers and their children were seated in comfortable chairs across from each other and measurement equipment was attached. During a brief habituation period of approximately 10 minutes, they completed a battery of self-report questionnaires. ECG was collected across the 34 minutes of the experiment (see Figure 1). Following a six minute baseline period in which participants were asked to rest quietly, they were given instructions for the pleasant events discussions and completed the PEC. After being told the chosen topics based on their ratings, they were given two minutes to quietly prepare for the conversations. They discussed a past event for three minutes and planned a future activity for the following three minutes. They were then asked to rest quietly for a six minute recovery period. Following the recovery period, participants were given instructions for the disagreement discussion and completed the IC. After being told the chosen topic based on their ratings, they were given two minutes to quietly prepare for the conversation. They were then asked to discuss the issue for six minutes. The experimentation ended with a final six minute recovery period. The experimenter remained in the room behind a curtain for the pleasant events discussions and left the room for the disagreement discussion. Analyses will not include the preparation periods because they cannot be analyzed as part of the discussion periods due to differences in speech. In addition, their durations do not provide enough data points to be analyzed separately in the model.

Figure 1. Experiment timeline.



2.4 PROPOSED ANALYSES

2.4.1 Initial analyses

Initial analyses will be conducted in order to characterize the overall sample as well as individual groups based on the demographic and clinical variables described above. In addition, t-tests will be conducted to determine whether the groups differ significantly on non-clinical, health-related factors known to be associated with HRV. Age (Antelmi et al., 2004), smoking status (Levin, Levin, & Nagoshi, 1992), and body mass index (Rissanen, Franssila-Kallunki, & Rissanen, 2001) will be considered for mothers, and age (Hollenstein, McNeely, Eastabrook, Mackey, & Flynn, 2012) will be considered for daughters. Variables will be included in the below models as covariates if they are found to differ significantly between groups. Data will be inspected for outliers and transformations will be made for distributional violations. Differences in resting baseline HF-HRV level (mean HF-HRV for the six minutes of baseline) and HF-HRV change (slope) between mothers/daughters with and without a history of depression will also be examined.

2.4.2 Primary analyses

Hierarchical linear modeling (HLM; Bryk & Raudenbush, 1987) will be employed to examine patterns of change in mothers' and daughters' HF-HRV over the course of measurement. Specifically, a piecewise two-level linear growth model will be used. Growth models measure change over time (level 1) as well as identify predictors of change at the individual level (level 2). At level 1 the outcome varies as a function of time, and at level 2 each regression coefficient defined by level 1 becomes an outcome variable to be predicted by individual level characteristics (Kenny, Kashy, & Cook, 2006). A piecewise linear growth model breaks up the growth trajectory into separate linear components which allows for comparison of rates of change during separate periods. In line with the hypotheses, it is expected that the rate of change for each period (i.e., pleasant events discussion, disagreement discussion) would vary. Therefore five separate growth slopes will be modeled for the following periods: baseline, pleasant events task (combination of the two discussions), first recovery period, disagreement discussion, and the second recovery period. Each period consists of six minutes of HF-HRV data. Separate models will be used for mothers and daughters. Level 1 will include the HF-HRV for each minute and is specified as follows:

$$HF\text{-}HRV_{ti} = \pi_{0i} + \pi_{1i}*(Baseline_{ti}) + \pi_{2i}*(Pleasant\ events\ task_{ti}) + \pi_{3i}*(Rest1_{ti}) + \pi_{4i}*(Disagreement\ task_{ti}) + \pi_{5i}*(Rest2_{ti}) + e_{ti}$$

where HF-HRV_{ti} is the outcome measure for individual *i* (mother or daughter) at time *t*; *t* represents the period of measurement, while π_{0i} represents initial status, and π_{ti} and e_{ti} represent the growth trajectories and error for each time period respectively.

The level 2 model will include the individual's group (history of depression/no history of depression) for each growth parameter as well as the individual's age for the intercept. The model is specified as follows:

$$\pi_{0i} = \beta_{00} + \beta_{01}*(Group_i) + \beta_{02}*(Age_i) + r_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11}*(Group_i) + r_{1i}$$

$$\pi_{2i} = \beta_{20} + \beta_{21}*(Group_i) + r_{2i}$$

$$\pi_{3i} = \beta_{30} + \beta_{31}*(Group_i) + r_{3i}$$

$$\pi_{4i} = \beta_{40} + \beta_{41}*(Group_i) + r_{4i}$$

$$\pi_{5i} = \beta_{50} + \beta_{51}*(Group_i) + r_{5i}$$

where each growth parameter in level 1 becomes an outcome variable, and r_{ti} represents error for each time period.

