Mother –Infant Vagal Regulation in the Face-To-Face Still-Face Paradigm Is Moderated by Maternal Sensitivity

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Article:

Parents' physiological regulation may support infants' regulation. Mothers (N = 152) and 6-month-old male and female infants were observed in normal and disrupted social interaction. Affect was coded at 1-s intervals and vagal tone measured as respiratory sinus arrhythmia (RSA). Maternal sensitivity was assessed in free play. Mothers and infants showed opposite patterns of RSA change. During disrupted interaction, mothers' RSA increased and infants' decreased, suggesting self-regulation of distress. During reunion, although the typical pattern was for infants to return to baseline levels, infants of sensitive mothers and sensitive mothers both showed a significant decrease in RSA from baseline. Mothers' and infants' physiological responses may be a function of mutual responsiveness.

Early infancy is a fundamental time for the emergence of physiological regulatory processes associated with healthy social-emotional and cognitive development. Although infants have rudimentary self-regulatory abilities, initially parents play an important role supporting the regulation of infants' physiological homeostasis (Spangler & Grossman, 1993; Spangler, Schieche, Ilg, Maier & Ackerman, 1994). Various theoretical perspectives propose that sensitive and responsive parenting may facilitate the organization of infants' physiological systems to achieve regulation, which is necessary to support more complex social-emotional and cognitive development (Panksepp, 2001; Schore, 2000; Siegel, 2001). Through repeated, day-to-day caregiving and play, parent–infant interactions provide the context for the emergence of infants' physiological and behavioral systems of regulation.

A growing body of research (discussed below) has examined infants' physiological regulation during parent–infant interaction; much less has examined parents' physiological regulation when interacting with infants. Parents who regulate their own reactions effectively are more likely to be able to sensitively attend and respond to the needs of their infants. The overall goal of the current study was to examine maternal sensitivity as a moderator of mothers' and infants' physiological regulation during parent – infant interaction.

Vagal Regulation and Social Interaction

Vagal tone, indexed by respiratory sinus arrhythmia (RSA), is thought to play a central role in the regulation of social interaction, behavior, emotion, and attention. Porges's (2007) polyvagal theory asserts that engagement with the environment is physiologically mediated by the ventral vagal complex, which effects parasympathetic control of the heart. Pathways originating in the nucleus ambiguus that regulate vagal influence on the heart are linked to those that regulate muscles controlling facial expressions and vocalizing (Porges, 2007). Thus, parents' and infants' vagal regulation should be important components of achieving mutually positive, optimally arousing social interaction and may potentially mediate the relation between parenting and change in infants' self-regulation across development (see review by Propper & Moore, 2006).

The influence of parenting on infants' physiological regulation during parent–infant interaction may occur through support for infants' capacity to regulate vagal tone, that is, to activate and to inhibit vagal tone as needed to support internal and external demands. During periods of relative quiescence when there are few demands to sustain or promote engagement with the environment, vagal tone is activated, contributing to a slowing down of heart rate and allowing a focus on internal, homeostatic processes. During situations that present some type of demands or challenges, these internal processes are disrupted and the autonomic nervous system increases cardiac output to initiate coping behaviors. As part of the coping process, vagal tone is typically inhibited or withdrawn (i.e., vagal tone decreases) when the environment requires active (rather than passive) participation and/or requires coping and self-regulatory behaviors. When environmental demands have ceased, vagal tone is once again activated to promote decreases in metabolic output and a return to a calm internal state.

In infancy, research has found RSA withdrawal in response to challenge to be related to positive outcomes, such as higher soothability (Huffman et al., 1998; Stifter & Corey, 2001), more attentional control (Huffman et al., 1998; Suess, Porges, & Plude, 1994), and better emotion regulation (Calkins, 1997; Porges, Doussard-Roosevelt, Portales, & Suess, 1994). In older children, a failure to withdraw RSA in response to a challenge task may be related to a lack of behavioral and emotional control (Porges, 1996; Wilson & Gottman, 1996). Thus, inhibition or withdrawal of RSA during a challenging situation (typically measured as a decrease in RSA from baseline to a challenge task) is thought to reflect more effective regulation, although it may also simply indicate individual differences in what is experienced as aversive or challenging.

Parenting Behaviors and Infants' Vagal Regulation

Empirical research has explored infants' vagal regulation in relation to parenting behaviors and to qualities of dyadic interaction. Moore and Calkins (2004) found that infants in dyads exhibiting lower synchrony in the Face-to-Face Still-Face Paradigm (FFSFP; Tronick, Als, Adamson, Wise, & Brazelton, 1978) showed higher cardiac arousal and failed to show RSA withdrawal (measured as a decrease from baseline) during mothers' still face and, when mothers resumed social engagement, these infants had more difficulty returning to the levels of arousal and RSA they showed during normal play prior to the still face. Research using measures of heart rate rather than RSA has revealed similar results. Infants of mothers categorized as more responsive, based on contingency to infants' behaviors, showed less negative affect and lower heart rate when mothers resumed social engagement during the FFSFP (Haley & Stansbury, 2003).

In a separate published report of the same study from which participants were drawn for the current article, maternal sensitivity was found to moderate the relation between purported genetic risk for behavior problems and development of infants' vagal regulation (Propper et al., 2008). Infants carrying the risk A_1^+ allele of the dopamine receptor D2 gene, which has been associated with novelty seeking, aggressiveness, and impulse control disorders in adolescents and adults, failed to show expected RSA withdrawal in response to mothers' disengagement in the still-face episode of the FFSFP at 3 and 6 months of age. By 12 months of age, however, infants with the risk allele who were also exposed to earlier sensitive maternal caregiving now displayed RSA withdrawal when separated from mothers, reaching levels that were comparable to infants who were not at genetic risk. Infants at genetic risk whose mothers were rated lower in sensitivity continued to show a failure to withdraw RSA. As RSA withdrawal in response to challenge is a purported indicator of effective physiological regulation, these findings suggest that a sensitive caregiver may promote the development of effective vagal regulation in infants at risk for problems related to self-regulation.

Mother–Infant Vagal Regulation Across the FFSFP

An emerging line of research is examining parents' vagal regulation during parent–infant interaction to understand the role that parents' self-regulation plays in support of a mutually positive, optimally arousing interaction. The current study observed mothers' and infants' change in RSA during the FFSFP, which has been used widely to examine infants' responses to a disruption in social interaction and to examine parents' and infants' abilities to reestablish social engagement after the disruption. In this procedure, parents are first asked to engage in normal play with their infants, then asked to become unresponsive to their infants by maintaining a still face, and then to resume normal interaction. Thus, the FFSFP provides an ideal context for examining mother–infant vagal regulation associated with social engagement and disengagement as articulated by the polyvagal theory.

