Infants' Vagal Regulation in the Still-Face Paradigm Is Related to Dyadic Coordination of Mother–Infant Interaction

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Abstract:

The authors investigated relations between mother–infant dyadic coordination and infants' physiological responses. Mothers (N = 73) and 3-month-old male and female infants were observed in the still-face paradigm, and mothers' and infants' affective states were coded at 1-s intervals. Synchrony and levels of matching between mother–infant affective states were computed, and infants' heart rate and vagal tone were measured. Infants showed increased negative affect and heart rate and decreased vagal tone during mothers' still-face, indicating physiological regulation of distress. Infants who did not suppress vagal tone during the still-face (nonsuppressors) showed less positive affect, higher reactivity and vagal suppression in normal play and reunion episodes, and lower synchrony in normal play with mothers. The results indicate that infants' physiological regulation in social interaction differs in relation to dyadic coordination of affective behaviors.

Article:

The development of behavioral and physiological systems to regulate emotion occurs rapidly in early infancy and is dependent on experience and, most important, experience in social interactions with parents (Calkins, 1994; Gunnar & Donzella, 2002; Schore, 2000; Tronick, 1989). Initially, infants rely on their parents' responsiveness to their affective signals for the regulation of emotion (Tronick, 1989), including help in regulating physiological arousal related to behavioral organization (e.g., Spangler & Grossman, 1993; Spangler, Schiechle, Ilg, Maier, & Ackermann, 1994).

Research using microanalytic measures of parents' and infants' affective behaviors in face-to-face interaction has revealed specific mechanisms that may explain how parents' behaviors support infants' regulation of emotion. In general, this research has found that infants respond contingently to the temporal structure and affective valence of early face-to-face interactions and parents coordinate face-to-face interactions with their infants to maintain mutually positive exchanges (Cohn & Tronick, 1987, 1988; Feldman, Greenbaum, & Yirmiya, 1999; Tronick & Cohn, 1989; Weinberg, Tronick, Cohn, & Olson, 1999). Specific processes of synchrony and matching affect have been identified as essential aspects of mutual regulation of emotion during parent–infant interaction. Both processes refer to the degree of coordination that occurs between parents' and infants' affective behaviors and both incorporate temporal information, but the two processes differ in the role that type of affective expression (e.g., positive, negative) plays.

Synchrony has been defined as the degree to which parents and infants change their affective expressions consistently together across time without regard for the type of expression that either partner is showing. For example, mothers typically are more positive than their infants across the course of an interaction but may modulate their positive affect, becoming more or less positive in response to change in their infants' affect. *Matching affect*, in contrast, has been defined as a parent and an infant being in the same affective state at the same time (Feldman et al., 1999; Tronick & Cohn, 1989; Weinberg et al., 1999). To date, whether the two processes describe distinct or similar functional aspects of mother–infant interaction has not been researched.

These qualities of dyadic coordination have been found to change with development, to differ for mother–son and mother– daughter dyads, and to differ between depressed and nondepressed mother–infant dyads. In one study, the percentage of time that mothers and infants spent in matched affective states increased between 3 and 6 months of age, suggesting a more coordinated and better-regulated interaction with development (Tronick & Cohn, 1989). In terms of synchrony, at 6 months but not at 3 months, mother–son dyads showed higher rates of synchrony than mother– daughter dyads (Tronick & Cohn, 1989; Weinberg et al., 1999). Because in that research male infants appeared to be more behaviorally distressed by mothers' still-face, the authors interpreted these findings to mean that male infants required more assistance in regulating emotion than female infants, therefore mothers synchronized their expressions with male infants to a greater degree. However, given that there have been mixed findings about sex differences in prior research on infants' responses to mothers' still-face, the role that infant sex plays in moderating dyadic synchrony is unclear.

Research from the literature on parental depression has identified dyadic coordination as an aspect of parent–infant interaction that is highly likely to be disrupted by depression. Field, Healy, Goldstein, and Guthertz (1990) found that mothers with high levels of depressive symptoms matched their infants' affective states less frequently than other mothers. When they did, they matched infants' negative affect more often and infants' positive affect less often, suggesting less mutually positive coordination. Similarly, during structured normal play interactions, depressed mothers were more negative and their babies were less positive compared with nondepressed mother–infant dyads, and infants' lower levels of positive affect were the result of reduced contingent responsiveness (Cohn, Campbell, Matias, & Hopkins, 1990).

Coordination of mother–infant vocal interaction has also been found to be affected by depression. Zlochower and Cohn (1996) found that mothers' contingent vocal responses to 4-month-old infants' vocalizations were delayed and more variable in clinically depressed mothers relative to nondepressed mothers and argued that because individuals are largely unaware of processes of synchrony and matching in social interaction, they have a harder time deliberately managing or changing those processes. In support of this, mothers with a lifetime history of depression, regardless of current clinical status, were found to be less synchronous in face-to-face interaction with their infants (Cohn, Schwartz, Allen, & Lewinsohn, 2003). Cohn et al. proposed that processes of interactive synchrony may have become established behavior patterns that did not change when episodes of depression remitted.

Developmental, infant sex, and parental depression differences in synchrony and matched affect suggest that these qualities of dyadic coordination may be correlated with other individual differences in child development. To date, relatively little research exists on the correlates of synchrony and matching affect during parent–infant interaction. One longitudinal study found that mothers who synchronized their affective expressions with their 6-month-old infants' expressions to a greater degree than other mothers had children who showed higher levels of self-control at 2 years of age (Feldman et al., 1999). Dyadic coordination in early mother–infant vocal interactions has been found to distinguish securely and insecurely attached infants (Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001). Together, these findings suggest that effective dyadic coordination in mother–infant interaction predicts more positive outcomes for children's self-regulation of emotion. Effective or optimal levels of synchrony and matching affect are still being investigated. Research findings are converging on the theory that moderate, rather than high or low, levels of dyadic coordination in mother–infant interactions during early infancy are associated with more optimal outcomes in the quality of mother– infant relationships (Jaffe et al., 2001; Malatesta, Culver, RichTesman, & Shepard, 1989; Moore, Cohn, & Campbell, 2004).

An important question is whether the processes of synchrony and matching affect support infants' physiological regulation during social interaction in the same way that they appear to support infants' behavioral regulation. The current study addressed this question by investigating relations between dyadic synchrony and matched affect and infants' behavioral and physiological regulation during the still-face paradigm (SFP; Tronick et al., 1978).