2.4.3 Exploratory analyses

Exploratory analyses will evaluate whether the trajectories of mothers' HF-HRV during the pleasant events and disagreement tasks are linked with daughters' trajectories of HF-HRV during those tasks. Parallel process growth curve modeling will be used for this purpose as it allows for analysis of simultaneous change in dyads over time (Kenny et al., 2006). By allowing for different slopes and intercepts for the two members as well as associations between them, it is possible to examine whether change in one member is related to change in the other member. Significant slope correlations would suggest that the rates of change of HF-HRV in mothers and daughters are linked.

2.4.4 Ancillary analyses

Changes in the heart rate of mothers and daughters during periods of observed vagal activation and withdrawal will be examined to aid in the interpretation of results and contribute to a better understanding of the autonomic processes that occur during dyadic interactions. It is expected that accelerations in heart rate will accompany vagal withdrawal and decelerations in heart rate will accompany vagal activation. Additionally, in order to compare the study's results with previous literature HF-HRV will be examined during the non-speaking periods (baseline, preparation, and recovery periods) with analyses of variance.

3.0 RESULTS

3.1 DEMOGRAPHIC AND CLINICAL CHARACTERISTICS

Data from 43 mothers and 45 daughters were used in analyses. Two mothers were excluded from analyses for heart rate abnormalities (i.e., arrhythmia, potential premature ventricular contraction). In order to identify outliers, standardized values for average HF-HRV during each period were examined. One mother and one daughter displayed *z* values greater than 2.5 for each period and were therefore excluded from subsequent analyses (Stevens, 2012). Demographic and clinical characteristics of mothers and daughters are presented in Tables 1 and 2 respectively. Mothers had a mean age of 46.95 (*SD* = 5.05) and were predominantly Caucasian (76.7%), married or living with a partner (65.1%), had attended at least some college (67.4%), and were non-smokers (83.7%). Daughters had a mean age of 15.36 (*SD* = 1.78). There were no differences among groups of mothers or daughters on any demographic variables (all *p*s > .05), therefore, other than age, no additional covariates were included in the models. Not surprisingly, mothers and daughters with a history of depression reported higher levels of self-reported depression and anxiety symptoms compared to the control mothers and daughters (all *p*s < .05).

Table 1. Demographic and clinical characteristics of mothers.

	Overall (N=43)	Control (N=23)	History of depression	Statistic

				(N=20)	
Age	M (SD)	46.95 (5.05)	47.33 (4.40)	46.50 (5.78)	t=0.53, *p*=.597
Race					χ^2=1.18, *p*=.554
Caucasian	*n* (%)	33 (76.7)	18 (78.3)	15 (75.0)	
African American	*n* (%)	9 (20.9)	5 (21.7)	4 (20.0)	
Mixed/Other	*n* (%)	1 (2.3)	0 (0.0)	1 (5.0)	
Education					χ^2=8.98, *p*=.062
High school diploma/GED	*n* (%)	4 (9.3)	1 (4.3)	3 (15.0)	
Partial/Full undergraduate	*n* (%)	16 (37.2)	10 (43.5)	15 (75.0)	
Graduate degree	*n* (%)	13 (30.2)	11 (47.8)	2 (10.0)	
Income					χ^2=14.67, *p*=.100
Less than $10,000	*n* (%)	1 (2.3)	0 (0.0)	1 (5.0)	
$10,000 - $29,999	*n* (%)	8 (18.6)	1 (4.3)	7 (35.0)	
$30,000 - $74,999	*n* (%)	14 (32.6)	7 (30.4)	6 (30.0)	
Greater than $75,000	*n* (%)	20 (46.5)	14 (60.9)	6 (30.0)	
Marital status					χ^2=4.92, *p*=.426
Married/Living with partner	*n* (%)	28 (65.1)	17 (73.9)	11 (55.0)	
Never married	*n* (%)	5 (11.6)	2 (8.7)	3 (15.0)	
Separated/Divorced	*n* (%)	9 (20.9)	3 (13.0)	6 (30.0)	
Widowed	*n* (%)	1 (2.3)	1 (4.3)	0 (0.0)	
Current smokers	*n* (%)	7 (16.3)	3 (13.0)	4 (20.0)	χ^2=0.09, *p*=.538
BMI	M (*SD*)	29.97 (7.24)	28.90 (7.07)	31.14 (7.42)	t=-1.00, *p*=.322
IDS-16	M (*SD*)	4.56 (4.15)	2.52 (1.31)	6.90 (5.04)	t=-3.78, *p*=.001
PROMIS	M (*SD*)	13.56 (5.60)	10.52 (3.36)	17.05 (5.89)	t=-4.50, *p*=.000

Table 2. Demographic and clinical characteristics of daughters.

