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## Shaping emotion regulation: attunement, symptomatology, and stress recovery within mother–infant dyads

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### Abstract

The foundations of emotion regulation are organized, in part, through repeated interactions with one's caregiver in infancy. Less is known about how stress physiology covaries between a mother and her infant within these interactions, leaving a gap in our understanding of how the biological basis of emotion regulation develops. This study investigated physiological attunement between mothers and their 5-month-old infants, as well as the influence of maternal depression and anxiety, during stress recovery. During the reengagement phase of the Still Face Paradigm, mother–infant dyads exhibited negative attunement, as measured by inverse covariation of respiratory sinus arrhythmia (RSA). Increases in maternal RSA corresponded to decreases in infant RSA, underscoring dyadic adjustment during recovery. Moreover, infant regulation differed as a function of maternal anxiety, with more anxious mothers having infants with higher RSA during reengagement. Implications for the consolidation of regulatory capabilities within the context of the early caregiving relationship are discussed.

### Keywords

emotion regulation; maternal anxiety; mother–infant relations; physiological attunement; respiratory sinus arrhythmia; RSA

## 1 INTRODUCTION

The substrates of emotion regulation are organized, in part, across the first months of life through intimate interactions and engagement with one's caregiver (Bornstein, 2013; Propper, 2012; Tronick & Beeghly, 2011). Once developed, emotion regulatory processes help an individual “to modulate, inhibit, and/or enhance emotional experiences and expressions,” and are, therefore, essential to psychosocial wellbeing (Calkins & Hill, 2007). Research has shown that, in the context of early primary relationships, the emotional wellbeing of the caregiver plays a pivotal role in the structuring and consolidation of an infant's emotion regulatory processes. Mothers who respond sensitively and contingently to their infants foster optimal regulatory abilities as the child matures, while mother–infant

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interactions that are disrupted due to maternal internalizing symptoms can lead to less optimal regulatory patterns (Feldman et al., 2009; Field, Pickens, Fox, & Nawrocki, 1995; Haley & Stansbury, 2003; Martinez-Torteya et al., 2014; Moore & Calkins, 2004; Propper, 2012). These behavioral characteristics of the mother, as well as the contemporaneous behaviors of her offspring, are likely supported by patterns of physiological activation and recovery (Feldman, 2007, 2012). By examining the covariation of these patterns within mother–infant dyads, we may uncover how the biological substrates of emotion regulation are organized, or disrupted, through interactions with caregivers in infancy.

Caregivers and infants co-create experiences of regulation; one member relies on the other to acknowledge, reciprocate, or expand upon his or her actions as the dyad works towards a mutually regulated state. Attunement, a relational approach that emphasizes bidirectional influences between a mother and infant, characterizes the ability of a dyad to jointly structure biobehavioral development of an infant through repeated experiences across the first months of life (Bornstein, 2013). Continued exposure to this temporal coordination of responding and recovery within a dyad may be a route through which maternal responsiveness shapes the regulatory capacity of an infant. Moreover, the attunement process may support infant regulation and dysregulation, depending on the mental health status of the mother (Laurent, Ablow, & Measelle, 2011). The aim of the current study was to investigate the degree of physiological attunement between mothers and their 5-month-old infants while reengaging following a relational stressor (i.e., still-face paradigm (SFP); Tronick, Als, Adamson, Wise, & Brazelton, 1978). Furthermore, this study explored whether physiological attunement was associated with maternal symptoms of postpartum depression and anxiety.

## 2 INTEGRATING EARLY EXPERIENCE THROUGH DYADIC ATTUNEMENT

Tronick's mutual regulation model (Tronick & Beeghly, 2011) posits that the foundation of self-regulation in childhood is structured through repeated interactions with a caregiver who responds promptly and sensitively to their infant's distress. This model argues that it is the reparation of mismatched biobehavioral states within a mother–infant dyad, rather than absolute matching of positive affect, that is most important to an infant's regulatory development. Over time, children begin to internalize that their needs will be met with appropriate care and that they play an active role in co-regulation, providing the framework to begin developing self-regulatory abilities. Research has supported this theory, showing that infants with responsive mothers show more attentional engagement with their caregiver, fewer resistant behaviors, and greater physiological regulation in response to stress, compared to their counterparts with less responsive mothers (Conradt & Ablow, 2010; Haley & Stansbury, 2003; Ham & Tronick, 2006; Kogan & Carter, 1996). However, uncertainty remains about the pathways through which maternal responsiveness and mental health influence an infants' regulatory development.

Physiological attunement, a phenomenon referred to by different yet conceptually similar terms (e.g., synchrony, coordination), describes the degree to which physiological reactivity and regulation for a mother and her infant are related from moment-to-moment. Parallel activation of stress physiology (i.e., positive attunement) occurs when increases, and

decreases, of stress reactivity are mirrored between members of a dyad. Mother–infant dyads also exhibit patterns of inverse activation (i.e., negative attunement) in which increases in reactivity by one member of the dyad are matched by decreases in the other member, or they may show unrelated physiologic activation [see Laurent, Ablow, and Measelle (2012) for further description of attunement trajectories]. Importantly, “positive” and “negative” attunement refers only to the direction of association between actors in the dyad, and does not endorse attunement as an advantageous regulatory state per se. For instance, mothers with elevated depressive symptoms demonstrated positive physiological attunement with their toddlers in response to a stressor (Laurent et al., 2011), highlighting a potential pathway through which the dysregulated stress response of a mother suffering from psychopathology may influence the biobehavioral development of her infant. Repeated experiences of physiological attunement with a caregiver may thus structure the biological substrates of emotion regulation for an infant, for better or worse.