Along with the well-documented behavioral still-face effect (Adamson & Frick, 2003) is evidence for a reliable physiological still-face effect. During the still face, infants typically show an increase in negative affect and looking away and a decrease in positive affect, and physiologically they show a decrease in RSA (Bazhenova, Plonskaia, & Porges, 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996). During the reunion, infants typically show a decrease in negative affect and an increase in positive affect, although they may remain more negative and less positive than in normal play. Physiologically during the reunion, infants typically show a return to baseline levels of RSA (Bazhenova et al., 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996). This pattern of behavioral and RSA change suggests that infants find social disengagement challenging and that their physiological regulation shifts to support attentional and affective behaviors presumably intended to elicit their nonresponsive partners and/or cope with their own distress. In the reunion, the typical increase in RSA suggests that infants' reengagement in social interaction helps them to regulate arousal and reorganize their behavior.

It should be noted that the Bazhenova et al. (2001) study observed infants interacting with a stranger. The same pattern of RSA change was found as with parents, suggesting a general mechanism of infants' dependence on a social partner to structure social interaction and to support regulation. Although Bazhenova et al. concluded that in infancy behavioral regulation depended on autonomic support, there is also evidence that infants' behavioral and physiological responses are commonly uncorrelated in infancy (e.g., Gunnar, Mangelsdorf, Larson, & Hertsgaard, 1989; Weinberg & Tronick, 1996; Zelenko et al., 2005). It is our supposition that behavioral and physiological systems develop toward both greater differentiation and greater functional, dynamic (i.e., "as needed") integration and that neither system is primary or underlies the other, rather, as the child develops, the two systems begin to function in an interrelated manner to achieve homeostasis and effective engagement with the environment. In general, we contend that it is parental support (or lack of) for mutual regulation during social interaction that supports and shapes the developmental process of effective functional integration of these systems.

Two pilot studies have found that mothers show a pattern of RSA change across the FFSFP that is converse to the pattern shown by infants (Ham & Tronick, 2006; Moore, 2005). In both studies, mothers showed an increase in RSA during the still-face episode, consistent with the constraint that they do not engage in any social behaviors with their infants. During the reunion episode, in contrast to infants who showed a return to baseline levels of RSA, mothers showed a decrease in RSA, consistent with the need for them to engage in behaviors that would structure the interaction and provide support for their infants' regulation. Moore (2005) also found a significant decrease in mothers' RSA from baseline levels during the normal play episode of the FFSFP, indicating that mothers' active support of social engagement and of infants' regulation of affective states is not limited to situations of recovery from distress or disruption, and underscores the role of a mother's own physiological regulation in providing sensitive responsiveness to her infant.

In other work from our research group, mothers with high basal or activation levels of cortisol, indicating higher physiological stress reactivity, were rated as more negative with their infants only if they failed to show RSA withdrawal in a challenge task (Mills-Koonce et al., 2007), providing additional support that parents who can regulate their own physiological reactivity effectively may be better able to respond in a sensitive and responsive manner to their infants.

The Current Study

The first goal of the current study was to examine change in RSA by mothers and infants across the FFSFP, with a particular emphasis on the reunion episode, which presents the dyad with the challenge of interactive repair after the disruption of social engagement. The second aim was to examine the relation of maternal sensitivity to change in mothers' and infants' RSA as they moved from disrupted social engagement to attempts to reengage in positive social interaction.

The current study extends prior research that has examined mothers' vagal regulation by replicating results in a larger and ethnically and economically diverse sample and extends earlier research on infants' vagal regulation by examining the role of maternal sensitivity in moderating change in mothers' and infants' RSA across episodes of the FFSFP. In the current study, assessments of maternal sensitivity were made independently of maternal responses in the FFSFP. Because ratings of maternal sensitivity are often influenced by infants' negative affect (with mothers of negative infants rated lower in sensitivity) and because many infants show negative behavior during the FFSFP, observation of maternal sensitivity outside of the experimental procedure was thought to provide a better index of the infants' typical experience of their mothers' sensitivity.

We expected to find the pattern of infants' change in RSA that has been found in several previous studies (Bazhenova et al., 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996), with a decrease in RSA (i.e., RSA withdrawal) during the still-face episode and a return to baseline levels during the reunion episode when infants could once again engage with mothers' support for dyadic interaction. We expected to find the converse pattern for mothers that has been found in prior pilot research (Ham & Tronick, 2006; Moore, 2005), with an increase in RSA during the still-face episode and a decrease in RSA (i.e., RSA withdrawal) from baseline during the reunion episode when mothers were expected to provide structure and support for dyadic interaction and infant regulation.

There have been no reported sex differences in infants' vagal regulation in the FFSFP in previous studies, and there have been mixed findings for sex differences in behavioral measures. Therefore, infant sex was examined but no specific hypotheses were made regarding the effect of infant sex on infants' or mothers' change in RSA. With regard to the role of maternal sensitivity in supporting infants' RSA regulation, hypotheses focused on responses during the reunion episode, which is likely to elicit individual differences in infants' and mothers' responses. We predicted that infants of mothers with higher levels of sensitivity would show a return to baseline levels of RSA during the reunion episode, as their mothers' responsiveness may provide better support for the infants' effective regulation and reorganization of behavior, whereas infants of less sensitive mothers would show decreased levels of RSA relative to baseline, suggesting a slower return to a regulated and organized state. We predicted that mothers higher in sensitivity would show a decrease in RSA in the reunion episode (i.e., RSA withdrawal) at a higher level than other mothers, assuming that they would more actively support social engagement and their infants' need to regulate. Alternatively, it was possible that highly sensitive mothers would have infants who would soothe more easily during the reunion episode and reengage more readily, reducing the demands on mothers to structure the interaction and assist in regulation, thus attenuating mothers' RSA withdrawal.

Because previous research has sometimes used measures of dyadic behavior rather than measures of maternal behavior, we also examined correlations between dyadic behavioral synchrony during the FFSFP and mothers' and infants' RSA. Based on previous research finding that infants in dyads that were lower in behavioral synchrony in face-to-face play showed greater physiological arousal and lower RSA (i.e., greater RSA withdrawal) in the reunion episode (Moore & Calkins, 2004), we expected that higher levels of dyadic behavioral synchrony would be related to infants' higher RSA and mothers' lower RSA in the reunion episode.