Developmental researchers have used the SFP extensively to assess parents' and infants' behaviors that reflect mutual regulation of emotion in social interaction. In this procedure, parents are first asked to engage in normal face-to-face play interactions with their infants and are then asked to become unresponsive to their infants for a brief period of time by maintaining a still face. A reunion episode follows, during which parents resume normal interaction. When a parent becomes still-faced, infants from 2 to 9 months of age respond with a predictable and rich set of behavioral responses, including decreased positive and increased negative affect; brief attempts to elicit adults' attention by smiling; and an increase in self-soothing behaviors, such as thumb-sucking (Moore, Cohn, & Campbell, 2001; Tronick et al., 1978; Weinberg & Tronick, 1994). The still-face episode of the procedure presents infants with a mildly stressful social situation that appears to amplify individual differences in emotionality, especially in the tendency to become distressed (Moore et al., 2001; Tronick et al., 1978). In the reunion episode, parents and their infants are faced with the task of restoring previous levels of mutually positive interaction, and that task may highlight individual differences in dyadic coordination and parental support of infants' emotion regulation.

INFANTS' PHYSIOLOGICAL RESPONSES IN THE STILL-FACE PARADIGM

In contrast to the extensive body of research on infants' behavioral responses in the SFP, we are aware of only four published studies that have assessed infants' physiological responses in the SFP (Bazhenova, Plonskaia, & Porges, 2001; Haley & Stansbury, 2003; Stoller & Field, 1982; Weinberg & Tronick, 1996). All four studies assessed infants between ages 5 and 6 months of age. Three of these studies examined mother–infant interaction (Haley & Stansbury, 2003; Stoller & Field, 1982; Weinberg & Tronick, 1996); the fourth used a stranger–infant interaction (Bazhenova et al., 2001). Haley and Stansbury (2003) modified the traditional SFP by adding a second still-face and reunion episode to increase the stressfulness of the procedure. Two studies examined physiological regulation of emotion by assessing vagal tone across episodes of the SFP

(Bazhenova et al., 2001; Weinberg & Tronick, 1996), whereas the most recent study (Haley & Stansbury, 2003) and the earliest study (Stoller & Field, 1982) examined only heart rate.

Heart rate and vagal tone are orthogonal measures of cardiac activity. Heart rate reflects degree of physiological arousal. Vagal tone reflects neural regulation of the heart, via the vagus nerve, and is measured in terms of respiratory sinus arrhythmia (RSA), an index of cardiac activity related to respiratory function and mediated by the parasympathetic nervous system. Because individuals can show increased heart rate without showing an accompanying suppression of vagal tone, assessing vagal tone in an investigation of infants' physiological responses to the SFP provides important information about physiological regulation that is unavailable from measures of heart rate alone.

Suppression of RSA is thought to support behaviors indicative of active coping (Porges, 1991, 1996; Wilson & Gottman, 1996); therefore increased suppression of RSA is expected during a stressful condition such as the still-face. A deficit in the ability to suppress RSA may be related to a lack of behavioral and emotional control (Porges, 1996; Wilson & Gottman, 1996). Recent research with infants indicates that greater suppression of RSA during challenging situations is related to better state regulation, greater self-soothing, more attentional control, and greater capacity for social engagement (Calkins, 1997; DeGangi, DiPietro, Porges, & Greenspan, 1991; Huffman et al., 1998; Stifter & Corey, 2001).

The two aforementioned studies that assessed vagal tone (Bazhenova et al., 2001; Weinberg & Tronick, 1996) identified a characteristic pattern of vagal regulation across the SFP. Five- and 6-month-old infants showed a decrease in heart period (HP), indicating an increase in heart rate and suggesting stress, and a decrease in RSA during the still-face relative to baseline levels, indicating a suppression of RSA to promote coping and self- soothing behaviors. During the reunion episode, HP and RSA returned to baseline levels (Bazhenova et al., 2001; Weinberg & Tronick, 1996). This up-and-down pattern of vagal regulation may reflect infants' increased need for emotion regulation in response to social disengagement and supports theories that infants rely on parental support to regulate emotion.

Weinberg and Tronick (1996) found that although physiological responses returned to initial levels in the reunion episode, infants continued to show distress behaviorally and showed higher levels of positive affect than in normal play, consistent with other research suggesting that in infancy autonomic and behavioral measures are loosely coupled (e.g., Gunnar, Mangelsdorf, Larson, & Hertsgaard, 1989). However, interpretations by Weinberg and Tronick (1996) were based on findings regarding mean levels of behavioral and physiological responses. From an individual differences perspective, Bazhenova et al. (2001) showed that changes in behavioral and physiological responses across the episodes of the SFP were correlated, suggesting that the two domains were linked. Consistent with this explanation, Haley and Stansbury (2003) found that infants' behavioral and physiological responses were correlated in their second still-face and reunion episodes but not in the first still-face and reunion episodes, suggesting that under higher conditions of stress, infants' behavioral and physiological systems were coordinated.

Bazhenova and colleagues (2001), using a modified stranger– infant SFP with a toy interaction prior to the stranger's still-face, identified a group of infants who did not follow the sample average pattern of vagal regulation across the SFP. Those infants did not show the expected suppression of RSA in the still-face episode. In addition, infants in the nonsuppressor group continued to show high levels of negative affect in the reunion episode following the still-face, whereas infants who followed the average pattern of vagal regulation and did suppress RSA during the still-face returned to prior levels of low negative affect. The authors did not speculate on the source of individual differences in infants' vagal regulation. There may be innate individual differences in autonomic functioning (Calkins, 1994; Stifter & Fox, 1991). Alternatively, individual differences in infants' physiological responses could be related to maternal behavior or to infants' expectations of maternal behavior, just as individual differences in behavioral responses have been found to be (e.g., Cohn & Elmore, 1988; Field, 1984; Kogan & Carter, 1996; Weinberg et al., 1999).

Two of the four studies that examined infants' physiological responses in the SFP reported relations between maternal behavior and infants' heart rate (Haley & Stansbury, 2003; Stoller & Field, 1982). Stoller and Field (1982) examined infants' behavioral responses and heart rate 5 s prior to mothers' still-face and during the first 10 s of mothers' still-face. Crying, gaze aversion, and negative facial expressions in the first 10 s of the still-face were related to increases in heart rate, whereas smiling was related to decreases in heart rate. Infants who showed congruent behavioral and physiological distress responses during the first 10 s of the still-face had mothers who smiled at their infants and stimulated them physically more frequently in the normal play interaction prior to the still-face episode than mothers of infants who showed distress to the still-face primarily in terms of physiological responses. One interpretation of these findings is that infants who signaled their mothers with negative affective expressions when they were physiologically aroused had learned that their mothers would be responsive to their affective expressions.

Consistent with these findings, Haley and Stansbury (2003) found that infants of mothers categorized as more responsive, on the basis of timing of their contingency to infants' behaviors during normal play and the first of the two reunion episodes presented in the modified SFP, showed less negative affect and lower heart rate during the second reunion episode. Of note, these differences were not evident in the first still-face and reunion episodes, suggesting that higher conditions of stress were needed to elicit individual differences based on maternal contingent responsiveness.