### 3 RSA: AN ONLINE MARKER OF PHYSIOLOGICAL ATTUNEMENT

Porges’ Polyvagal Theory posits that patterns of activation and withdrawal of the parasympathetic “vagal brake” (i.e., regulation by the myelinated vagus nerve on cardiac output) are associated with approach behavior and self-regulation early in life, thereby providing the foundation for social engagement (Porges, 2003, 2007). While engagement of the vagus nerve is thought to promote restorative processes, withdrawal of the vagal brake shifts attentional and regulatory resources to cope with arousal induced by the social environment. Patterns of vagal functioning are commonly indexed by respiratory sinus arrhythmia (RSA), which describes fluctuations in heart rate across the respiration cycle in response to environmental demands (Porges, 2007). RSA, and by extension vagal functioning, is particularly sensitive to the early caregiving environment (Propper, 2012).

In infancy, patterns of moderate change and recovery in RSA levels have been linked to better self-soothing, attentional control, and sociability, as well as better emotion regulation (Calkins & Hill, 2007; Field & Diego, 2008; Moore & Calkins, 2004; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). Temporary decreases in RSA, a marker of vagal brake withdrawal, allow an individual to respond rapidly to changing environmental demands while conserving or delaying other stress response systems (e.g., HPA axis) for more acute demands. Reductions in RSA reflect an active attempt from an infant to cope with distress by shifting attention toward their caregiver in hopes of utilizing her for mutual regulation and the reduction of distress. More significant changes in RSA and/or failure to recover homeostasis following stress often predict difficulties with emotion regulation later in development (Bazhenova, Plonskaia, & Porges, 2001). On the maternal side, research suggests an organized pattern of physiological activation that motivates mothers to respond to infant distress, with initial increases in RSA followed by reductions at peak infant distress (Oppenheimer, Measelle, Laurent, & Ablow, 2013). Ultimately, an overall reduction in RSA mobilizes mothers to soothe their distressed infants, and can thereby be considered an adaptive behavior that facilitates sensitive and responsive caregiving (Mills-Koonce et al., 2009). This reduction in RSA in response to infant distress, however, was not present in mothers suffering from depression (Oppenheimer et al., 2013), suggesting a route by which

maternal internalizing symptoms may impact the development of regulatory capacities in infancy.

In addition to individual differences in maternal responsiveness, the manifestation and function of physiological attunement between mother and child may differ based on the demands of a situation. Research has shown that mother–child dyads exhibit positive concordance in RSA when the demands of a laboratory task induce minimal levels of stress, such as during a habituation task (Bornstein & Suess, 2000) or a cleanup task (Lunkenheimer et al., 2015). When laboratory tasks are stressful, however, mother–child dyads have been shown to exhibit divergent patterns of RSA activity. For instances, Moore et al. (2009) found that maternal RSA increased in response to the SFP and decreased during the reunion episode. Infant RSA, on the other hand, decreased during the SFP and increased over the course of the reunion episode (Moore et al., 2009). This pattern of physiological reactivity and regulation in response to the still-face suggests negative physiological attunement. Physiological attunement may thus serve different functions depending on situational demands, further supporting the role of parasympathetic processes in the development of flexible regulatory development.

#### 4 MATERNAL SYMPTOMATOLOGY HINDERING DYADIC ATTUNEMENT

Responsive parenting may not be easily implemented for all mothers. Major depression is prevalent during the childbearing years (see Goodman, 2007 for a review), with 12-month prevalence estimates at approximately 10% among mothers in the United States (Ertel, Rich-Edwards, & Koenen, 2011). Multiple mechanisms through which maternal depression can impact a child's development have been suggested. Particularly relevant to the experience-dependent maturation of RSA is postnatal exposure to negative maternal cognitions, behaviors, and affect, which may disrupt maternal responsiveness and subsequent attunement (Goodman, 2007; Goodman & Gotlib, 1999; Laurent et al., 2011). Mothers experiencing depressive symptoms have been shown to adjust more slowly and less consistently (Zlochower & Cohn, 1996), provide less contingent responses (Field, Healy, Goldstein, & Guthertz, 1990), and be less synchronous in normal interactions with their infants (Moore & Calkins, 2004) compared to non-depressed mothers.

Maternal anxiety, which often occurs alongside depression, has also been identified as a risk factor for later emerging psychopathology in offspring (Barker, Jaffee, Uher, & Meughan, 2011; Beidel & Turner, 1997). Mothers suffering from elevated anxiety symptoms tend to display hyper-vigilance and overarousal during interactions with their child, and exhibit more controlling behavior, particularly in regards to restricting opportunities for exploration (Edwards, Rapee, & Kennedy, 2010; McLeod, Wood, & Weisz, 2007; Rapee, Schniering, & Hudson, 2009; Schrock & Woodruff-Borden, 2010; Wood, McLeod, Sigman, Hwang, & Chu, 2003). Prior research examining the effects of postnatal maternal anxiety on sensitive parenting and mother–infant interactions is limited and results have been mixed. For instance, while some researchers have found a positive association between maternal anxiety and sensitive parenting (Kaitz, Maytal, Devor, Bergman, & Mankuta, 2010; Murray, Cooper, Creswell, Schofield, & Sack, 2007), others have found the opposite pattern (Feldman, Greenbaum, Mayes, & Erlich, 1997; Nicol-Harper, Harvey, & Stein, 2007). The severity of

comorbid depressive symptoms may also have an effect on this association, as mothers who are depressed and have high anxiety exhibit less exaggerated affect and play when interacting with their infants, compared to depressed mothers who are low on anxiety (Field et al., 2005). Recent work from Beebe et al. (2011) has helped to clarify these inconsistent findings. They found that anxious mothers exhibit both vigilant (e.g., exaggerated attention and responsiveness toward the infant) and withdrawn (e.g., reduced emotionality) behavior toward their infants; differences depended on the modality being assessed. This pattern of behavior may aid a mother in reducing arousal while allowing her to maintain attention and responsiveness to the needs of one's child.