Method

Participants

The participants in the current study were selected from a larger sample (N = 206) of families recruited by the Durham Child Health and Development Study, which included approximately equal numbers of African and European American families from both lower and higher income groups. Mother–infant dyads (51% male infants) that completed both the FFSFP and a free-play task at 6 months were studied in this report (N = 152). Families were recruited from a largely urban community via fliers and postings at birth and parenting classes, as well as through telephone contact information from birth records. Infants included in the study were healthy, full term, and born without significant birth complications.

The FFSFP was conducted at infant ages 3 and 6 months, but mothers' physiological data were collected only at 6 months, so the 6-month procedures are the focus of this report. There was an approximately 10% rate of attrition between ages 3 and 6 months. Of those remaining in the study, 8 infants were too sleepy or distressed to begin the FFSFP and technical (video or cardiac monitoring) problems resulted in a complete loss of data for 11 dyads in the FFSFP and 6 in the free-play task, resulting in the sample of 152 mother –infant dyads for which there were data for both procedures.

Family's race was determined by self-reported race of the mother; income status was determined by whether the family was above or below 200% of the federally established poverty threshold. The dyads studied in this report were 57% African American and 43% European American. The majority (71%) were in two-parent families. Half of the families (52%) were low income (below 200% of the poverty level). A total of 13% of mothers had no high school degree, 43% had either a high school diploma or a General Education Development (GED) credential, 11% had some college or vocational school, and 33% had a 4-year bachelors degree or higher.

Procedure

Mother–infant free play. To evaluate maternal sensitivity, mother–infant interaction was observed in the home in a free-play task at infant age 6 months. Mothers were provided a standard set of toys and instructed to interact with their children as they normally would if playing during some free time on a typical day. The task lasted 10 min and was videotaped for later coding.

Free play interactions were coded by two independent coders, who were unaware of the study's hypotheses, according to a coding system used by the National Institute of Child Health and Human Development (NICHD) Study of Early Child Care (NICHD Early Child Care Research Network, 1997). Seven subscales of maternal behavior were coded (sensitivity/responsiveness, intrusiveness, detachment/ disengagement, positive regard, negative regard, stimulation of cognitive development, and animation) on a scale from 1 to 5, indicating the degree to which the behavior characterized the interaction. Coders were trained to reliability until intraclass correlation coefficients (ICCs) of .80 or greater were established and maintained with criterion coders (and for each individual pair of coders). All interactions were double coded and final scores were agreed upon by conferencing.

An overall maternal sensitivity composite score was created (guided by factor analyses) by aggregating the scores for five of the subscales, including sensitivity/responsiveness, positive regard, stimulation of cognitive development, animation, and detachment/disengagement (reversed scored). Inter-rater ICCs for the 6-month sensitivity score ranged from .82 to .98. The average ICC across all coders was .89. As part of the larger study, participants were also observed at 12 months in a 10-min free play interaction and, although the 12-month data are not the focus of the current report, the stability coefficient for the sensitivity score between 6 and 12 months was .67, suggesting adequate test–retest reliability.

The free play interaction and method for computing the sensitivity composite score were very similar to procedures used in the NICHD Study of Early Childcare (NICHD Early Child Care Research Network, 1997). That study has reported excellent predictive validity for sensitivity measured in the 10-min free play interaction, predicting many aspects of child development, including attachment security, self-control, compliance, behavior problems, and social competence (NICHD Early Child Care Research Network, 1997, 1998, 1999, 2001a, 2001b, 2002, 2004a, 2004b,2005).

Mother–infant FFSFP. The FFSFP was conducted during a laboratory visit at 6 months of age. The mean time between home visits during which the free play interaction described earlier was conducted, and the laboratory visit was 11.8 days (SD = 12.1). Scheduling of 6-month home and laboratory visits varied for families depending on their availability; the majority (74%) had home visits first and laboratory visits second. Because families had participated in assessments during an earlier 3-month visit and because tasks varied between the home and the laboratory assessments, we did not expect that order of home and lab visits would affect findings.

Mothers placed infants in an infant seat and sat in a chair directly in front of the infants. Mothers were given specific instructions for each episode of the FFSFP (normal play, still face, reunion). For the normal play episode, mothers were instructed to play with their babies as they normally would. Immediately after the 2-min normal play episode, following standard FFSFP procedures, mothers were told to turn away from their infants for 15 s, then to turn back toward their infants for the still-face episode. Mothers were instructed to look at their infants for 2 min without responding in any way with facial or vocal expressions and were assured that the examiner would stop the still-face episode if the infant became too distressed. A 2-min reunion episode followed the still face in which mothers were instructed to respond to their babies in any way they felt was appropriate. If an infant was unable to be soothed at any point in the procedure, the FFSFP was stopped. The episodes of the FFSFP were video recorded using a split-screen procedure so that the behaviors of both mothers and infants could be observed. Two cameras were used, with one focused on the infant and the other on the mother. The video output from the two cameras was combined using a split-screen generator and a time code was added to the videotape.

Coding infants' and mothers' affective behaviors. Infants' and mothers' behaviors were coded by trained coders naive to hypotheses of the current study. Different coders were assigned to code mothers' and infants' behaviors. In separate passes through the videotapes, facial affect and direction of gaze were coded at 1-s intervals. Affect was coded as positive, neutral, or negative, and gaze was coded as toward or away from partner. If coders were unable to see infants' or mothers' faces (e.g., mother's face obscured the infant's, infant turned away), affect was coded as missing. Infants' behaviors were coded in all three episodes of the FFSFP. Mothers' behaviors were coded only during the normal play and reunion episodes as their behavior was constrained to be neutral in the still-face episode.

Coders were initially trained to reliability using a large pool of video recorded FFSFP interactions. To assess interobserver agreement in the current study, 15% of the interactions were selected randomly and coded by a second coder. Agreement was calculated as both coders observing the same behavior within one second of each other and quantified using kappa to correct for chance agreement. Overall, coders reliably identified affect (κs = .89 for infants, .83 for mothers) and direction of gaze (κs = .90 for infants, .85 for mothers).

To determine the total amount of time during the episodes of the FFSFP that an infant and a mother each spent in positive and in negative affective states, the time series of the positive and negative affect codes for infants and for mothers were aggregated separately. The total number of seconds in which each affect code occurred was calculated for mothers and for infants for each relevant episode of the FFSFP (normal play and reunion for mothers; normal play, still face, and reunion for infants). Affect scores were computed as percentages of total valid interaction time.