As discussed above, depressed mothers are likely to show lower levels of responsiveness and coordination when interacting with their infants (Cohn et al., 1990, 2003; Field et al., 1990; Zlochower & Cohn, 1996). Thus, some infants may be unable to rely on parental support for help in regulating emotion, and this may have an effect on their developing systems of self-regulation. Research finding that infants of nondepressed mothers showed a developmental increase in vagal tone between 3 and 6 months whereas infants of depressed mothers did not (Field, Pickens, Fox, & Nawrocki, 1995) suggests that interacting with a depressed mother may inhibit the development of effective emotion regulation and lends further support to theories about the importance of parents' scaffolding of infants' emotion regulation.

Continued study of the relations between dyadic coordination of parent–infant affective behaviors and infants' physiological responses in the SFP promises to extend our understanding of parents' vital role in the rapid emergence of emotion regulation systems in the first months of life. The current study was the first, of which we are aware, to report relations between qualities of mother–infant dyadic coordination and infants' vagal regulation in the SFP.

AIMS OF THE CURRENT STUDY

The overall goal of the current study was to examine relations between dyadic coordination in mother–infant interaction and infants' physiological responses to the SFP. We formulated a number of aims to address this goal. First, we aimed to replicate prior findings on characteristic patterns of vagal regulation across the SFP in a younger group of infants, extending previous research on 5- and 6-month-old infants' vagal regulation in the SFP to 3-month-old infants. Research from a behavioral perspective found that 3-month-old infants' affective behaviors were closely related to the organization of their mothers' behaviors (Cohn & Elmore, 1988), whereas by 6 months of age, infants became more independent in structuring interactions with their mothers (Cohn & Tronick, 1987). Furthermore, differences in mother–son and mother–daughter synchrony were found in 6-month-old infants but not in 3-month-old infants (Tronick & Cohn, 1989). From a physiological perspective, longitudinal research has identified a developmental increase in vagal tone between 3 and 6 months in infants of nondepressed mothers but not in infants of depressed mothers (Field et al., 1995). Together, these findings suggest that at 3 months of age, parental influence on infants' emerging abilities to regulate emotion may be particularly acute and may be related to important developmental and individual differences in emotion regulation.

Second, we investigated individual differences in patterns of vagal regulation at a younger age than previously studied and in the context of parent–infant, rather than stranger–infant, interaction. Twelve-month-old infants' vagal regulation was found to be unrelated to social engagement with strangers (Stifter & Corey, 2001); therefore individual differences in patterns of vagal regulation could vary considerably between parent–infant and stranger–infant interactions.

Third, we examined relations between dyadic coordination of mother–infant affective behaviors and infants' physiological responses in the SFP. Dyadic synchrony and level of matched affect were measured as indices of the quality of dyadic coordination. On the basis of prior research reporting relations between mothers' behaviors and individual differences in patterns of infants' behavioral and physiological responses to mothers' still-face (Haley & Stansbury, 2003; Stoller & Field, 1982) and the large body of research on parental support of infants' behavioral regulation in response to mothers' still-face (e.g., Cohn & Elmore, 1988; Field, 1984; Kogan & Carter, 1996; Weinberg et al., 1999), we hypothesized that mean levels of, and individual differences in, infants' physiological responses in the SFP would be related to qualities of mother–infant dyadic coordination.

Fourth, the study examined whether maternal depression was related to dyadic coordination and to mean levels of and individual differences in infants' physiological responses in the SFP. Prior research on maternal depression (e.g., Cohn et al., 1990, 2003; Field, 1984; Field et al., 1990, 1995) supported our hypothesis that depression would reduce dyadic coordination. Hypotheses regarding infants' physiological responses were exploratory. On the one hand, infants of depressed mothers could show higher reactivity and less effective vagal regulation in the SFP because of a lack of adequate parental support for emotion regulation. On the other hand, because prior research has found that infants of depressed mothers were not as distressed by mothers' still-face as infants of nondepressed mothers (Field, 1984), infants of depressed mothers could show less physiological reactivity to mothers' still-face.

METHOD

Participants

Expectant mothers in their last trimesters of pregnancy were recruited from private doctors' offices, clinics, and prenatal classes in a midsize Southeastern city for a larger, longitudinal study of the development of emotion regulation. Mothers (N = 270) were given a packet including a brief description of the study, the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961), and a demographic questionnaire. All mothers who returned these materials received a gift certificate to a local business.

Expectant mothers who met screening criteria for depression (i.e., had a BDI score of 12 or greater and did not endorse suicidal ideation) and a comparable group of mothers who did not meet criteria were invited to participate in the study. Mothers who agreed to participate, delivered full-term singletons, and participated in laboratory assessments with their infants at age 3 months (n = 73) were participants in the current study. All infants (30 female and 43 male) were within normal limits for birth weight with no pre- or postnatal complications. Families were primarily middle- to upper-class and European American (81%), with 14% African American, 1% Asian American, and 4% identifying their ethnicity as "mixed." At the 3-month assessment, infants ranged in age from 10.0 to 14.5 weeks (M = 12.45, SD = 1.27) and mothers ranged in age from 18 to 41 years of age (M = 29.10, SD = 5.44).

Procedures

Maternal depressive symptoms. Mothers were mailed the BDI at 3 months postpartum and were instructed to complete and return the questionnaire at the 3-month laboratory visit. The mean BDI score was 6.9 (SD = 4.9, range = 1–25). Mothers were categorized into two groups on the basis of the severity of depressive symptoms at infants' age 3 months, a procedure used in prior research examining the effect of maternal depression on infants (e.g., Field et al., 1990; Hernandez-Reif, Field, del Pino, & Diego, 2000). Mothers who scored at least 1 standard deviation above the mean (12 and above) were categorized into the high depressive symptom group. All other mothers were categorized into the low depressive symptom group. The depressed (n = 13) and nondepressed (n = 60) groups of mothers did not differ in mothers' age, SES, education, or infant sex.

Mother–infant SFP. Mothers changed infants into a gender-neutral colored sleeper and the experimenter attached the heart rate monitoring equipment (described in more detail below). A gender-neutral sleeper was used to avoid any bias coders may have had regarding behaviors of male and female infants. Mothers placed infants into an infant seat and sat in a chair directly in front of the infants. Next, mothers were given specific instructions for each episode of the SFP (normal play, still-face, reunion). During this period, which lasted 3 min, a baseline measure of the infant's heart rate was collected. The baseline episode was designed to minimize stimulation to achieve a measure of infants' heart rate while in a neutral condition; infants were not receiving social attention from their mothers, who were attending to the experimenter, or any stimulation from toys or other objects.

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 SFP 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.

The episodes of the SFP 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." Gaze was coded as "toward" or "away." If coders were unable to see the infants' or mothers' faces (e.g., mother's face obscured the infant's, infant turned away), affect was coded as missing. Following previous research (e.g., Campbell, Cohn, & Meyers, 1995; Moore, Cohn, & Campbell, 1997, 2001), information from affect and gaze was combined to assign one of six mutually exclusive categories of behavior at each second, on the basis of behavioral descriptors specified in the Monadic Phases coding system (Tronick, Als, & Brazelton, 1980). These affective state codes were scaled across a 6-point range, from 1 (*very negatively engaged*) to 6 (*very positively engaged*).