The behavioral correlates of maternal anxiety are, potentially, intrusive and may impede a dyad's capacity to achieve a mutually regulated state. At a physiological level, the vigilance and overarousal associated with maternal anxiety may translate into impairments in infant regulatory development. The effect of maternal anxiety on parasympathetic regulation in infancy is understudied and poorly understood. One study (Ham & Tronick, 2006) found that infants who recovered from the still-face had the largest increase in RSA from still-face to reunion. These infants had mothers who displayed sensitive parenting behaviors, decreased in RSA during the reunion episode, and did not exhibit signs of elevated physiological anxiety, compared to mothers whose infants did not recover from the still-face (Ham & Tronick, 2006).

## 5 THE CURRENT STUDY

Few studies have examined physiological attunement during mother–infant interactions, thereby leaving a gap in our understanding of how RSA might covary within mother–infant dyads during the stress recovery/reengagement periods thought to be critical to infant regulation. The goal of the current study was to expand on a relational understanding of the biological substrates of emotion regulation by investigating mother–infant RSA attunement following a stressor [see Laurent et al. (2012) and Papp, Pendry, and Adam (2009) for similar approaches]. Furthermore, we examined whether maternal symptoms of depression and anxiety impacted infant RSA and mother–infant physiological attunement.

The current study had three primary hypotheses. First, we hypothesized that mothers and infants would show negative physiological attunement during the reunion episode of the still face procedure, such that an overall decrease in maternal RSA to reengage and relieve her infant's distress would be associated with an increase in infant RSA as the dyad worked toward a state of mutual physiological recovery. The psychological burden associated with internalizing symptoms may restrict mothers' responsiveness to their infant's distress. Accordingly, our second hypothesis was that the degree of physiological attunement would vary by maternal internalizing symptoms such that attunement would be more pronounced in mother–infant dyads with fewer symptoms, as compared to their more symptomatic counterparts. Finally, we hypothesized that an infant's average RSA during the reunion episode would be associated with maternal internalizing symptoms such that mothers who had more symptoms would have infants with lower RSA overall. Such reduced RSA would support the contention that exposure to maternal psychopathology diminishes the infant's capacity to recover from stress (Propper, 2012).

## 6 METHODS

### 6.1 Participants

Mothers ( $n = 105$ ) were recruited for risk of parenting difficulties from local hospitals and public assistance organizations (e.g., Lane County Women, Infants, and Children) during the third trimester of their first pregnancy. Women were invited to participate in the study if they scored in the clinical range on the Screening Scale for Problems in Parenting (11 or above out of a possible 25; Avison, Turner, & Noh, 1986) and/or the 9-item version of the Center for Epidemiological Studies-Depression scale (12 or above out of a possible 36; Radloff, 1977). Mothers were assessed once prenatally (T1: mean age = 24.11 years,  $SD = 4.77$ ) and three times postnatally with their child: at 5-months (T2), 17-months (T3), and 5-years (T4) after birth. The current study focused on the T2 assessment ( $N = 95$ ; see demographics, Table 1). In keeping with the population from which these participants were recruited, approximately 41% of mothers reported their household income to be less than \$20,000 at the T2 lab visit.

### 6.2 Procedure

**6.2.1 Still-face paradigm**—Mother–infant dyads participated in the SFP (Tronick et al., 1978), a well-validated interpersonal stressor (Mesmen, van Ijzendoorn, & Bakermans-Kranenburg, 2009). Infants were seated in a highchair facing their mothers who were approximately 18 in. away. Mothers were asked to interact normally with their infants for 2 min. Following the initial play period, mothers were signaled to avert their gaze for 15 s, after which they turned back to their infant with an emotionless or neutral face (i.e., still-face episode). Mothers were asked to maintain this appearance for 2 min and not to touch or talk to their child. After 2 min, mothers were signaled to look away for 15 s once again, and then reengage with their infants (i.e., reunion episode); the reunion episode lasted for 1 min. The procedure was stopped if the infant became too fussy, and reinitiated when the infant was soothed if possible. The current study focused on recovery of both mother and infant during the reunion episode of the SFP.

### 6.3 Measures

**6.3.1 Maternal depression**—Mothers reported depressive symptoms at the 5-month visit using the Edinburgh Postnatal Depression Scale (EPDS; Cox, Holden, & Sagovsky, 1987). The EPDS is a 10-item self-report measure that assesses depressive symptomatology in mothers following the birth of a child. Scores on the EPDS are summed and range from 0 to 30, with higher values indicating higher depressive symptoms. Given the physical adjustment and strain that accompanies the transition to motherhood, the EPDS focuses on cognitive, rather than somatic, symptoms of depression (Cox et al., 1987). The EPDS has demonstrated exceptional sensitivity (95%) and specificity (93%), as well as split-half reliability ( $\alpha = .87$ ) making it a valid and reliable measure of postpartum depression (Cox et al., 1987; Harris, Huckle, Thomas, Johns, & Fung, 1989). However, research has shown that the EPDS does not exclusively measure depression and may be useful in identifying symptoms of anxiety as well (Brouwers, van Baar, & Pop, 2001); this is not surprising given the known overlap between these forms of internalizing psychopathology. Within the current

sample, mothers scored on average just below the suggested clinical cutoff range of 9–13 ( $M = 7.58$ ,  $SD = 2.31$ ). EPDS scores were grand-mean centered prior to the primary analysis.