Dyadic behavioral synchrony. Following previous research (e.g., Moore & Calkins, 2004), to assess the degree to which each dyad's social behavior was synchronized, first a separate social engagement score was computed at each second for each mother and for each infant during the normal play and reunion episodes by combining information from affect (positive, neutral, and negative) and direction of gaze (toward and away). Social engagement scores ranged from 1 to 6 with 1 indicating the lowest level of engagement (negative affect and gaze away from partner) and 6 indicating the highest level of engagement (positive affect and gaze toward partner). Pearson correlation coefficients were computed between the social engagement scores for mothers and infants. In this way, two scores were computed for each dyad, indexing level of dyadic behavioral synchrony during normal play and level of dyadic behavioral synchrony during the reunion episode.

Cardiac monitoring. At the beginning of the laboratory visit, electrodes were placed on mothers' and infants' chests and were connected to separate preamplifiers, the output of which was transmitted to a monitor configured to collect heart interbeat intervals (IBI; Mini Logger 2000; Mini-Mitter Corp., Bend, OR). After the mother and infant were acclimated, baseline IBI was collected. During a 2-min baseline period, mothers were asked not to interact with or provide toys to their infants so that stimulation was minimized and IBI could be measured as accurately as possible during a neutral and calm state. IBI data were continuously collected throughout the FFSFP, with electronic signals sent to the monitor to mark the start and end of the baseline period and each episode of the FFSFP.

Data files of the IBI data for the entire period of collection were transferred to a computer for artifact editing. Artifacts are common in cardiac data collected in this manner, particularly with infants, because body movements affect detection of IBI. IBI data were edited and analyzed using MXEdit software (Delta Biometrics, Bethesda, MD). Data files that required editing of more than 10% of the data or that were incomplete due to technical problems (e.g., the infant pulled off electrodes during the procedure) were not included in analyses. This resulted in missing data for individual episodes (see below).

After editing the IBI files, measures of RSA and heart period (HP) were derived using Porges's (1985) method. First, RSA and HP were calculated in 15-s epochs during the baseline period and each 2-min episode of the FFSFP. Although this epoch duration is brief, it is typical for studies of short duration tasks and has been validated by previous research (Huffman et al., 1998). Second, mean values of RSA and of HP during the baseline period and during each episode of the FFSFP were computed for use in analyses. Larger values of RSA indicate greater mean vagal tone; larger values of HP indicate longer mean HP (e.g., lower heart rate) during the episodes. Measures of skewness and kurtosis were examined and data were found to be normally distributed.
Missing cardiac data. Cardiac data were missing from approximately 20% of each of the episodes (baseline, normal play, still face, and reunion), which is common in research with young infants who tend to be noncompliant with physiological recording procedures. A greater than typical amount of cardiac data was missing for mothers due to unexpected problems with equipment. Initially, a chest strap was used to collect cardiac data from mothers, but later in the study, direct wire leads were used when it became apparent that the chest strap method was not providing reliable data. Eight dyads did not complete the FFSFP because the infant became too fussy or fell asleep. The remainder of cardiac data was missing because more than 10% of the data for a participant's episode had to be edited for artifacts (most often due to movement), indicating unreliable data, or because of technical problems (e.g., infant pulled off electrode or chewed on lead or other equipment failure, including problems with the chest strap method).

Main analyses were conducted separately for mothers and for infants and were, therefore, based on numbers of mothers and infants (not dyads) for which there were data. RSA data were available for 89 infants and 105 mothers in the baseline episode, 102 infants and 116 mothers in the normal play episode, 98 infants and 115 mothers in the still-face episode, and 95 infants and 118 mothers in the reunion episode. The data analytic method used (PROC MIXED in SAS Version 9.1) analyzes all available data (i.e., does not delete missing data listwise). Sixty-seven infants and 95 mothers had complete RSA data across all four episodes of the FFSFP.

Correlations between mother – infant variables were based on numbers of dyads with data for both mothers and infants in individual episodes. RSA data were available for 66 dyads in the baseline episode, 85 dyads in the normal play episode, 86 dyads in the still-face episode, and 83 dyads in the reunion episode. Forty-eight dyads had complete cardiac data in every episode for mothers and for infants. Data were not missing systematically by ethnicity, infant sex, or income group.

Results

Preliminary Analyses

Means and standard deviations for infants' and mothers' RSA measures are presented in Table 1.

Relations among infants' behavior and physiology. Positive affect was stable across all episodes of the FFSFP (rs ranged from .33 to .57, all ps < .001). Negative affect was stable across all episodes of the FFSFP (rs ranged from .19 to .68, all ps < .05). RSA and HP were stable across baseline and all episodes of the FFSFP (rs ranged from .66 to .81, all ps < .001). RSA was correlated with HP at baseline and in each episode of the FFSFP (rs ranged from .27 to .49, all ps < .05).

In the normal play episode, RSA was correlated with positive, r(94) = .26, p < .05, and negative, r(94) = -.21, p < .05, affect. RSA in the reunion episode was correlated with positive affect, r(86) = .27, p < .05. HP in the reunion episode was correlated with positive, r(87) = .28, p < .01, and negative, r(87) = -.40, p < .001, affect.

Relations among mothers' behaviorand physiology. Positive affect was unstable between the normal play and the reunion episodes. Because few mothers showed any negative affect during the FFSFP, maternal negative affect was not analyzed. RSA and HP were stable across baseline and all episodes of the FFSFP (rs ranged from .66 to .91, all ps < .001). RSA was correlated with HP at baseline and in each episode of the FFSFP (rs ranged from .33 to .63, all ps < .01). RSA and HP were uncorrelated with mothers' affect within or across baseline and episodes of the FFSFP.

Relations among mother–infant behavior and physiology. There were few bivariate relations among mother and infant variables. Consistent with other research, mothers' and infants' positive affect during the normal play episode were positively correlated, r(141) = .21, p < .05. Infants' negative affect during the reunion episode was negatively related to mothers' RSA, r(105) = -.25, p < .05, such that mothers showed lower RSA during reunion when infants displayed more negative affect. Because of this, infants' negative affect was initially included in main analyses of mothers' change in RSA across the FFSFP. Infants' positive affect during the reunion episode was negatively related to mothers' HP, r(104) = -.24, p < .05, such that mothers showed shorter HP when infants displayed more positive affect. Mothers' and infants' baseline HP were correlated, r(66) = .32, p < .01. There were no relations between infants' RSA and mothers' RSA and thus these were analyzed in separate models in main analyses.