Coding categories were labeled as follows: *high negative, low negative, look away, attend, low positive, and high positive*. For infants, *high negative* indicated negative affect with gaze away from mother. *Low negative* included negative affect with gaze toward mother. *Look away* was coded for neutral facial expressions with gaze away from mother, and attend was coded for neutral facial expressions with gaze toward mother. *Low positive* included smiles with gaze away from mother, and *high positive* included smiles with gaze toward mother. Infant interactive behaviors were coded for infants in all three episodes of the SFP.

For mothers, *high negative* included facial expressions of anger or irritation and rough or intrusive handling. *Low negative* included sad facial or neutral affect with mother's posture slumped or leaning away from baby. *Look away* and *attend* were coded as for infants. *Low positive* included simple smiles with gaze directed toward or away from baby, and *high positive* included exaggerated facial expressions of surprise or play, smiling with rhythmic vocalizations or body movements, and empathic reflections of the infant's expression. 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.

Reliability. Coders were initially trained to reliability using a large pool of videorecorded SFP interactions. To assess interobserver agreement in the current study, a second coder coded a randomly selected 15% of the interactions. Agreement was calculated as both coders observing the same behavior within 1 s of each other and quantified using kappa to correct for chance agreement. Overall, coders reliably identified affect (κ = .89 for infants, .83 for mothers) and direction of gaze (κ = .90 for infants, .85 for mothers).

Dyadic coordination. Following prior research (e.g., Tronick & Cohn, 1989), to assess qualities of dyadic coordination of mother–infant interaction, two variables were created on the basis of mothers' and infants' affective behaviors. First, to assess the synchrony of each dyad's interaction, we computed the zero-order correlation between the second-bysecond affective state codes of infants and mothers, separately for each dyad and for each of the episodes in which mothers and infants interacted (normal play and reunion). Because the affective state codes were scaled across a range of 1 to 6, the synchrony correlation coefficient provided a measure of how coordinated, without necessarily being matched, the dyad's affective states were across time. These variables (synchrony in normal play and synchrony in reunion) were transformed using Fisher's Z transformation prior to data analyses.

Second, a new variable was computed at each second of the normal play and reunion episodes indicating whether the mother and infant displayed the same type of affect (positive, neutral, negative) at that second. Then the total number of seconds across each episode in which the affective states of mother and infant matched was calculated for each dyad. Because lengths of the episodes varied (some were shortened if the infant became fussy and amounts of missing data varied), the total scores were expressed as a percentage of valid episode length.

Percentage scores of infants' and mothers' affective behaviors. Following previous research (Campbell et al., 1995; Moore et al., 1997, 2001), to determine the total amount of time during the episodes of the SFP that an infant and a mother each spent in the 6 different affective states, we aggregated the time series of the affective state codes for infants and for mothers separately. A procedure similar to that described above for computing the percentage of time that a mother and infant spent in matched affective states was used to compute percentage scores for each of the six affective state codes. The total number of seconds in which each affective state code occurred was calculated for mothers and for infants for each relevant episode of the SFP (normal play and reunion for mothers; normal play, still-face, and reunion for infants). Scores were computed as percentages of total valid interaction time.

The six percentage scores for each mother and for each infant in each episode of the SFP were combined further. Because base rates of high negative were low for infants and mothers, high negative and low negative scores were collapsed into a percentage of negative affect score for infants and for mothers. To be consistent with prior research investigating infants' physiological responses in the SFP (Bazhenova et al., 2001), we computed a measure of infant positive engagement (defined as the percentage of time that an infant spent in a nonnegative affective state with gaze toward mother) as the sum of infant attend and infant high positive. This variable was computed only for infants because mothers almost never showed negative affect or looked away from their babies; therefore, the value would have been nearly 100% for all mothers. Instead, because base rates of high positive were relatively low for mothers, the scores for high positive and low positive were collapsed into a percentage of mother positive affect score.

For the purposes of the current study, the following percentage of affective state variables were of interest: Infants' negative affect and positive engagement in normal play, still-face, and reunion episodes and mothers' negative affect and positive affect in normal play and reunion episodes.

Heart rate monitoring. The researcher placed three disposable pediatric electrodes in an inverted triangle pattern on the child's chest while the child was seated at a table next to the mother. The electrodes were connected to a preamplifier, the output of which was transmitted to a vagal tone monitor (VTM-1; Delta Biometrics, Inc., Bethesda, MD) for R-wave detection. A data file containing the heart interbeat intervals (IBIs) for the entire period of collection was transferred to a laptop computer for later artifact editing (resulting from child movement) and analysis.

The IBI data files were edited and analyzed using MXEdit software (Delta Biometrics, Inc., Bethesda, MD). Editing the files consisted of scanning the data for outlier points relative to adjacent data and replacing those points by dividing them or summing them so that they would be consistent with the surrounding data. Data files that required editing of more than 2% of the data (e.g., 12 data points in a 5-min period) were not included in the analyses. Porges's (1985) method of calculating RSA was used. This method applies an algorithm to the sequential IBI data. The algorithm uses a moving 21-point polynomial to detrend periodicities in HP slower than RSA. Then, a bandpass filter extracts the variance of HP within the frequency band of spontaneous respiration in young children (0.24–1.04). Although lower frequency bands may be studied, research with young children has consistently examined this band and identified associations to child functioning (Huffman et al., 1998; Porges, 1996; Stifter & Fox, 1991). This estimate of RSA is derived by calculating the natural log of this variance and is reported in units of ln(ms)2. HP and RSA were calculated every 30 s for the 3-min baseline period and every 15 s during each of the 2-min episodes of the SFP (normal play, still-face, reunion). These epoch durations are typical for studies of short duration tasks (Huffman et al., 1998). The mean RSA of the 15-s or 30-s epochs within each episode was used in subsequent analyses. Larger values of HP indicated slower heart rate, and larger values of RSA indicated greater vagal tone, which putatively describes a state that does not require active regulation of emotion.

Computation of change in HP and RSA. Following previous research (e.g., Calkins, 1997; Stifter & Corey, 2001), to create measures of physiological regulation, we computed difference scores in HP and RSA relative to baseline levels for each episode of the SFP. Positive values of change in HP from baseline (ΔHP) reflected a decrease in HP from baseline, suggesting increased arousal. Negative values of ΔHP indicated an increase in HP from baseline, suggesting decreased arousal. Positive values of change in RSA (ΔRSA) indicated a decrease in RSA from baseline, suggesting attempts to regulate emotion. Negative values of ΔRSA indicated an increase in RSA from baseline, suggesting a state that did not require active regulation. ΔHP and ΔRSA provided measures of the relative degree of regulation from a neutral, nonregulated state.