**6.3.2 Maternal anxiety**—Mothers reported anxiety symptoms using the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988). The BAI is a 21-item inventory that asks participants to report on cognitive, emotional, and physiological aspects of anxiety. The BAI has shown high internal consistency (Cronbach's  $\alpha = .92$ ) and test-retest reliability ( $r = .75$ ), and, unlike the EPDS, has been shown to differentiate between anxiety and other commonly co-occurring psychopathology, such as depression (Beck et al., 1988). At each of the assessments, mothers from our sample completed the BAI; on average, mothers in the current sample reported mild anxiety at the 5-month assessment ( $M = 6.57$ ,  $SD = 6.96$ ). Mothers' BAI scores were 5% winsorized prior to analyses to reduce the impact of outliers. BAI scores were also grand-mean centered prior to the primary analysis.

**6.3.3 Physiological data**—RSA was assessed continuously while mother–infant dyads participated in a battery of tasks at 5 months, including the SFP. Prior to a baseline assessment, heart rate, and respiration monitoring equipment was attached to both mothers and their infants; the mothers then fitted their infants in a gender-neutral sleeper to prevent the infant from pulling the electrodes.

Information about the validity, reliability, and application of the heart rate and respiration monitoring equipment, as well as detailed descriptions of how files were edited, are presented elsewhere (Conradt, Measelle, & Ablow, 2013; Oppenheimer et al., 2013). In general, data files in which more than 2–3% of the data needed to be edited were not included in the analyses. RSA was computed from the respiration and interbeat interval data using the Grossman's peak-valley technique (Grossman, 1983; Grossman, Karemaker, & Wieling, 1991). Due to high correlation among adjacent time points, RSA values were grouped into 5-s epochs and averaged, thereby creating twelve time points for analysis (Table 2). Previous research supports the use of short epoch durations to analyze patterns of RSA reactivity when tasks are brief, in order to allow for more epochs in the time series analysis (Huffman et al., 1998; Moore et al., 2009; Oppenheimer et al., 2013). Mother and infant RSA values were 3% winsorized and natural-log transformed prior to the primary analysis to reduce skewness.

## 6.4 Analytic approach

Due to a lack of statistical independence between mother and infant physiology, hierarchical linear modeling (HLM; Raudenbush and Bryk, 2002) was selected to model attunement of mother and infant RSA during the 60-s reunion episode of the SFP. The first model examined how maternal RSA covaried with infant RSA. At Level-1, infant RSA was estimated with an intercept term, which captured each infant's average RSA level across recovery, and a maternal RSA term, a group-mean centered time-varying covariate representing how relative changes in a mother's RSA related to changes in her infant's RSA across time points (i.e., physiological attunement within a dyad). Next, the mother's mean RSA (grand-mean centered) was entered as a Level-2 predictor of the infant RSA intercept to examine whether mothers with higher absolute levels of RSA had infants with higher/

lower RSA. Thus, the group-mean centered maternal RSA variable reflected within-dyad variability (i.e., physiological attunement), whereas the grand-mean centered maternal RSA variable reflected variability relative to other dyads (see Kreft, de Leeuw, and Aiken (1995) and Paccagnella (2006) for further discussion). Maternal report of concurrent anxiety and depressive symptoms and infant baseline RSA were then examined as Level-2 predictors of between-dyad differences in the infant's average RSA. Finally, maternal report of concurrent anxiety and depressive symptoms were examined as Level-2 predictors of between-dyad differences in attunement of mother–infant physiology (see Model below for infant RSA two-level equation as described above).

Level-1:

$$\text{infant RSA}_{ij} = b_{0j} + b_{1j}(\text{Mom RSA})_{ij} + e_{ij}$$

Level-2:

$$\begin{aligned} b_{0j} &= g_{00} + g_{01}(\text{Mom RSA}) + g_{02}(\text{EPDS}) + g_{03}(\text{BAI}) + g_{04}(\text{infant baseline RSA}) + u_{0j} \\ b_{1j} &= g_{10} + g_{11}(\text{EPDS}) + g_{12}(\text{BAI}) + u_{1j} \end{aligned}$$

The same approach was used to for the second model, which examined how infant RSA covaried with maternal RSA. At Level-1, maternal RSA across the episode was estimated with an intercept term and time-varying infant RSA (group-mean centered) at Level-1. The infant's mean RSA (grand-mean centered) was then entered as a Level-2 predictor of the mother's RSA intercept. Finally, maternal baseline RSA was used in place of infant baseline RSA as a Level-2 predictor of between-dyad differences in average maternal RSA across the reunion episode. As in the previous model, maternal anxiety and depressive symptoms were entered as Level-2 predictors of both maternal mean RSA across the episode and physiological attunement (see Model below for maternal RSA two-level equation).