		Overall (N=45)	**Control (N=25)**	**History of depression (N=20)**	**Statistic**
Age	M (*SD*)	15.36 (1.78)	14.96 (1.69)	15.86 (1.81)	t=-1.72, *p*=.093
CDI	M (*SD*)	48.80 (15.60)	39.88 (5.73)	59.95 (16.92)	t=-5.08, *p*=.000
PROMIS	M (*SD*)	15.27 (7.53)	11.52 (3.55)	19.95 (8.59)	t=-4.12, *p*=.000

3.2 HF-HRV IN MOTHERS

In the unconditional model, significant variability was found in the intercept and slope parameters for all periods (*p*s $\leq .02$), indicating that there was a significant amount of variability to be explained in initial values and slopes of HF-HRV in mothers. The conditional model contained the fixed effects of age and group on the intercept, fixed effects of group on the slope during each period, and random effects for each period (see Tables 1 and 2 in Appendix). In this model, the intercept and all slopes other than the baseline slope were found to be significantly different from zero. The likelihood ratio test for model comparison with the unconditional model showed a reduction in deviance of 21.86 ($p = .003$) in the conditional model.

3.2.1 Baseline

There were no group differences in initial HF-HRV values ($p = .423$). However, age was a significant predictor of the initial value ($p = .006$) and explained 15.2% of its variance. As expected, groups of mothers also did not differ significantly on their baseline slopes ($p = .776$). Overall, the amount of change over the period was non-significant ($p = .335$).

3.2.2 Task and rest periods

Control mothers displayed positive slopes in HF-HRV during both pleasant events and disagreement tasks, and negative slopes during rest periods following the tasks. In contrast, mothers with a history of depression showed a minimal amount of change in HF-HRV during both task and rest periods. See Table 3 for amount of change during each period and amount of variance explained by group. There was a trend toward a group difference in slopes during the pleasant events task (p = .063) and no group difference was found during the disagreement task (p = .226). Group differences were found in slopes during the rest periods following both the pleasant events (p = .014) and disagreement tasks (p = .031). For a visual representation of group differences in trajectories, see Figure 2.

3.3 HF-HRV IN DAUGHTERS

In the unconditional model, significant variability was found in the intercept and slope parameters of all periods (ps ≤ .04) except for baseline (χ^2 = 43.29, p > .50). Because there was not a significant amount of variability in slopes of HF-HRV to be explained during baseline, random effects for this period were not included in the conditional model. The conditional model contained the fixed effects of age and group on the intercept, fixed effects of group on the slope during each period, and random effects for each period except for baseline (see Tables 3 and 4 in Appendix). In this model, the intercept and all slopes were found to be significantly different from zero. The likelihood ratio test for model comparison with the unconditional model showed a reduction in deviance of 10.71 (p = .001) in the conditional model.

3.3.1 Baseline

There were no group differences in initial HF-HRV values (p = .466). Age was not a significant predictor of the initial value (p = .180). Groups of daughters also did not differ significantly on their baseline slopes (p = .558). Over the course of the period, both controls and daughters with a history of depression displayed a slight decrease in HF-HRV. See Table 3 for specific values.