To confirm that infants were in a neutral state during the baseline condition, we coded the frequency of infant negative and positive affect in 5-s intervals of the 3-min baseline condition and computed them as a percentage of the length of the condition. Mean levels of negative affect

(M = .03, SD = .09) and positive affect (M = .01, SD = .05) during baseline were low. Fifty of the 73 infants (69%) were completely neutral throughout the baseline episode, 6 (8%) showed some positive affect, and 17 (23%) showed some negative affect. Of the 17 infants who showed any negative affect during baseline, 14 showed levels less than 10%, that is, less than or equal to one standard deviation above the mean. Infants were grouped into those who showed any negative affect and those who showed none so that the effects of baseline negative affect on physiological and behavioral measures could be assessed.

Missing data. Heart rate data from 8 participants were missing because of equipment malfunction due to excessive static electricity during the winter months. In addition, if the standard deviation across epochs was greater than 1.00 for RSA (indicating a high degree of variability over the course of the episode and calling into question the validity of the mean RSA value), that episode was excluded from subsequent analyses. High levels of variability typically are due to movement artifact. In all, data were available for 62 infants in the baseline and reunion episodes, 61 infants in the normal play episode, and 60 in the still-face episode. There were no differences in infant age, infant sex, or any of the behavioral measures between infants with complete physiological data and those with missing data.

RESULTS

First, preliminary analyses and correlations among infants' behavioral and physiological responses and between mothers' behavior and infants' behavioral and physiological responses are presented. Second, results of analyses replicating prior research on characteristic patterns of infants' behavioral and physiological responses across the SFP are presented. Third, results of analyses examining individual differences in patterns of RSA suppression across the SFP are presented. Fourth, analyses examining relations between dyadic coordination and infants' physiological responses in the SFP are presented. Finally, analyses examining the role of maternal depression are presented.

Preliminary Analyses

Infant sex was unrelated to infants' and mothers' behavioral variables, infants' physiological variables, dyadic synchrony, and matched affect. Therefore, infant sex was not considered in subsequent analyses.

Infants were grouped into those who showed any negative affect in the baseline condition (n = 17) and those who showed none (n = 56) so that the effects of baseline negative affect on behavioral and physiological measures could be assessed. There were no group differences in infants' or mothers' positive engagement, dyadic synchrony, or matched affect in any of the SFP episodes. There were no differences in HP and RSA during baseline between the two groups and no group differences in HP, RSA, ΔHP, or ΔRSA in any of the SFP episodes. The group of infants who displayed any negative affect in the baseline condition showed higher levels of negative affect in the normal play episode, $F(1, 72) = 12.27$, $p < .01$, and in the still-face episode, $F(1, 72) = 13.5\ 1$, $p < .0\ 1$, than infants who showed no negative affect in the baseline condition. To explore the effect that baseline negative affect might have on results, we conducted subsequent analyses of variance of infants' physiological responses in the following ways: excluding the 17 infants who showed baseline negative affect, including the 17 infants, and (c) including the 17 infants using baseline negative affect as a covariate. Results from the various methods were similar. To be conservative and to retain all data for analyses, we report results below from analyses including all infants and using baseline negative affect as a covariate.

Correlations among infants' behavioral and physiological responses. Table 1 shows correlations among infants' behavioral and physiological responses. Levels of infants' positive engagement were stable between the normal play and still-face episodes. Levels of negative affect were stable between the normal play and still-face episodes and between the still-face and reunion episodes. Positive engagement was unrelated to any of the physiological measures. Negative affect and HP were negatively correlated in the reunion episode, such that higher levels of negative affect were related to shorter HP. Negative affect and ΔHP were positively correlated in the still-face and reunion episodes, such that higher levels of negative affect were related to larger decreases in HP from baseline.

HP, RSA, ΔHP, and RSA suppression were stable across episodes. In general, measures of HP and RSA and measures of ΔHP and ΔRSA in the various episodes showed moderate positive correlation.

Correlations between maternal behaviors and infants' responses. Pearson correlation coefficients were computed between mothers' positive affect in normal play and infants' positive engagement and negative affect in each of the three episodes of the SFP and between mothers' positive affect in the reunion and infants' positive engagement and negative affect in the reunion. Of the eight correlation coefficients, mothers' positive affect in normal play was significantly related to infants' negative affect in the still-face episode ($r = -.23$, $p < .05$), and mothers' positive affect in the reunion episode was related to infants' positive engagement ($r = .42$, $p < .01$) and negative affect in the reunion episode ($r = -.38$, $p < .01$).

Pearson correlation coefficients were computed between mothers' positive affect in normal play and infants' physiological responses at baseline and in each of the three episodes of the SFP and between mothers' positive affect in the reunion, infants' physiological responses at baseline, and infants' physiological responses in the reunion. Of the twenty correlation coefficients, few were significant. Mothers' positive affect in the reunion episode was related to baseline HP ($r = .30$, $p < .05$) and HP in the reunion episode ($r = .38$, $p < .01$).

Patterns of Mothers' and Infants' Responses Across the SFP

Change in infants' and mothers' affective behaviors and dyadic coordination across the SFP. Repeated measures analyses of variance were conducted with planned contrasts among episodes and baseline negative affect as a covariate (see Table 2). As expected, infants showed higher levels of negative affect in the still-face than in the normal play episodes, $F(1, 71) = 68.83$, $p < .01$, or in the reunion episode, $F(1, 71) = 7.56$,$p <.01$. Consistent with prior research (e.g., Weinberg & Tronick, 1996), levels of negative affect were higher in the reunion than in the normal play episode, $F(1, 71) = 27.08$, $p < .01$. Infants showed lower levels of positive engagement in the still-face than in the normal play episode, $F(1, 71) = 103.54$, $p < .0 1$, or in the reunion episode, $F(1, 71) = 45.5 1$, $p < .01$. Infants showed higher levels of positive engagement in the normal play episode than in the reunion episode, $F(1, 71) = 4.62$, $p < .05$.

Table 1

Correlations Among Infants' Behavioral and Physiological Responses Across the Still-Face Paradigm