Maternal sensitivity. Maternal sensitivity ranged from a score of -1 to 19 (M = 10.52, SD = 4.04). There were no relations between maternal sensitivity and mothers' or infants' affect in the FFSFP. There were no relations between maternal sensitivity and infants' RSA. Maternal sensitivity and infants' HP were correlated in the still-face episode, r(91) = .24, p < .05, such that higher levels of sensitivity were related to infants' longer HP (i.e., slower heart rate). Maternal sensitivity was negatively correlated with mothers' RSA in the reunion episode, r(110) = -.30, p < .01, such that higher levels of sensitivity were related to lower levels of RSA. Maternal sensitivity and dyadic behavioral synchrony were uncorrelated.

Table 1

Descriptive Statistics for Respiratory Sinus Arrhythmia

Episode	*N*	*M*	*SD*
Infant			
Baseline	89	3.68	0.85
Normal play	102	3.50	0.93
Still face	98	3.38	0.96
Reunion	95	3.44	0.95
Mother			
Baseline	105	5.63	1.24
Normal play	116	5.79	1.24
Still face	115	5.95	1.24
Reunion	118	5.53	1.12

Model Specification

In order to examine infants' and mothers' change in RSA across the FFSFP, a general linear mixed model with repeated measures approach was used. Models were estimated using the PROC MIXED procedure in SAS Version 9.1. This data analytic method handles repeated measures efficiently by modeling the covariance structure (Little & Rubin, 1987) and is recommended by methodologists as an appropriate way to accommodate missing data (Schafer & Graham, 2002). Restricted maximum likelihood was used in reporting model parameters, and degrees of freedom were estimated using the between-within method. The dependent variable was RSA for infants or for mothers across the FFSFP (separate models were conducted for infants and mothers as their RSA values were uncorrelated) with episode as the within-subjects factor (baseline, normal play, still face, and reunion). Because change in RSA from baseline was the factor of interest, a reference cell coding was employed such that the first sampling occasion/ intercept represented the baseline estimate and all other episodes (normal play, still face, and reunion) represented change from baseline RSA.

Table 2

Mean Respiratory Sinus Arrhythmia (RSA) Across the FFSFP for African American and European American Infants

	N	*M*	*SD*	*N*	*M*	*SD*
	African American			European American		
RSA episode baseline	47	3.75	0.9	42	3.59	0.81
RSA episode normal play	55	3.66	0.95	47	3.34	0.88
RSA episode still face	53	3.55	0.94	45	3.17	0.93
RSA episode reunion	50	3.65	0.97	45	3.21	0.89

Two models (an infant RSA model and mother RSA model) were examined. The models included the intercept (baseline), demographic variables, FFSFP episode (normal play, still face, and reunion), centered maternal sensitivity (Aiken & West, 1991), and the interaction of FFSFP Episodes x Maternal Sensitivity (terms multiplied) as predictors of infant RSA and mother RSA. Given the stratification of the sample, demographic control variables included both income group and ethnic group. Infant sex was included to test for possible sex differences in RSA. Because infants' negative affect was correlated with mothers' RSA during the reunion episode, infants' negative affect was initially included in the model of mothers' change in RSA across the FFSFP. There were no differences in results for the model that included infant negative affect and the one that did not; therefore, results were reported for the more parsimonious model, to retain data. Binary variables were coded as 0 and 1 to ease interpretation: Ethnicity was coded as 0 for African Americans and 1 for European Americans, sex was coded as 0 for boys and 1 for girls, and income was coded as 0 for below poverty group and 1 for above poverty group. Thus, estimates obtained for these variables are interpreted for the group coded as 1.

Infants' Change in RSA Across the FFSFP

There was a main effect for ethnicity with European American infants having lower levels of RSA across the FFSFP than African American infants (see Table 2). For all infants, RSA decreased from baseline to the still-face episode, consistent with earlier research (see Table 3). There was no main effect for maternal sensitivity. There was a Maternal Sensitivity x FFSFP Episode interaction (see Table 3). Mean values of infants' RSA across baseline and each episode of the FFSFP are shown for the sample mean and for terciles of maternal sensitivity in Figure 1. Follow-up probing of the Maternal Sensitivity x Episode interaction revealed that change in infants' RSA from baseline to the reunion episode was significant at 1 SD above on maternal sensitivity, $t(260) = —2.70$, $p < .01$. Contrary to prediction, the change was a decrease in RSA from baseline to the reunion episode only for infants who had mothers highest in sensitivity (see Figure 2). Thus, infants' change in RSA from baseline to the reunion episode of the FFSFP was moderated by mothers' sensitivity.

Mothers' Change in RSA Across the FFSFP

There were no effects for demographic variables. RSA changed from baseline to the still-face episode (see Table 4). On average, as indicated by mean values in Table 1 and seen in Figure 1, mothers showed a reverse pattern compared to infants, with an increase in RSA from baseline to the still-face episode, consistent with previous studies, as seen in Table 4. There was no main effect for maternal sensitivity. Parallel to the infant model, there was a Maternal Sensitivity x Episode interaction (see Table 4). Mean values of mothers' RSA across baseline and each episode of the FFSFP are shown for the sample mean and for terciles of maternal sensitivity in Figure 1. Follow-up probing of the Sensitivity x Episode interaction revealed that change in mothers' RSA from baseline to the reunion episode was significant at 1 SD above on maternal sensitivity, $t(260) = —2.50$, $p < .05$. As predicted, this change was a decrease in RSA from baseline to reunion only for mothers who were highest in sensitivity (see Figure 3). Thus, mothers' change in RSA from baseline to the reunion episode was moderated by maternal sensitivity.

Dyadic Behavioral Synchrony

As predicted, higher dyadic behavioral synchrony, based on the correlation between mother–infant behavioral states of social engagement in the normal play episode, $r(108) = -.20$, $p < .05$, and in the reunion episode, $r(104) = -.20$, $p < .05$, were correlated with lower levels of mothers' RSA in the reunion episode, suggesting that in dyads that were more behaviorally synchronous, mothers showed lower RSA in the reunion episode. There were no significant relations between dyadic behavioral synchrony and infants' RSA.