3.3.2 Task and rest periods

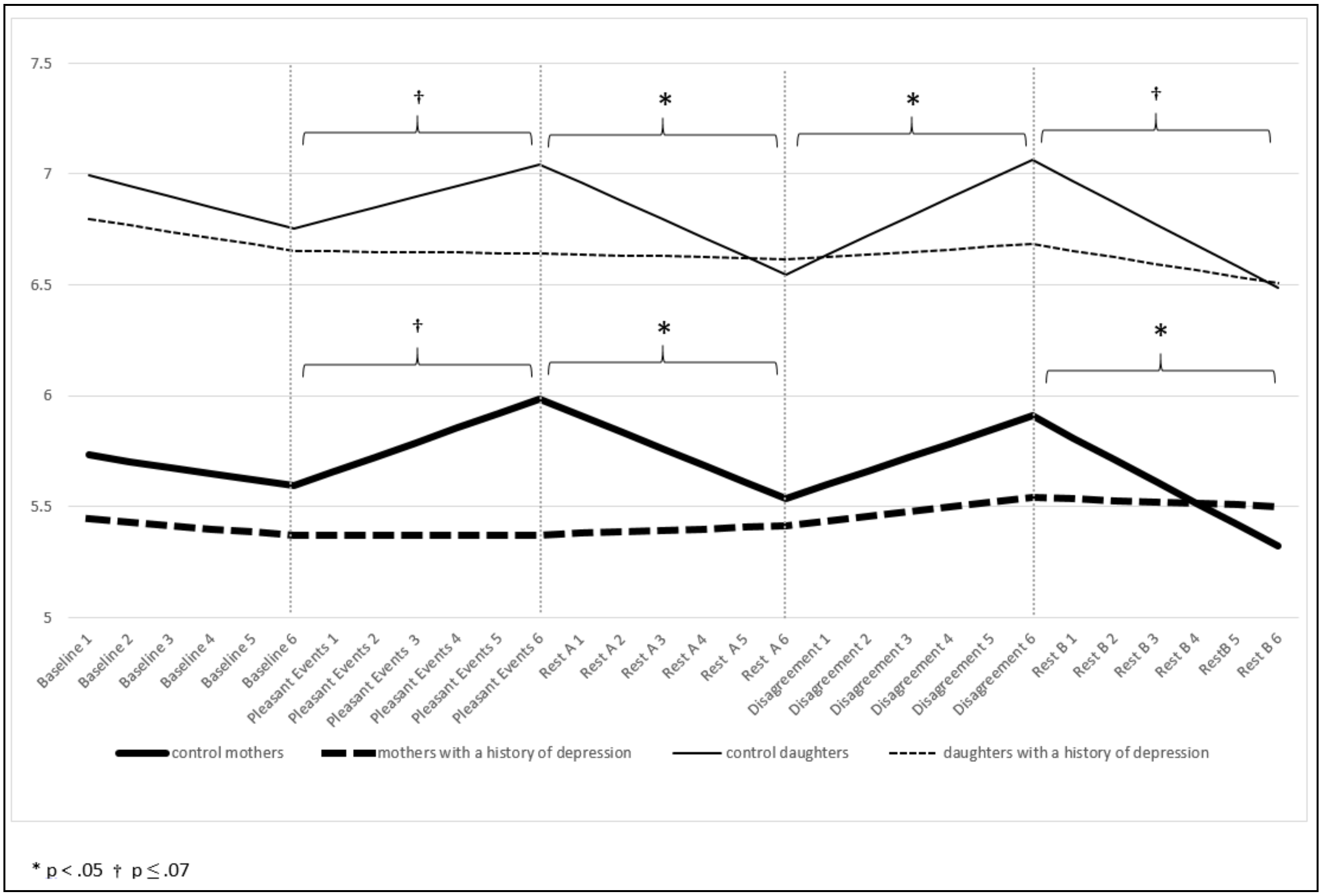
Daughters showed patterns of responsiveness similar to mothers such that control daughters displayed positive slopes in HF-HRV during both pleasant events and disagreement tasks, and negative slopes during rest periods following the tasks, and daughters with a history of depression showed a minimal amount of change in HF-HRV during both task and rest periods (see Table 3). There was a trend toward a group difference in slopes during the pleasant events task (p = .071) and a significant group difference in slopes during the disagreement task (p = .018). A group difference was also found during the rest period following the pleasant events task (p = .004) and there was a trend toward a group difference in the rest period following the disagreement task (p = .051). For a visual representation of group differences in trajectories, see Figure 2.

Table 3. Change in HF-HRV, amount of variance explained by group, and effect size of group during each period.

	Participant Type	Change in HF-HRV		Proportion of variance	*d*
		Controls	History of depression		
Baseline	Mothers	-0.14	-0.08	*n/a*	.09
	Daughters	-0.24	-0.14	*n/a*	.04
Pleasant Events Task	Mothers	+0.39	+0.00	15%	.60†
	Daughters	+0.29	-0.01	14%	.56†
Rest A	Mothers	-0.45	+0.04	28%	.80*
	Daughters	-0.49	-0.02	43%	.92*
Disagreement Task	Mothers	+0.37	+0.13	7%	.38

	Daughters	+0.43	+0.06	23%	$.75^{*}$
Rest B	Mothers	-0.59	-0.04	19%	$.70^{*}$
	Daughters	-0.58	-0.18	21%	$.61^{\dagger}$

Figure 2. HF-HRV of mothers and daughters.



3.4 SENSITIVITY ANALYSES

Eight mothers and 10 daughters reported taking antidepressants at the time of the study. The above analyses were run with and without these participants and patterns of responsiveness (see Appendix Figure 1) as well as effect sizes of group differences were similar. Therefore, data from these participants remained in the model.