Level-1:

$$\text{Maternal RSA}_{ij} = b_{0j} + b_{1j}(\text{Infant RSA})_{ij} + e_{ij}$$

Level-2:

$$\begin{aligned} b_{0j} &= g_{00} + g_{01}(\text{Infant RSA}) + g_{02}(\text{EPDS}) + g_{03}(\text{BAI}) + g_{04}(\text{maternal baseline RSA}) + u_{0j} \\ b_{1j} &= g_{10} + g_{11}(\text{EPDS}) + g_{12}(\text{BAI}) + u_{1j} \end{aligned}$$

## 7 RESULTS

### 7.1 Preliminary analyses

Descriptive statistics for variables of interest are presented in Table 2. Associations among these variables (Table 3), as well as potential confounding variables, were examined prior to the primary analyses. Maternal report of anxiety (i.e., BAI) and depressive (i.e., EPDS)



symptoms were highly correlated ( $r = .53, p < .001$ ), such that higher anxiety was associated with increased depressive symptoms. Maternal BAI scores were also positively correlated with mean infant RSA,  $r = .25, p < .05$ . Maternal EPDS scores were not associated with mean maternal or infant RSA (Table 2). Maternal EPDS scores were, however, negatively associated with household income ( $r = -.24, p < .05$ ) and maternal education ( $r = -.22, p < .05$ ), such that higher postpartum symptoms were associated with lower household income and lower educational attainment. There were no significant associations between mean maternal or infant RSA and any of the demographic variables or infant sex.

Descriptive graphs of mean RSA at each 5-s epoch for mothers (Figure 1) and infants (Figure 2) were visually examined prior to the primary analyses. Whereas average maternal RSA decreased across the reunion episode, consistent with physiological support of soothing behaviors, infants showed an average increase in RSA, consistent with physiological recovery (dotted lines, Figures 1 and 2). Moreover, the graphs suggested a pattern of negative physiological attunement that differed depending on which half of the Reunion episode was being examined. A large initial increase in maternal RSA was mirrored by a sharp decrease in infant RSA during the first half of the reunion episode. During the second half of the episode, maternal RSA decreased while infant RSA increased, marking a change in the nature of mother–infant attunement. As shown by the standard deviations in Table 2, both mother and infant physiology demonstrated considerable variability between individuals, suggesting that sample-wide analyses may not adequately capture individual differences in co-regulatory process across mother–infant dyads.

Prior to conducting the primary analyses, the reunion episode was split in half, thereby creating two segments of six 5-s epochs each (i.e., two 30-s segments). By dividing the reunion episode, we hoped to probe a more dynamic association between physiological attunement and maternal internalizing symptoms across the episode.

## 7.2 Primary analyses

A baseline HLM model for infant RSA that included only a random intercept and Level-1 residual term was constructed. The intraclass correlation was computed to determine the proportion of variance in the outcome that could be attributed to within- versus between-dyad differences. Approximately 32% of the variability in the outcome was attributable to between-dyad differences, supporting the inclusion of both Level-1 (within-dyad) and Level-2 (between-dyad) predictors to explain variance in infant RSA. Significant variability remained to be explained in the intercept ( $\chi^2[80] = 515.94, p < .001$ ), further supporting the inclusion of Level-2 predictors.

Differences in physiological attunement, as represented by the time-varying covariate at L1, emerged as a function of episode segment (Table 3). Physiology of mother–infant dyads showed significant attunement during the first segment ( $b = -.13, p = .03$ ), and were at significance during the second segment ( $b = -.12, p = .05$ ). This means that an increase in RSA by a mother was, in general, matched by a simultaneous decrease in RSA by her infant, and vice versa. EPDS and BAI scores were initially entered as L2 predictors of the intercept only (i.e., mean infant RSA), and then as moderators of physiological attunement. Results revealed a significant main effect of maternal anxiety during both the first ( $b = .02, p = .02$ )

and second ( $b = .04, p < .001$ ) halves. Mothers who reported higher anxiety symptoms had infants who, on average, had higher RSA during the Reunion episode; this effect was significantly stronger during the second segment ( $z = -2.00, p = .02$ ). Mothers' depressive symptoms were not significantly associated with infant RSA above and beyond the effect of maternal anxiety. The effect of both maternal anxiety and depression on physiological attunement failed to reach significance (Table 3). This means that attunement between mother and infant physiology did not differ as a function of the mother's postpartum internalizing symptoms.

Given the bidirectional nature of physiological attunement, we also examined how infant RSA covaried with maternal RSA. Once again, differences in physiological attunement emerged as a function of episode segment. Mother–infant dyads exhibited negative physiological attunement during the first segment, though this effect was only marginally significant ( $b = -.09, p = .07$ ). Mother and infant physiology was not significantly attuned during the second segment of the Reunion ( $b = -.08, p = .16$ ). Results revealed a significant main effect of maternal anxiety on average maternal RSA across recovery, but only during the second segment ( $b = .04, p = .01$ ). Mothers who reported more anxiety symptoms had, on average, higher RSA during the second half of the Reunion episode. No other effects reached significance (Table 4).

### 7.3 Secondary analyses

The final model was applied to data from the play episode of the SFP, to determine whether the identified pattern of physiological attunement was unique to stress recovery. The play period was divided into four segments, with each segment representing 30-s periods during the 120-s episode. Physiological attunement was not observed in any of the segments ( $ps > .61$ ). Infant baseline RSA significantly predicted average infant RSA across segments of the play episode ( $ps < .01$ ), with higher baseline RSA being associated with higher average RSA across each segment. None of the other L2 variables (i.e., maternal psychopathology, average maternal RSA during play) predicted infant RSA across segments of the episode ( $ps > .13$ ).