Response	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Affect—NPE	—	.43*	.14	−.05	.06	−.13	.12	.14	−.11	−.07	−.01	.07	.11	.07	−.03	−.16	.11
2. Affect—SFE	.46*	—	.41*	−.10	.03	.03	.04	−.22	−.04	−.21	−.12	.26*	.20	−.19	−.09	.13	.16
3. Affect—RE	−.12	−.02	—	−.03	.10	.01	.12	−.08	−.03	−.12	.08	.19	.02	−.30*	−.05	.39*	.17
4. HP—Baseline	.05	−.02	−.02	—													
5. RSA—Baseline	.09	−.04	−.02	.46*	—												
6. HP—NPE	.13	−.04	.02	.84*	.42*	—											
7. RSA—NPE	.19	−.07	.09	.27*	.81*	.37*	—										
8. Δ HP—NPE	−.14	.04	−.07	.38*	.17	−.19	−.14	—									
9. Δ RSA—NPE	−.16	.05	−.17	.33*	.27*	.06	−.35*	.50*	—								
10. HP—SFE	.09	−.01	−.01	.87*	.38*	.80*	.28*	.22	.14	—							
11. RSA—SFE	.17	−.03	−.09	.43*	.81*	.41*	.72*	.08	.12	.51*	—						
12. Δ HP—SFE	−.08	−.01	−.01	.20	.19	.04	−.04	.29*	.38*	−.31*	−.19	—					
13. Δ RSA—SFE	−.10	−.02	.11	.13	.38*	.04	.20	.18	.27*	−.18	−.24	.61*	—				
14. HP—RE	.01	−.07	.12	.74*	.42*	.73*	.43*	.08	.01	.75*	.44*	−.06	.06	—			
15. RSA—RE	.15	−.03	.13	.27*	.69*	.34*	.78*	−.06	−.18	.29*	.72*	−.03	.03	.53*	—		
16. Δ HP—RE	.05	.07	−.19	.27*	.02	.07	−.26*	.38*	.43*	.10	−.06	.35*	.09	−.45*	−.40*	—	
17. Δ RSA—RE	−.09	−.00	−.19	.16	.19	.01	−.14	.27*	.55*	.03	−.06	.26*	.40*	−.24	−.58*	.56*	—

Note. Coefficients for affect variables above the diagonal represent negative affect; those below the diagonal represent positive engagement. NPE = normal play episode; SFE = still-face episode; RE = reunion episode; HP = heart period; RSA = respiratory sinus arrythmia (vagal tone).

* $p < .05$.

Table 2
Mean Values of Infants' Physiological Responses and Infants' and Mothers' Behavioral Responses Across Episodes of the Still-Face Paradigm

	Baseline		Normal Play		Still-Face		Reunion				
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	η^2
Infant negative affect			0.09_a	0.10	0.36_b	0.27	0.23_c	0.24	35.90**	2, 71	.51
Infant positive engagement			0.51_a	0.25	0.23_b	0.15	0.44_c	0.26	63.76**	2, 71	.65
Mother negative affect			0.00	0.00			0.01	0.07			
Mother positive affect			0.73_a	0.18			0.65_b	0.18	9.40**	2, 71	.12
Dyadic synchrony			0.13_a	0.15			0.18_b	0.17	3.13*	1, 72	.04
Dyadic matched affect			0.36_a	0.17			0.29_b	0.16	7.86**	1, 72	.10
HP	410.69_a	30.64	409.33_a	28.76	393.35_b	31.54	405.43_c	32.60	21.01**	3, 56	.53
RSA	2.82_a	0.75	2.84_a	0.76	2.64_b	0.71	2.92_a	0.89	5.04**	3, 56	.21
Δ HP			1.36_a	16.75	17.34_b	15.71	5.27_c	22.91	16.92**	2, 57	.37
Δ RSA			-0.02_a	0.47	0.18_b	0.46	-0.11_a	0.65	5.53**	2, 57	.16

Note. Values with different subscripts within rows differ significantly at $p < .05$. HP = heart period; RSA = respiratory sinus arrythmia (vagal tone).
* $p < .05$. ** $p < .01$.

Because mothers showed almost no negative affect, analyses were not conducted for this variable. As seen in Table 2, mothers showed higher levels of positive affect in the normal play than in the reunion episode. Mother–infant dyads showed lower levels of synchrony in the normal play than in the reunion episode and higher levels of matched affect in the normal play than in the reunion episode.

Change in HP and RSA across the SFP. Following prior research (Bazhenova et al., 2001; Weinberg & Tronick, 1996), to assess absolute change in HP and RSA between baseline and each of the three episodes of the SFP, we conducted repeated measures analyses of variance with planned contrasts among episodes and baseline negative affect as a covariate (see Table 2). HP was shorter in the still-face episode than in the baseline condition, $F(1, 58) = 62.20$, $p < .01$, and was shorter in the reunion episode than in the baseline condition, $F(1, 58) = 6.8 8$, $p < .05$. HP was shorter in the still-face than in the normal play episode, $F(1, 58) = 34.38$, $p < .01$, and longer in the reunion than the still-face episode, $F(1, 58) = 9.32$, $p < .01$. HP was shorter in the reunion than in the normal play episode, $F(1, 58) = 4.86$, $p < .05$.

RSA, $F(1, 58) = 7.4$, $p < .01$, differed from baseline only during the still-face episode. RSA decreased between the normal play and still-face episodes, $F(1, 58) = 4.24$, $p < .05$, and increased between the still-face and reunion episodes, $F(1, 58) = 11.25$, $p < .01$. RSA did not differ between the normal play and reunion episodes.

Differences in levels of ΔHP and ΔRSA among episodes of the SFP. To assess mean differences in levels of ΔHP and ΔRSA among the episodes of the SFP, we conducted repeated measures analyses of variance with planned contrasts among episodes and baseline negative affect as a covariate (see Table 2). ΔHP and ΔRSA were computed as difference scores from baseline to provide a measure of change in HP and RSA, respectively, from a neutral, nonregulated state; higher values of ΔHP and ΔRSA indicated greater decreases in HP and RSA from baseline. This set of analyses examined which episode(s) produced the greatest amount of change in HP and RSA.

Infants showed greater levels of ΔHP in the still-face than in the normal play episode, F(1, 58) = 34.38, p < .01, or in the reunion episode, F(1, 58) = 9.32, p < .01, indicating greater decreases in HP during the still-face. ΔHP was greater in the reunion than the normal play episode, F(1, 58) = 4.86, p < .05. Infants showed greater levels of ΔRSA in the still-face than in the normal play episode, F(1, 58) = 4.24, p < .05, or in the reunion episode, F(1, 58) = 11.25, p < .01, indicating greater suppression of RSA during the still-face. Levels of ΔRSA did not differ between the normal play and reunion episodes.

Individual Differences in Patterns of Vagal Regulation

To replicate prior research identifying individual differences in patterns of vagal regulation across the SFP (Bazhenova et al., 2001), we divided the infants into two groups. Those who showed a pattern of vagal regulation similar to the group average, defined by a decrease in RSA between the normal play and still-face episodes and an increase in RSA between the still-face and reunion episodes, were categorized into the *suppressor group* (n = 28). Infants who did not show a decrease in RSA during the still-face episode relative to the normal and reunion episodes were categorized into the *nonsuppressor* group (n = 32). Resulting groups were approximately equal in size, similar to the size of groups identified by Bazhenova et al. (2001). The two groups did not differ on any demographic variables or infant sex. Level of baseline negative affect did not differ between the suppressor groups. Figure 1 presents differences between groups in infants' behavioral and physiological responses. Following Bazhenova et al., values are displayed as *z* scores.

There was no difference between groups in infants' negative affect in any of the episodes. Infants in the suppressor group showed higher levels of positive engagement in the normal play episode, F(1, 57) = 5.98, p < .05, and the reunion episode, F(1, 57) = 9.90, p < .01.