3.5 EXPLORATORY ANALYSES

Four parallel process growth models were examined to evaluate relationships between change in HF-HRV in mothers and daughters during the pleasant events and disagreement discussions. Separate models were run for control dyads (n = 23) and dyads with a history of depression (n = 19) for both the pleasant events and disagreement tasks. For initial HF-HRV values during the pleasant events task, a strong positive association (τ =.432) was found for control dyads and no association was found for dyads with a history of depression (τ =.164). For mothers' and daughters' slopes during the pleasant events task, a very strong positive association (τ =.771) was obtained for control dyads and a moderate negative association (τ =-.404) was obtained for dyads with a history of depression. During the disagreement task, a moderate association (τ =.326) was found for initial values in control dyads and a weak association (τ =.250) was found for dyads with a history of depression. For mothers' and daughters' slopes during the disagreement task, no association was found for control dyads (τ =.127) and a strong negative association was obtained for dyads with a history of depression (τ =-.507).

3.6 ANCILLARY ANALYSES

3.6.1 Heart rate in mothers

In the unconditional model, significant variability was found in the intercept and slope parameters of all periods (ps $\leq$ .002). The conditional model contained the fixed effects of age and group on the intercept, fixed effects of group on the slope during each period, and random effects for each. In this model, the intercept as well as slopes during the baseline and second recovery periods were significantly different from zero (*p*s $\leq$ .001). Slopes during all other periods were not significantly different from zero. The likelihood ratio test for model comparison with the unconditional model showed a non-significant reduction in deviance of 6.64 ($p > .500$) in the conditional model. There were no group differences found in initial values and age was not a significant predictor of the initial value. During baseline and the second recovery, both groups displayed a decrease in heart rate.

3.6.2 Heart rate in daughters

In the unconditional model, significant variability was found in the intercept and slope parameters for all periods (*p*s $\leq$ .002) except baseline ($p > .500$) and the first recovery period ($p = .192$). Because there was not a significant amount of variability in slopes of heart rate to be explained during these periods, random effects for these periods were not included in the model. As planned, age was included as a covariate for the intercept. The conditional model contained the fixed effects of age and group on the intercept, fixed effects of group on the slope during each period, and random effects for each. In this model, the intercept as well as slopes during the baseline and second recovery periods were significantly different from zero (*p*s $\leq$ .006). Slopes during all other periods were not significantly different from zero. The likelihood ratio test for model comparison with the unconditional model showed no reduction in deviance ($p > .500$) in the conditional model. There were no group differences found in initial values and age was not a significant predictor of the initial value. During baseline and the second recovery, both groups displayed a decrease in heart rate.

3.6.3 Non-speaking periods

Separate repeated measures analyses of variance tests with Greenhouse-Geisser corrections were run for mothers and daughters in order to examine the effect of period on HF-HRV in mothers and daughters in non-speaking periods only. In addition to baseline and the two rest periods, the two-minute preparation periods for both the pleasant events and disagreement tasks were examined. Results showed that mean HF-HRV did not significantly differ by period in mothers or daughters, respectively (F = 1.12, p = .348; F = .314, p = .827). In addition, there were no period by group interactions in mothers or daughters (F = .716, p = .566; F = .201, p = .906).

4.0 DISCUSSION

Maternal depression has been consistently associated with child psychiatric illness, especially in adolescent girls. Depressed mothers often have difficulty regulating their own emotions and display diminished emotional reactivity when interacting with their children. In order to better understand the physiologic correlates of such interpersonal difficulties and the role they may play in the intergenerational transmission of depression, the present study examined vagal responsiveness in pairs of mothers and adolescent daughters with and without a history of depression during pleasant events and disagreement discussion tasks as well as post-task rest periods. Because vagal function in depression has typically been assessed individually, rather than within interpersonal contexts, this study is the first to our knowledge to examine vagal responsiveness during social interactions between members of dyads in which both individuals have been diagnosed with depression.

Our hypotheses that mothers and daughters with a history of depression would display a pattern of diminished vagal responsiveness to interactions and less dynamic changes in HF-HRV toward baseline during post-task rest periods were supported. Results showed that mothers and daughters with a history of depression displayed minimal vagal responsiveness during the discussion tasks and post-task rest periods. In contrast, control mothers and daughters displayed vagal activation, as indexed by positive slopes in HF-HRV, during both discussion tasks, and a return toward baseline during post-task rest periods (see Figure 2). These results suggest that on average, while control mothers and daughters displayed vagal flexibility and activation during both pleasant events and disagreement discussions, mothers and daughters with a history of depression exhibited a lack of flexible and sensitive vagal responsiveness.

Results are consistent with the Emotion Context Insensitivity Theory (Rottenberg et al., 2005) and previous studies showing blunted parasympathetic response in depressed individuals (Bylsma et al., 2014; Rottenberg et al., 2007). However, despite the theorized importance of the vagal system for social interactions and the proposed sensitivity of the system to changing environmental demands, this study was the first to provide evidence of blunted parasympathetic response in individuals diagnosed with depression *during* social interactions. Most studies have examined the vagal responsiveness of depressed individuals during nonsocial experimental tasks such as the cold pressor task, watching video clips, or giving a speech, which may not represent how individuals respond to social interactions in close relationships. Because impairment in social relationships is common to depression (Segrin & Abramson, 1994) and implicated in the intergenerational transmission of depression (Weissman et al., 2006), our study may provide enhanced ecological validity to examine these issues.