## 8 DISCUSSION

Mother–infant dyads displayed negative (i.e., inverse) physiological attunement in response to a relational stressor; an increase in maternal RSA typically corresponded to a time-matched decrease for her infant, and vice versa. This implies that while mothers were attempting to self-regulate early in the task, their infants were simultaneously mobilizing a physiological response, thereby creating an opportunity to utilize their mothers as a resource to cope with distress. In addition, overall reductions in maternal RSA across the recovery period were mirrored by increases in infant RSA, thus providing support for previous findings suggesting that mothers become more physiologically aroused as a means to support caregiving (Mills-Koonce et al., 2009). Physiological attunement was not uniform across the episode, with mother–infant dyads demonstrating stronger negative RSA attunement during the first segment of the episode, presumably when the infant was in need of greatest regulatory support following the still face. Physiological attunement may be

indicative of a dyad's ability to promptly respond to the effects of stress. More specifically, the pattern of negative attunement demonstrated in the present study may be adaptive during early stress recovery as the mother and her infant work to attain a regulated state. Regular exposure to this type of relational physiological process may canalize an infants' regulatory physiology, thereby supporting a pathway through which regulated, as well as dysregulated, maternal psychobiology can structure regulatory development.

It is worth noting that prior work has reported the opposite pattern of mother-child physiological attunement. Bornstein & Suess (2000) found a marginally significant positive association in baseline-to-task change in RSA for a mother and her 2-month-old infant. Furthermore, Lunkenheimer et al. (2015) found that mothers and their preschool children exhibit positive RSA concordance during a battery of laboratory tasks. Discrepant findings from the present study may be attributable, in part, to the situational demands placed on the dyads. Previous studies that reported positive attunement utilized tasks that induce minimal levels of stress (e.g., free-play task). A child's distress is likely moderate and, potentially, manageable in response to these types of tasks; this level of arousal may support mother-child interactions given that demands for physiological regulation are minimal. However, when a mother-child dyad is exposed to high levels of distress (e.g., still-face; Moore et al., 2009) or conflict (e.g., externalizing problems, Lunkenheimer et al., 2015) they have exhibited divergent patterns of parasympathetic activity. Thus, physiological attunement may serve a unique function in response to the context of a mother-child interaction, which differ depending on the regulatory demands placed on the dyad. The present study supports this assertion. We found that mother-infant dyads exhibited negative physiological attunement during stress recovery, particularly in the period immediately following reengagement. This effect was robust in that it was found in both the parent-to-child and child-to-parent analyses, although the child-to-parent effect was only marginally significant. There was no evidence, however, of physiological attunement during the minimally stressful free-play episode. Negative physiological attunement following a distressing event or interaction may facilitate coregulation through the infants' engagement with the mother while she recovers from distress. This dyadic regulatory process may function differently in minimally stressful situations, as less demand for physiological regulation may be placed on the dyad. Additional research is necessary to determine how physiological attunement differs across stressful and non-stressful situations. Moreover, more research is needed to determine how this dyadic regulatory processes changes across early development, given the child's increasing ability to self-regulate in times of distress.

Contrary to our hypothesis, the degree of physiological attunement did not differ as a function of maternal internalizing symptoms. One possible explanation for this finding is that the present study focused on a mother's concurrent symptoms rather than examining changes across the perinatal period. Previous work (Laurent et al., 2011) found that instability of maternal depression (e.g., a shift from lower prenatal to higher postnatal symptoms) predicted greater attunement of HPA reactivity between mothers and their toddlers in response to a stressor. Alternatively, it may be that the effects of maternal internalizing symptoms had limited opportunity to influence mother-infant physiological attunement given that the current assessment was relatively early in the development of dyadic coordination. Thus, the divergent finding in the current study may be due, in part, to

differences in the timing of assessment and focus on concurrent rather than the course of symptoms over time. Future research should examine whether stability of maternal internalizing symptoms across the perinatal period is related to RSA attunement between mother and infant, as well as how this association differs based on the timing of assessments.

Although not associated with dyadic attunement, differences in maternal postnatal anxiety did predict individual differences in infants' average RSA levels across the recovery phase of the still face. Mothers who reported higher levels of anxiety had infants with higher RSA during the reunion, especially during the second half of the episode. This finding is not unexpected given the known behavioral correlates of anxiety, particularly maternal hyper-vigilance or alertness (Beebe et al., 2011; Rapee et al., 2009). While the psychological strain associated with anxiety may have detrimental effects on other aspects of a new mother's experience, our data suggest that it may afford advantages in some parenting contexts; that is, anxiety may be associated with an alertness (hyper-alertness) that mobilizes a mother to promptly soothe her distressed infant, which would subsequently lead to quicker recovery of infant RSA. Alternatively, research has shown that high RSA in infancy is a marker of both regulation and greater engagement with the environment (Conradt et al., 2013). It may be that the infant's with higher RSA were more engaged and stimulated compared to their lower RSA counterparts; this increased engagement may be associated with hyper-alertness during stress recovery from mothers with elevated symptoms of anxiety.