Analyses of variance with baseline negative affect as a covariate indicated that levels of baseline HP and RSA did not differ between groups. RSA differed between the two groups in the normal play episode, F(1, 57) = 13.93, p < .01, and the reunion episode, F(1, 57) = 10.04, p < .01, with infants in the suppressor group showing higher levels of RSA. ΔHP differed between the two groups in the normal play episode, F(1, 57) = 10.36, p < .0 1, and the reunion episode, F(1, 57) = 12.76, p < .01, with infants in the suppressor group showing less of a decrease in HP. ΔRSA differed between the two groups in the normal play episode, F(1, 57) = 31.7 1, p < .0 1, the still-face episode, F(1, 57) = 6.07, p < .05, and the reunion episode, F(1, 57) = 13.54, p < .01, with infants in the suppressor group showing greater decreases in RSA during the still-face episode and infants in the nonsuppressor group showing greater decreases in RSA during the normal play and reunion episodes.

To examine patterns of change across episodes in infants' behavioral and physiological responses, we conducted repeated measures analyses of variance with episode as the within-subjects factor and planned contrasts between adjacent episodes separately for each group. Significant differences between episodes are indicated in Figure 1.

Analyses of variance were used to assess suppressor group differences in maternal behavior. There was no difference in mothers' positive affect between groups.

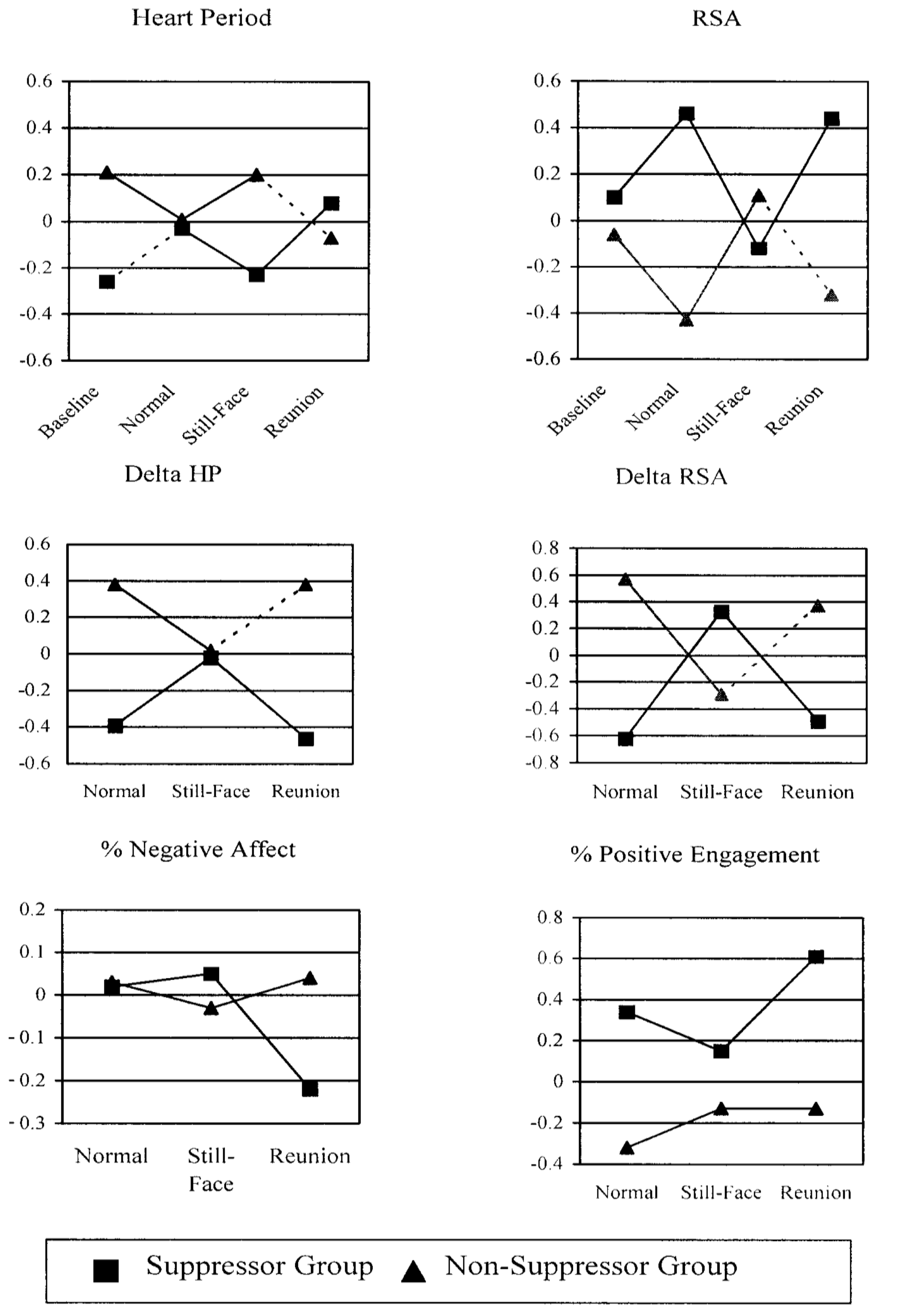

Figure 1. **Infants' behavioral and physiological responses by suppressor group. Solid lines indicate significant change ($p < .05$) between adjacent episodes (for the suppressor group, $df = 1, 27$; for the nonsuppressor group, $df = 1, 31$). RSA = respiratory sinus arrhythmia (vagal tone); HP = heart period.**

Dyadic Coordination and Infants' Physiological Responses in the SFP

Correlations among variables. Dyadic synchrony in normal play was related to ΔHP in the normal play episode ($r = —.26$, $p < .05$), such that in less synchronous dyads, infants showed greater decreases in HP. Matched affect in the reunion episode was related to ΔHP ($r = —.34$, $p < .01$) and ΔRSA ($r = —.36$, $p < .01$) in the reunion episode, such that infants in dyads showing lower levels of matched affect had greater decreases in HP and RSA. Dyadic synchrony in normal play was related to level of matched affect in normal play ($r = .28$, $p < .05$). Levels of matched affect were stable between the normal play and reunion episodes ($r = .27$, $p < .05$).

Dyadic coordination and individual differences in infants' vagal regulation. Dyads in the suppressor group were more synchronous than dyads in the nonsuppressor group in the normal play interaction (Ms = .16 and .06, respectively), $F(1, 58) = 7.05$, $p < .05$.

Role of Maternal Depression

Mothers' BDI scores were uncorrelated with infants' and mothers' affective behaviors, infants' physiological responses, dyadic synchrony, and matched affect. Mothers categorized into the depressed group on the basis of level of depressive symptoms, on average, had infants with longer HP in the reunion episode, $F(1, 58) = 4.25$, $p < .05$, and lesser ΔHP from baseline to reunion episode, $F(1, 58) = 4.03$, $p < .05$, than mothers categorized into the nondepressed group. There was no relation between suppressor group status and maternal depression group status. Mother–infant dyads in the depressed group showed lower synchrony in the normal play episode, $F(1, 71) = 6.22$, $p < .05$, and higher levels of matched affect in the reunion episode, $F(1, 71) = 4.12$, $p < .05$, than dyads in the nondepressed group.