Porges's polyvagal theory suggests that positive social affiliation, such as during a positive discussion between parent and child, should be associated with vagal activation. The lack of vagal activation in mothers and daughters with a history of depression may suggest an inability to flexibly adjust one's level of physiological arousal in order to appropriately respond to environmental demands. It may also suggest that these dyads lacked a sense of comfort or safety during the discussion or that pairs were not fully engaged with each other. For example, given depressed individuals' tendency to ruminate (Nolen-Hoeksema, 2000), it is possible that these dyads were distracted by internal negative thoughts rather than fully focusing on the external social interaction. Research has shown that rumination in dysphoric individuals interferes with effective interpersonal problem-solving (Lyubomirsky & Nolen-Hoeksema, 1995).

Notably, control mothers and daughters exhibited increases in HF-HRV during the disagreement discussion. We originally expected groups to exhibit vagal withdrawal, indicative of a stress response, as such responses have been observed during a disagreement task in married couples (Smith et al., 2011). This lack of vagal withdrawal may be due to the difference in dynamics between parent-child relationships and romantic relationships between two adults. In addition, parenting norms and social desirability biases may discourage mothers from engaging in salient arguments with their children in a laboratory setting. The topics chosen for this task were typically less threatening (i.e., cleaning the child's room or fighting with siblings), whereas romantic partners may choose more significant problems to discuss (i.e., problems with in-laws, finances). In fact, in order to minimize the possibility of extreme distress we chose topics that participants indicated as engendering only moderate conflict (rather than severe).

It was also unexpected that a decrease in heart rate was not found for controls during the discussion tasks. This may suggest that both the sympathetic and parasympathetic systems were activated during the discussions. One would typically expect heart rate to decrease as HF-HRV increases (and vice versa) as seen during independent tasks; however, these results underscore the complexity of social interactions and suggests that both systems play a role in an individual's engagement with others. For example, activation of the parasympathetic nervous system supports behavioral responses involved in prosocial engagement and the sympathetic nervous system provides energy for the interaction, keeping one focused and alert. Future research is needed with measures that can be more clearly linked to the sympathetic nervous system (i.e., impedance cardiography or galvanic skin response) in order to improve identification of the specific influences of each system during social interactions.

In addition to individual patterns of responsiveness, we examined covariation of vagal responsiveness in mother-daughter pairs. A strong positive correlation was obtained among control dyads during the pleasant events discussion and no association was found for control dyads during the disagreement discussion. This suggests that within individual control dyads, mothers and daughters experienced and responded to the pleasant events discussion in similar ways. In contrast, during both pleasant events and disagreement discussions, a negative association between mothers' and daughters' patterns of responsiveness was obtained among dyads with a history of depression. These inverse correlations suggest that in individual dyads with a history of depression, mothers and daughters experienced the pleasant events and disagreement tasks in different ways (i.e., one individual increased in HF-HRV and the other decreased). It is important to consider that while group level analyses suggested a blunted response in dyads with a history of depression, the negative associations found in individual dyads suggests that some individual variability is present within this group. Such variability may be explained by unknown moderators and will be important for future studies to consider. In addition, it was unexpected that dyads with a history of depression showed a negative association in patterns of HF-HRV during the disagreement discussion as other studies have shown positive associations during times of elevated negative affect (i.e., Papp, Pendry, & Adam, 2009; Waters, West, & Mendes, 2014).

A limitation of studying vagal responsiveness during social interactions is the inability to control for changes in respiration. While it is standard to control for respiration during the examination of vagal responsiveness because of its known influence on HRV, it is difficult to reliably measure respiration during speech. Bernardi and colleagues (2000) found that free speech decreased respiration, thus increasing low frequency power and decreasing high frequency power in RR interval. This would suggest that false sympathetic activation and parasympathetic withdrawal may be present during speech; however, in the present study vagal *activation* was exhibited during speaking periods. The significant differences between controls and individuals with a history of depression are unlikely to be solely an artifact of speaking. Future studies will be needed to better understand complex systems underlying social engagement.

Additional study limitations included a small sample size and thus low power for the type of analyses that were run; yet, we were able to detect large group differences despite this limitation. In addition, because our sample included only female participants the results cannot be generalized to males. Finally, at the time of the study a subset of our participants were taking antidepressants which may be associated with diminished HF-HRV level (Kemp et al., 2010; Licht et al., 2008). When participants on antidepressants were removed from analyses, the patterns of responsiveness were similar. To our knowledge, there have not been any studies that have examined the effect of antidepressant use on *slopes* of HF-HRV during laboratory based interactive tasks. This will be important for future studies to investigate.