Limitations must be considered when interpreting findings from the current study. This study focused on covariation of physiology across time (i.e., attunement) between mother and infant, and thus does not describe the overall trajectory of stress recovery within the dyad. An inclusive analysis of mother–infant regulatory processes should also examine associations between recovery trajectories (i.e., post-stress slopes and/or quadratic terms) within dyads, rather than focusing exclusively on time-matched covariation. This more global assessment of stress recovery, assessed through dyadic growth models, will complement the moment-to-moment effects explicated in the present study by examining the factors (e.g., maternal internalizing symptoms) that alter the overall trajectory of dyadic recovery. Future work should also utilize a longer reunion period to determine whether the pattern of positive physiological attunement present in older children (e.g., Lunkenheimer et al., 2015) emerges over the course of stress recovery. It may be that negative attunement exhibited in the initial moments after a stressor precedes a period of non-attunement, after which positive attunement emerges and coregulation is achieved. Due to time restraints, the present study was unable to examine this potentially dynamic coregulatory process. In addition, the current analyses used relatively short (5 s) RSA epochs. While previous research supports the use of short epochs to examine RSA reactivity during brief tasks (Huffman et al., 1998; Moore et al., 2009; Oppenheimer et al., 2013), more research is needed to understand the function and interpretability of RSA in such brief time periods.

An assessment of moment-to-moment fluctuations in behavior as they relate to either physiology or maternal psychopathology was not included; therefore, interpretations that are predicated on potential behavioral correlates of the dyadic attunement process should be interpreted with caution. Going forward, it will be important to explore the behavioral correlates of mother–infant physiological attunement during stress recovery to illuminate

how varying degrees of moment-to-moment responsiveness influence biobehavioral attunement within the dyad. Furthermore, mean levels of both maternal anxiety and maternal depressive symptoms were below the clinical threshold. The lower levels of postpartum symptoms may, in part, contribute to the lack of identified association between internalizing symptoms and physiological attunement. Re-examining this association with a clinical population of mothers may be warranted, given that previous research has demonstrated an effect of depressive symptoms on attunement of other components of the stress response system (Laurent et al., 2011). Maternal anxiety was associated with parasympathetic processes in infancy despite the low levels of reported symptoms, lending support for the need for more research examining the role of postpartum anxiety in the formation of early regulatory capacities.

Despite these cautions, the present study expands our understanding of how emotion regulation develops within the context of the early caregiving relationship and offers ideas for subsequent research. A comprehensive understanding of how attunement structures early emotion regulatory maturation will undoubtedly require examination of how the process changes across development, from early infancy through the development of self-regulation in later childhood. Future research should also attempt to replicate our findings involving maternal anxiety to determine whether benefits to an infant's apparent regulatory capacity are fleeting or lasting. One could speculate that, although initially beneficial due to its role in mobilizing a mother, prolonged exposure to this form of hyper-responsiveness could potentially hinder recovery, thereby inhibiting a return to homeostatic levels.

The present study advances our understanding about how the biological substrates of emotion regulation are structured in infancy. By examining covariation in stress physiology within mother–infant dyads, we were able to not only explicate an online relational process through which early regulatory capabilities are potentially consolidated, but also further describe the extent to which maternal internalizing symptoms influences stress recovery. Although replication is needed, this study provides initial evidence that dyadic coordination of physiology can differ as a function of situational stress. Continued examination of regulatory development through biobehavioral attunement in the early caregiving relationship may help clarify the pathways through which parenting practices influence the foundations of offspring emotion regulation, as well as illuminate specific maladaptive processes receptive to early intervention.

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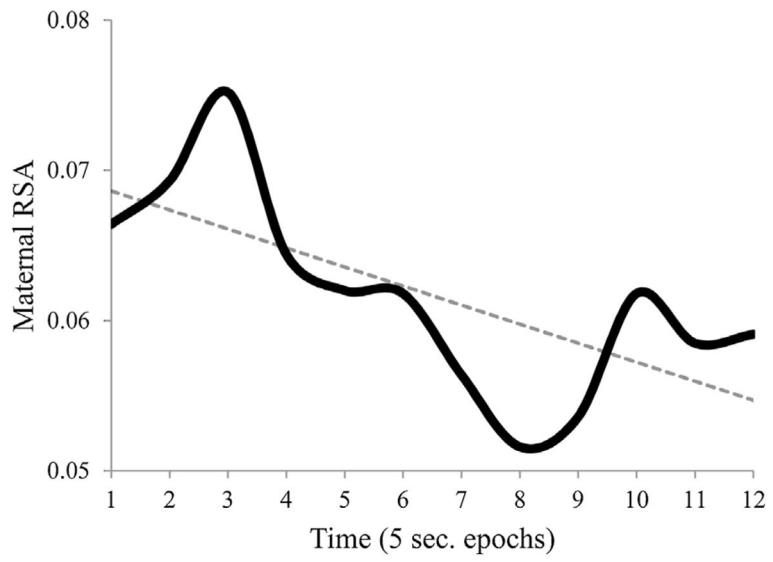
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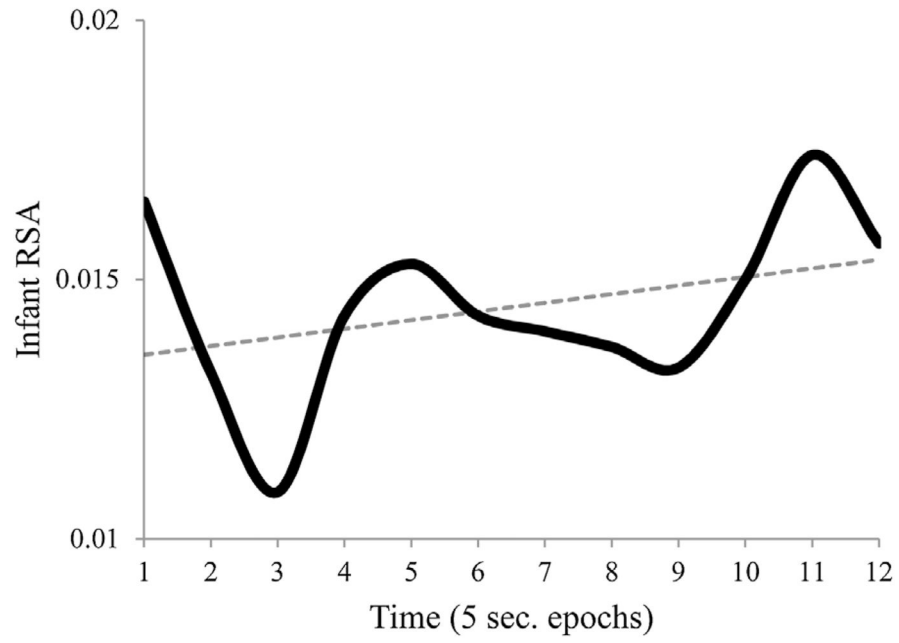
**FIGURE 1.**  
Mother's mean RSA across reunion episode