Table 3

Change in Respiratory Sinus Arrhythmia in Infants as a Function of the Still-Face Procedure and Maternal Sensitivity

	Fixed effects					
	Coefficient	*SE*	*T*	*df*	*p*	*d*
Intercept baseline	3.839	0.17	23.19	115	**.00**	4.32
Gender	−0.0661	0.15	−0.43	115	.67	
Race	−0.3229	0.16	−2.02	115	**.05**	0.38
Poverty	−0.1012	0.18	−0.57	115	.57	
Normal play	−0.0635	0.07	−0.86	258	.39	
Still face	−0.1891	0.07	−2.55	258	**.01**	0.32
Reunion	−0.1223	0.08	−1.63	258	.11	
Material sensitivity	0.0269	0.02	1.08	115	.28	
Sensitivity × Normal	−0.0276	0.02	−1.49	258	.14	
Sensitivity × Still Face	−0.0172	0.02	−0.93	258	.36	
Sensitivity × Reunion	−0.0519	0.02	−2.69	258	**.01**	
	Random effects					
	Coefficient	*SE*	*Z*	*p*	*d*	
Intercept	0.6159	0.09	6.69	**.00**	0.83	

Post Hoc Analyses

To explore factors that could help explain the unexpected finding that infants of highly sensitive mothers showed greater RSA withdrawal in the reunion episode, we examined additional models of change in infants' responses across the FFSFP. Based on research finding that infants of depressed mothers became less distressed by mothers' still face (Field, 1984), we reasoned that infants of highly sensitive mothers might have become more physiologically aroused (showed shorter HP) and behaviorally distressed (showed greater negative affect) in response to mothers' still face than other infants and that this could have carried over into the reunion episode explaining their greater RSA withdrawal. Also, infants of highly sensitive mothers may have been more likely to use behaviors to signal their affective states to their mothers to elicit mothers' support. Because RSA withdrawal is thought to support active coping behaviors, greater behavioral expressivity could also explain greater RSA withdrawal for infants of highly sensitive mothers. Therefore, we examined three additional models: change in infants' HP from baseline across the FFSFP and change in infants' negative and positive affect from normal play across the FFSFP. Demographic variables were added as specified above for the model of infants' RSA.

Consistent with the model for infants' RSA and with the correlation between RSA and HP, there was a decrease in HP from baseline to the still-face episode, $t(260) = -6.58$, $p < .001$, and from baseline to reunion, $t(260) = -5.47$, $p < .001$, for all infants. There was a nonsignificant trend for maternal sensitivity in the direction of infants of more sensitive mothers having greater HP, $t(114) = 1.83$, $p = .07$, suggesting lower arousal. Consistent with the well-documented behavioral still-face effect, infants' negative affect increased from normal play to the still face, $t(276) = 5.95$, $p < .001$, and reunion, $t(278) = 9.01$, $p < .001$, episodes, and positive affect decreased from normal play to the still-face episode, $t(290) = -10.49$, $p < .001$. There were no effects for maternal sensitivity on infants' negative or positive affect. There were no effects for ethnicity, income, or infant sex for HP, negative, or positive affect.

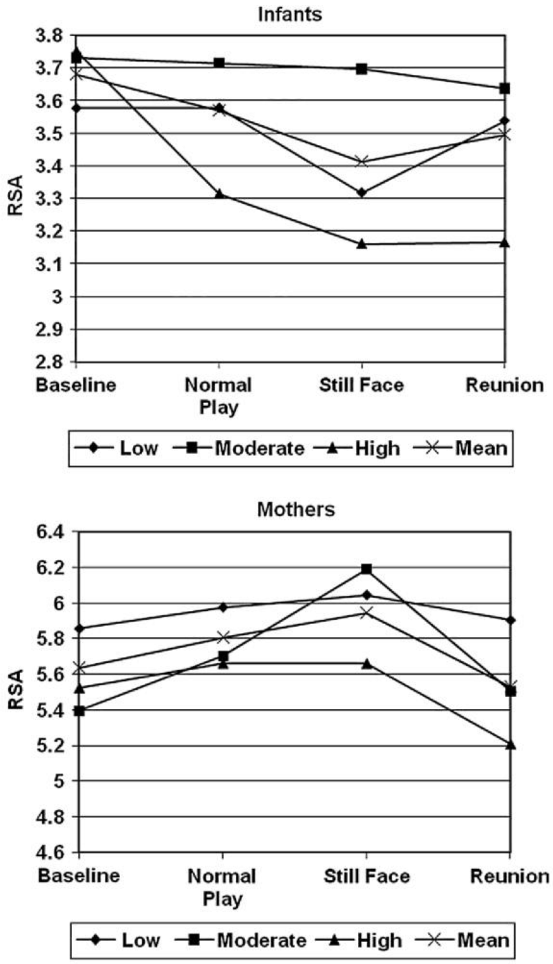

Figure 1. Infants' and mothers' respiratory sinus arrhythmia (RSA) across the Face-to-Face Still-Face Paradigm by level of maternal sensitivity.

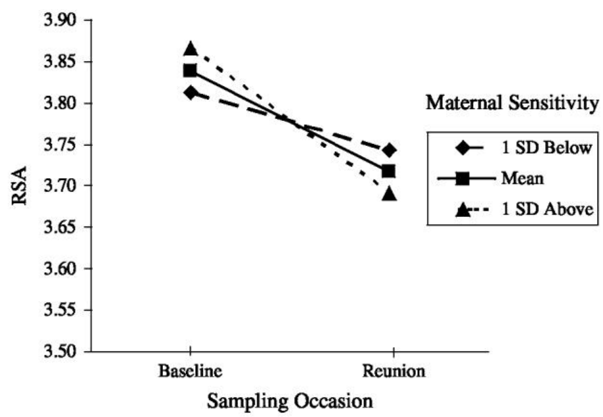

Figure 2. Maternal sensitivity moderates change in infants' respiratory sinus arrhythmia (RSA) from baseline to reunion.

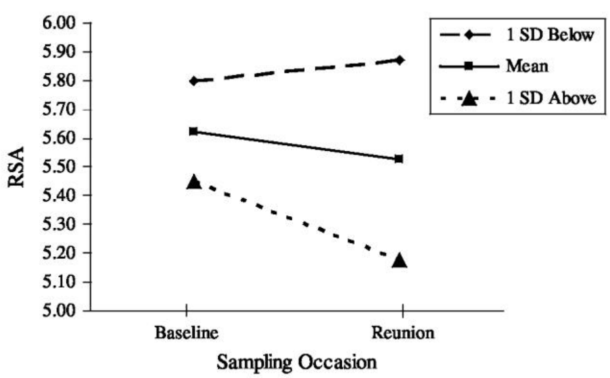

Figure 3. Maternal sensitivity moderates change in mothers' respiratory sinus arrhythmia (RSA) from baseline to reunion.