There are several potential clinical implications of this study. First, the lack of vagal flexibility in dyads with a history of depression may interfere with mothers' abilities to interact with their daughters in a sensitive and warm manner, which may in turn impact daughters' abilities to develop adaptive regulation strategies necessary for social interactions within and outside of the family. In order to better understand the broader influence of such physiological dysregulation, future work should also examine the association of physiological measures with behavioral and affective components of social interactions. Connell and colleagues (2011) found that in mothers with elevated depression symptoms, higher maternal resting HF-HRV was associated with mother and adolescent engagement in a wider range of emotions across multiple interactions. Crowell and colleagues (Crowell et al., 2014) found that during a conflict discussion, depressed adolescents became physiologically and behaviorally dysregulated simultaneously.

Our results are consistent with studies demonstrating that depressed mothers often experience impaired communication with their children (Lovejoy et al., 2000), a deficit that is thought to contribute to worse outcomes in offspring of depressed parents (Weissman et al., 2006). Considering the importance of interpersonal factors in the onset and maintenance of depression, one potential area for intervention is to treat *dyads* and focus on improving positive social engagement and communication. In addition, given the high concordance in control dyads during the pleasant events discussion, treatment strategies aimed at eliciting and sustaining mutual positive emotional interactions may be beneficial for dyads with a history of depression. Greater positive concordance has been shown to be important for the socialization of emotions within families as well as the development of supportive parent-child relationships (Criss, Shaw, & Ingoldsby, 2003). Finally, as the current study highlights the role of physiologic processes in parent-child interactions, treatment strategies may include a focus on physiologic responsiveness using techniques such as biofeedback.

5.0 APPENDIX

Table 4. Mothers: HF-HRV fixed effects.

Fixed effect	Symbol	Coefficient	Std. error	*t*-ratio	*d.f.*	*p*
Initial status	π_0					
Controls	β_{00}	5.730888	0.241211	23.759	40	<0.001
History of Depression	β_{01}	-0.286299	0.354017	-2.916	40	0.423
Mother's Age	β_{02}	-0.075054	0.025734	-0.809	40	0.006
Baseline slope	π_1					
Controls	β_{10}	-0.027752	0.029639	-0.936	41	0.355
History of Depression	β_{11}	0.012417	0.043400	0.286	41	0.776
Pleasant events task slope	π_2					
Controls	β_{20}	0.065665	0.023134	2.839	41	0.007
History of Depression	β_{21}	-0.064966	0.034012	-1.910	41	0.063
Rest A slope	π_3					
Controls	β_{30}	-0.075224	0.021634	-3.477	41	0.001
History of Depression	β_{31}	0.081935	0.031887	2.570	41	0.014
Disagreement task slope	π_4					
Controls	β_{40}	0.062202	0.022641	2.747	41	0.009
History of Depression	β_{41}	-0.040843	0.033260	-1.228	41	0.226
Rest B slope	π_5					
Controls	β_{50}	-0.097987	0.027941	-3.507	41	0.001
History of Depression	β_{51}	0.091127	0.040794	2.234	41	0.031

Table 5. Mothers: HF-HRV random effects.

Random Effect	Symbol	Std. Deviation	Variance Component	d.f.	χ^2	p
Initial status	r_0	1.08247	1.17175	40	349.49325	<0.001
Baseline slope	r_1	0.07974	0.00636	41	62.66649	0.016
Pleasant events task slope	r_2	0.07270	0.00529	41	74.15834	0.001
Rest A slope	r_3	0.06511	0.00424	41	71.44500	0.003
Disagreement task slope	r_4	0.07168	0.00514	41	77.00963	<0.001
Rest B slope	r_5	0.09367	0.00877	41	85.83535	<0.001
Level 1 error	e	0.57500	0.33062			