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**FIGURE 2.**  
Infant's mean RSA across reunion episode

**TABLE 1**

Demographic statistics at 5-month postpartum

	Mean/Percentage	SD	Range
Age			
Mother (years)	24.50	4.68	18–39
Infant (weeks)	20.77	2.74	16–31
Household income			
Less than \$9,999	20%		
\$10,000–20,000	21%		
\$21,000–40,000	39%		
\$41,000–60,000	5%		
Greater than \$61,000	2%		
Did not report at T2	13%		
Highest education			
Some high school	5%		
HS diploma or GED	22%		
Some college/2-yr degree	37%		
4-yr college degree	9%		
Some school beyond college	5%		
Graduate/professional degree	3%		
Did not report at T2	19%		
Married	40%		
Caucasian	81%		

TABLE 2

Descriptive statistics and correlations among variables of interest

	1.	2.	3.	4.	Mean	SD	Range
BAI <sup>a</sup>	–				6.57	6.96	0–28
EPDS	.53***	–			7.58	2.31	4–15
Maternal	.24***	.07	–		.062	.052	.01–.25
RSA <sup>b</sup>							
Infant	.254*	.01	.07	–	.014	.013	.001–.07
RSA <sup>b</sup>							

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p = .06$ .

<sup>a</sup>5% winsorized for normality.

<sup>b</sup>RSA values were condensed into 12 epochs of 5 s averages and 3% winsorized for normality. RSA values were natural log transformed prior to analyses.

**TABLE 3**

Analysis of attunement and internalizing symptoms on infant RSA during each segments of the reunion episode

	Coefficient	SE	<i>p</i>
First segment of episode			
Maternal RSA–L1 (Attunement term) <sup>a</sup>	–.13	.06	.03
Maternal RSA–L2 <sup>b</sup>	–.01	.06	.89
EPDS	–.03	.03	.24
BAI	.02	.01	.02
Baseline RSA	.10	.07	.18
Maternal RSA–L1 × BAI	<.01	.06	.97
Maternal RSA–L1 × EPDS	–.01	.02	.70
Second segment of episode			
Maternal RSA–L1 (Attunement term) <sup>a</sup>	–.12	.06	.05
Maternal RSA–L2 <sup>b</sup>	–.13	.07	.05
EPDS	–.04	.03	.13
BAI	.04	.01	<.001
Baseline RSA	<–.01	.09	.93
Maternal RSA–L1 × BAI	<–.01	.01	.71
Maternal RSA–L1 × EPDS	–.02	.03	.54

<sup>a</sup>Maternal RSA–L1: group-mean centered time-varying covariate representing how relative changes in a mother's RSA related to changes in her infant's RSA across reunion episode (physiological attunement).

<sup>b</sup>Maternal RSA–L2: mother's grand-mean centered RSA as a Level-2 predictor of infant RSA intercept.

**TABLE 4**

Analysis of attunement and internalizing symptoms on maternal RSA during each segment of the reunion episode

	Coefficient	SE	<i>p</i>
First segment of episode			
Infant RSA–L1 (attunement term) <sup>a</sup>	–.09	.05	.07
Infant RSA–L2 <sup>b</sup>	.14	.10	.17
EPDS	<–.01	.04	.95
BAI	.01	.02	.48
Baseline RSA	.05	.12	.65
Infant RSA–L1 × BAI	.01	.01	.39
Infant RSA–L1 × EPDS	–.01	.02	.66
Second segment of episode			
Infant RSA–L1 (attunement term) <sup>a</sup>	–.08	.05	.16
Infant RSA–L2 <sup>b</sup>	–.01	.10	.95
EPDS	–.03	.04	.34
BAI	.04	.01	.01
Baseline RSA	–.05	.12	.70
Infant RSA–L1 × BAI	<.01	.01	.61
Infant RSA–L1 × EPDS	–.02	.03	.41

<sup>a</sup> Infant RSA–L1: group-mean centered time-varying covariate representing how relative changes in an infant's RSA related to changes in his/her mother's RSA across reunion episode (physiological attunement).

<sup>b</sup> Infant RSA–L2: infant's grand-mean centered RSA as a Level-2 predictor of maternal RSA intercept.