Table 4
Change in Respiratory Sinus Arrhythmia in Mothers as a Function of the Still-Face Procedure and Maternal Sensitivity

	Fixed effects					
	Coefficient	*SE*	*T*	*df*	*p*	*d*
Intercept baseline	5.62	0.21	27.10	119	**.00**	4.97
Gender	−0.05	0.19	−0.27	119	.79	
Race	0.08	0.19	0.42	119	.67	
Poverty	0.00	0.21	0.01	119	.99	
Normal play	0.16	0.09	1.73	324	.09	
Still face	0.32	0.09	3.56	324	**.00**	0.40
Reunion	−0.09	0.09	−1.06	324	.29	
Material sensitivity	−0.04	0.03	−1.23	119	.22	
Sensitivity × Normal	−0.01	0.02	−0.28	324	.78	
Sensitivity × Still Face	−0.01	0.02	−0.58	324	.56	
Sensitivity × Reunion	−0.05	0.02	−2.19	324	**.03**	0.24
	Random effects					
	Coefficient	*SE*	*Z*		*p*	*d*
Intercept	0.97	0.14	6.87		**.00**	0.76

Discussion

To understand how parent–infant interaction may facilitate the development of infants' physiological regulation, the present study examined mothers' and infants' vagal regulation, indexed in this study by change in RSA, across the FFSFP, an experimental procedure that provides an ideal context for examining changes in

RSA that occur with social engagement and disengagement. A second goal was to examine the role that maternal sensitivity played in mothers' and infants' vagal regulation.

As in previous studies (Bazhenova et al., 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996), infants typically showed a decrease in RSA from baseline (i.e., RSA withdrawal) during the still-face episode. Mothers, as predicted, showed the opposite pattern, increasing RSA during the still-face episode. These findings fit the polyvagal theory of social engagement (Porges, 2007). When mothers disengaged from active social interaction, their RSA increased. Infants, on the other hand, were faced with eliciting social interaction and regulating any distress they may have experienced without mothers' assistance. Vagal tone is typically inhibited (withdrawn) when environmental demands require a person to actively engage with the environment or engage in coping behaviors. When mothers resumed interacting with their infants, infants returned to baseline levels of RSA, presumably because mothers once again became more active in structuring the interaction and helping infants to organize their behavior. It is noteworthy that the same pattern of vagal regulation across the FFSFP for mothers and infants was found in this economically diverse sample as has been found in prior research on middle-class samples (e.g., Bazhenova et al., 2001; Ham & Tronick, 2006; Moore & Calkins, 2004; Weinberg & Tronick, 1996).

Contrary to prediction, infants of the most sensitive mothers did not follow this pattern. Instead, they showed lower RSA in the reunion episode than other infants, continuing to show a significant decrease from baseline. Highly sensitive mothers, as expected, showed lower RSA during the reunion episode than other mothers, consistent with the demands of the situation for them to support the reestablishment of social engagement with their infants and to assist their infants with regulating any distress they may have felt from the disruption in their play.

One possibility was that infants of sensitive mothers were more aroused and distressed by mothers' disengagement and that carried over into the reunion episode, leading to lower RSA. Analyses of physiological and behavioral signs of arousal and distress did not support this explanation; in fact, there was a trend for infants of sensitive mothers to show greater HP throughout the entire FFSFP, suggesting they were less physiologically aroused than other infants. Another possibility was that infants of sensitive mothers were more likely than other infants to show spontaneous behaviors to elicit their mothers' attention and that their lower RSA may have supported these behaviors. But infants of sensitive mothers did not show greater amounts of negative or positive affect than other infants in any episode of the FFSFP.

However, we found that a greater decrease in mothers' RSA was associated with a higher level of behavioral dyadic synchrony in both normal play and reunion episodes, suggesting that sensitive mothers and their infants were more mutually responsive to each other even though affective valence did not differ. Because mutual responsiveness indicates an active role by both mother and infant in initiating and responding to behaviors, the polyvagal theory would predict a decrease in vagal tone to facilitate this greater level of engagement. Consistent with the conclusion of Bazhenova et al. (2001), decreased RSA is likely to reflect increased metabolic demand that is not uniquely associated with negative affect. Thus, we propose that, taken together, our findings regarding change in RSA and behavioral synchrony suggest that sensitive mothers and infants of sensitive mothers were equally active and engaged in cocreating a mutually responsive social interaction and that this was reflected in the consistent direction of change in RSA (a decrease) and the association between that change for mothers and dyadic behavioral synchrony.

Although sensitive mothers and infants of sensitive mothers, on average, showed the same direction of change in RSA (a decrease) during the reunion episode, whereas the typical pattern that has been found in prior research is for mothers and infants to show the opposite direction of change, it is important to note that findings regarding change in RSA were based on analyses conducted separately for mothers and infants. We were unable, due to missing data, to examine whether mother –infant physiological responses were more highly correlated for dyads within the highly sensitive group of mothers. Furthermore, it is possible for mothers and infants to show opposite patterns of change, on average, and to still show physiological synchrony within dyads, although in that case, there would be a negative correlation between mothers' and infants' physiological responses.

Thus, we do not believe that our findings indicate that physiological synchrony was a function of maternal sensitivity. Furthermore, we do not propose that physiological synchrony necessarily denotes a better interaction. For example, a distressed infant may show high levels of physiological arousal and vagal reactivity. A mother who responds with moderate arousal and reactivity may be better able to respond actively, flexibly, and sensitively to the infant. This would, presumably, be observed as a lack of physiological synchrony. Other research, however, supports the conclusion that dyadic physiological synchrony is related to better outcomes. Ham and Tronick (2006) suggested that dyads that are most physiologically synchronous may also be the most behaviorally synchronous and physiological synchrony between mothers and infants has been found to be related to secure attachment, which, of note, was also related to behavioral and physiological concordance in infants (Zelenko et al., 2005). Examining synchrony between and among mothers' and infants' behavioral and physiological responses is an important direction for future research. To explore these constructs, measures and methods that take into account and are sensitive to temporal, dynamic, and dyadic qualities of the interaction would need to be employed. For example, when infants are negative and mothers smile in response, what responses do infants exhibit next both behaviorally and physiologically?