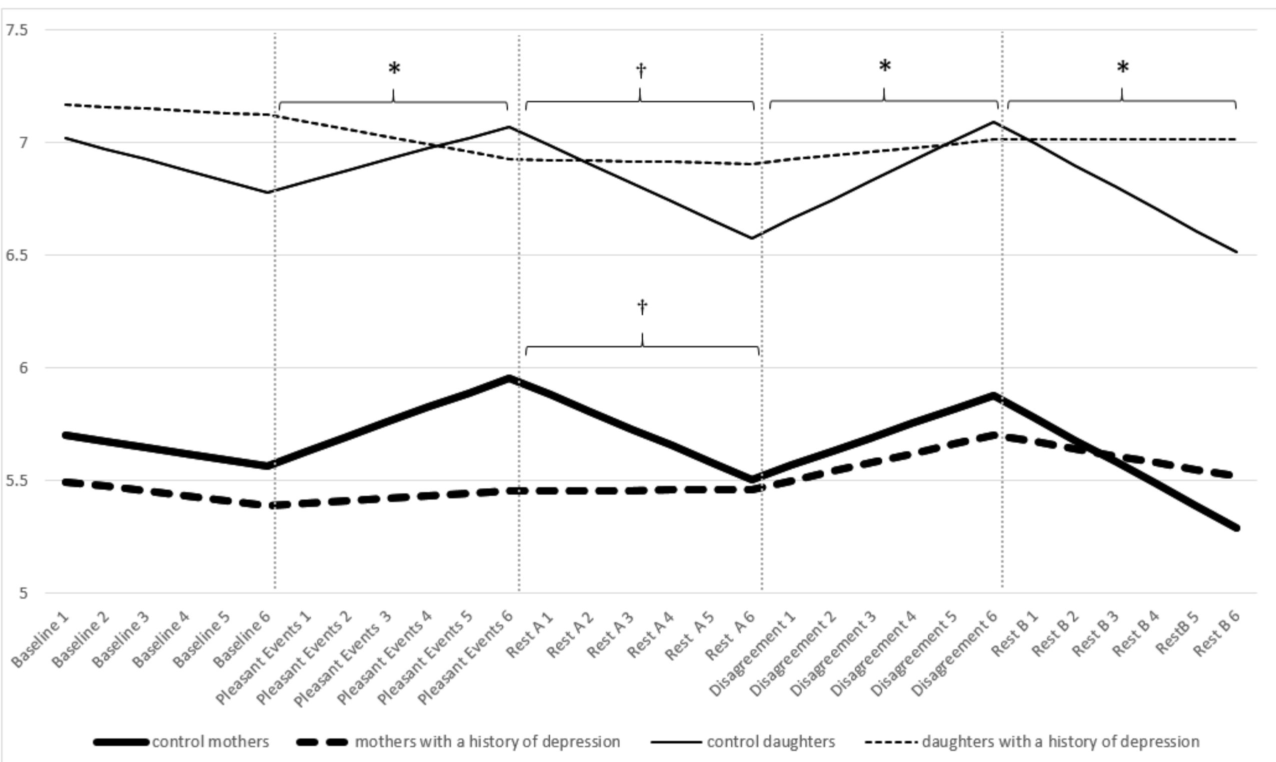
Table 6. Daughters: HF-HRV fixed effects.

Fixed effect	Symbol	Coefficient	Std. error	*t*-ratio	*d.f.*	*p*
Initial status	π_0					
Controls	β_{00}	6.993519	0.175610	39.824	42	<0.001
History of Depression	β_{01}	-0.196232	0.266833	-0.735	42	0.466
Daughter's Age	β_{02}	-0.086768	0.063590	-1.364	42	0.180
Baseline slope	π_1					
Controls	β_{10}	-0.048273	0.022151	-2.179	1117	0.030
History of Depression	β_{11}	0.019419	0.033163	0.586	1117	0.558
Pleasant events task slope	π_2					
Controls	β_{20}	0.048359	0.018163	2.663	43	0.011
History of Depression	β_{21}	-0.050477	0.027284	-1.850	43	0.071
Rest A slope	π_3					
Controls	β_{30}	-0.082490	0.017338	-4.758	43	<0.001
History of Depression	β_{31}	0.078600	0.026120	3.009	43	0.004
Disagreement task slope	π_4					
Controls	β_{40}	0.086295	0.020447	4.220	43	<0.001
History of Depression	β_{41}	-0.075516	0.030669	-2.462	43	0.018
Rest B slope	π_5					
Controls	β_{50}	-0.096509	0.022336	-4.321	43	<0.001
History of Depression	β_{51}	0.067107	0.033355	2.012	43	0.051

Table 7. Daughters: HF-HRV random effects.

Random Effect	Symbol	*SD*	Variance Component	*d.f.*	χ^2	*p*
Initial status	r_0	0.78058	0.60930	42	723.29814	<0.001
Pleasant events task slope	r_2	0.04501	0.00203	43	67.35585	0.010
Rest A slope	r_3	0.04157	0.00173	43	58.17729	0.061
Disagreement task slope	r_4	0.06754	0.00456	43	79.98392	<0.001
Rest B slope	r_5	0.06710	0.00450	43	70.56583	0.005
Level-1 error	e	0.54151	0.29324			

Figure 3. HF-HRV of mothers and daughters excluding participants on antidepressants.



* $p < .05$ † $p \leq .07$

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