Our assumption in undertaking the current research was that experience in social interaction shapes the development of infants' capacities to effectively regulate engagement with the environment, whether that engagement is within social or nonsocial contexts. That infants of highly sensitive mothers showed a greater decrease in RSA in the reunion episode is consistent with findings from our research group with 12-month-old infants, in which maternal sensitivity predicted a developmental increase between 6 and 12 months in RSA withdrawal (i.e., decrease in RSA from baseline) for infants carrying a genetic risk allele associated with behavioral regulatory disorders in adolescents and adults (Propper et al., 2008). Together our findings suggest that sensitive parenting may have an effect on concurrent functioning of and change over time in infants' physiological self-regulation, particularly in response to challenges of social interaction. This could have important effects on children's family relationships and, later, peer relationships and the transition to school where they are required to interact with a number of new adults and children. It may also affect the development of attention and cognitive skills to the extent that they are associated with effective physiological regulation.

Another finding was that African American infants showed higher levels of RSA at baseline and across the FFSFP than European American infants. This same pattern was found in another large sample of African American and European American infants, with African American infants showing higher baseline RSA and higher levels of RSA during testing using the Bayley Scales of Infant Development at 7 and 15 months of age (C. Stifter, personal communication, July 22, 2007) and thus was not sample specific. Nor are ethnic differences specific to vagal tone. Salivary α-amylase, an enzyme produced by salivary glands and a relatively new measure of individual differences in sympathetic stress reactivity in infants (Granger et al., 2006), was found to be higher in African American infants at 5, 10, and 12 months than European American infants (Granger et al., 2007; Hill-Soderlund et al., 2008).

Higher salivary α-amylase is associated with a stress reaction considered to be an appropriate response to challenge in the environment and higher levels of basal RSA are typically associated with greater reactivity to environmental stimulation. Together these results suggest greater levels of stress in African American infants but also may suggest a more responsive, attentive, and reactive disposition, perhaps representing a better preparedness for challenge (Beauchaine, 2001). The findings could relate to evidence that higher basal RSA in early infancy has been found to be associated with higher reactivity, expressivity, and difficult temperament (Porges et al., 1994; Stifter & Fox, 1990; Stifter, Fox, & Porges, 1989). However, a normative developmental shift appears to occur for infants with high basal RSA who, as toddlers, have been found to be higher in sociability and positive affect (Porges et al., 1994). Researchers have proposed that environmental experiences are likely to be instrumental in determining whether infants with high basal RSA develop effective self-regulatory ability or take a path to stability in negative reactivity (e.g., Calkins, 1994; Fox, Schmidt, Henderson,

& Marshall, 2007). It may also be that sympathetic (e.g., salivary α-amylase) and parasympathetic (e.g., RSA) measures interact and/or interact with environmental experiences to contribute to developmental outcomes in self-regulation.

Although understanding ethnic similarities and differences may be an important direction for future research, individual variability within ethnic groups should not be overlooked. In adults, there are distinct individual differences in reactivity; some individuals respond with parasympathetic activation, some with sympathetic activation, and others with activation of both systems (Berntson & Cacioppo, 2007). Therefore, an important direction for future research is to examine individual differences in patterns of behavioral and physiological responses across the FFSFP or other challenge tasks and to examine these patterns in relation to parenting and various relevant environmental experiences. Little previous research has taken this approach.

Stifter and Jain (1996) categorized infants in terms of behaviors that indicated reactivity/distress and behaviors indicating regulation. Infants who reacted with distress to frustration but who also displayed high levels of regulatory behaviors had higher RSA. Ham and Tronick (2006) identified four patterns of reactivity based on combined behavioral and physiological responses to the FFSFP and found that infants who failed to show RSA withdrawal in response to the still-face but who also did not show behavioral signs of distress were the most positive and engaged with their mothers during the reunion episode, emphasizing the point that a lack of RSA withdrawal in response to a presumably challenging context may not necessarily indicate ineffective regulation and that it is important to take both physiological and behavioral responses into account.

In future research, incorporating different types of functional behaviors (reactive and regulatory) and different types of physiological measures that index sympathetic and parasympathetic functioning, and measuring both mothers' and infants' responses would be a compelling way to assess the development of infants' self-regulation in the context of parent – infant interaction. The tendency of researchers to interpret RSA withdrawal in response to challenge as a marker of effective regulation and to equate it with desirable developmental outcomes is clearly too simplistic a view. To move beyond this perspective requires incorporating multimeasure approaches.

Methods for measuring dyadic processes should be expanded in future research. In the current study, measures were primarily at a global level of individual functioning (e.g., mean levels of RSA and total percentages of negative affect during episodes). An exception was the measure of dyadic behavioral synchrony, which assessed the degree to which mothers' and infants' states of social engagement were correlated second-by-second across time. In particular, measures that instantiate temporal and dyadic processes that occur across parent–infant interaction are likely to be more informative than global measures of individual partners' responses.
Future longitudinal research is critical to understanding how environmental experiences affect the development of infants' physiological regulation. Although we did not find effects of income on mothers' or infants' physiological responses, it is possible that, over time, living in an impoverished environment could have a differential impact on infants' vagal regulation and could moderate the relation between maternal sensitivity and developmental outcomes in this domain.

There were various limitations of the current research. First, expected difficulties associated with obtaining valid cardiac data from young infants and unexpected technical problems resulted in a considerable amount of missing data for infants and mothers. There may have been insufficient power to detect interaction effects between maternal sensitivity and HP, negative, and positive affect, which could affect our understanding of why infants of sensitive mothers continued to show low RSA in the reunion episode. In addition, the amount of missing physiological data precluded our ability to conduct more extensive within-dyad analyses, which may have provided a stronger test of mother – infant physiological synchrony in relation to maternal sensitivity. Second, we examined only parasympathetic reactivity. Although we did examine HP to better understand results, HP is correlated with RSA and is not independent of parasympathetic influences. Thus, we are limited in drawing firm conclusions about what it means that infants of sensitive mothers showed the greatest decrease in RSA in the reunion episode. Furthermore, no causal direction is implied. Sensitive mothers may appear sensitive because of the behavioral reactivity and responses of their infants, which may be related to their physiological responses.

In summary, the 1st year of life is an important time for the development of infants' behavioral and physiological self-regulation. Parents may shape this development through their help in alleviating negative emotions, reinforcing positive ones, and structuring the social interactions in which infants practice and eventually consolidate their self-regulatory capacity. Findings regarding the role of maternal sensitivity in mother – infant vagal regulation extend our understanding of the impact that parenting may have on emerging physiological processes that provide a foundation for positive social-emotional and cognitive outcomes.

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