DISCUSSION

In this study, we examined relations between dyadic coordination of mother–infant affective behaviors and 3-month-old infants' physiological responses across episodes of the SFP. This method provided a unique perspective on parental support of infants' emotion regulation. It afforded the opportunity to assess infants' responses in multiple domains during conditions in which mothers were available to support emotion regulation (normal play and reunion episodes) and a condition in which mothers' support was withdrawn and that was likely to elicit the need for emotion regulation (still-face episode). Our findings replicated earlier research and provided important new insights regarding the functions of dyadic coordination in mother–infant interaction.

First, our results replicated findings from psychophysiological research with older infants in the SFP (Bazhenova et al., 2001; Weinberg & Tronick, 1996) and with infants interacting with strangers in the SFP (Bazhenova et al., 2001). Consistent with that research, infants' HP and RSA were significantly lower in the still-face episode than in the baseline condition and both HP and RSA showed a decrease between the normal play and still-face episodes, rising again between the still-face and reunion episodes. The pattern of findings reflected infants' reactivity to the still-face and the regulatory process of RSA suppression, which is thought to occur when an infant reaches a state of arousal requiring active coping and to subside when active coping is no longer required (Porges, 1996; Wilson & Gottman, 1996). Together with behavioral observations of increased negative affect and decreased positive engagement during the still-face relative to the normal play and reunion episodes, infants' responses portrayed a coherent pattern of behavioral and physiological sensitivity to mothers' social engagement, disengagement, and re-engagement.

This set of responses may have served several purposes. Increased reactivity may have triggered behaviors (e.g., negative affect) that communicated infants' states to mothers and/or behaviors that assisted in self-regulation (e.g., looking away). Increased RSA suppression may have provided physiological support for those behaviors. Of note, consistent with Haley and Stansbury (2003), we found that infants' behavioral and physiological responses were uncorrelated in normal play interactions with the mother, but when the need to regulate emotion was activated by the stress of the still-face, behavioral and physiological systems began to work in concert, suggesting a coherent set of functional responses.

Our results are particularly revealing in light of earlier research that identified a developmental increase in mean levels of RSA between 3 and 6 months (Field et al., 1995). We found that the pattern of RSA regulation across episodes of the SFP at 3 months of age was the same as the pattern found at 6 months of age, suggesting that the function of behavioral and physiological responses to engagement and disengagement in parent–infant interaction is the same at earlier ages, even though mean levels may change with development.

Similarly, the current findings also replicated prior research on individual differences in RSA regulation across the SFP that studied older infants interacting with strangers (Bazhenova et al., 2001). Similar to findings at age 5–6 months, at 3 months of age there was a group of infants that showed RSA suppression in response to the still-face and a group that did not. Infants in the nonsuppressor group were as behaviorally negative during the still-face as other infants and showed similar decreases in HP, signs that they were distressed by mothers' disengagement. However, they did not exhibit the regulatory response of RSA suppression during the still-face, suggesting that they had less effective mechanisms for self-regulation than infants who did exhibit RSA suppression. Nonsuppressor-group infants also looked very different from infants in the suppressor group in both the normal play and the reunion episodes, showing significantly lower levels of positive engagement and higher levels of reactivity and RSA suppression. In fact, after mothers' reengagement in the reunion episode, these infants maintained a level of arousal that was not significantly different from their level of arousal in response to the still-face. Thus, for this group of infants, there was a carryover of both physiological and behavioral distress from the still-face, whereas infants who effectively suppressed RSA during the still- face showed a carryover of behavioral distress only.

One explanation is that infants in the suppressor group used signs of behavioral distress to signal their mothers for support in regulation and they were able to use that support effectively. Although there were no differences in mother–infant dyadic coordination during the reunion episode between the suppressor and nonsuppressor groups, lowered synchrony of mother–infant interaction in normal play in the nonsuppressor group suggested that there were distinct differences in mother–infant dyadic coordination for infants who subsequently did not effectively regulate arousal.

Because the nonsuppressor group of infants was also less positively engaged and more physiologically aroused during normal play, it is difficult to determine the direction of effect between decreased dyadic synchrony and less effective physiological regulation. Some researchers have concluded (Tronick & Cohn, 1989; Weinberg et al., 1999) that a higher level of synchrony reflects increased maternal support for infants' emotion regulation, that is, synchrony occurs in response to infants' arousal. Some evidence in the current study supports this conclusion. First, levels of synchrony increased between the normal play and reunion episodes, suggesting that mothers were actively increasing the degree of coordination between their affective expressions and their infants' expressions to help their infants regulate increased distress. Second, infants in the nonsuppressor group were more highly aroused during normal play and level of dyadic coordination was lower, suggesting that the lack of synchrony in the presence of infants' arousal resulted in infants' maintaining that higher level of reactivity.

However, other findings could be interpreted to mean that lower dyadic synchrony precedes infants' higher reactivity and less effective regulation. In the current research, mothers were grouped into those with relatively high levels of depressive symptoms and those with relatively low levels of depressive symptoms, on the basis of their responses on the BDI. Mothers with high levels of depressive symptoms and their infants showed lower dyadic synchrony during normal play, consistent with prior research and with theoretical expectations that depression may impair a mother's ability to support effective emotion regulation. We found no differences in the behavioral or physiological responses of infants of mothers with high levels of depressive symptoms compared with infants of other mothers or any differences in mothers' behaviors. Furthermore, the range of depressive symptoms measured continuously was uncorrelated with infants' or mothers' responses. These findings, which are contrary to some prior research using high-risk or clinically depressed samples, are consistent with evidence that other risk factors may mediate or moderate the relation between maternal depression and infant outcomes, including family adversity and the severity, course, and timing of depressive symptoms. The mothers in this study were from primarily middle- to upper-class families and overall experienced a relatively low level of depressive symptoms, thus minimizing the impact of maternal depression on infants' and mothers' responses.

Of importance, earlier research found that at 3 months of age, there were no differences in RSA between infants of mothers with high levels of depression compared with other infants but that by 6 months, these infants showed lower RSA (Field et al., 1995), suggesting that maternal depression was related to impaired development of infants' vagal regulation between 3 and 6 months. This finding and our finding that infants of depressed mothers were in dyads that showed less synchrony in normal play identified dyadic synchrony as a potential key mediator of the relation between maternal depression and later outcomes in infants' emotion regulation. Longitudinal research between 3 and 6 months of age would be needed to investigate this hypothetical mechanism.

Results from the current research may also shed light on the distinctive functions of synchrony and matched affect in regulating dyadic interaction in different social contexts. The process of synchrony, which reflected the degree to which mothers and infants coordinated their behaviors over time, appeared to be related primarily to the quality of dyadic interaction in normal play. In contrast, matched affect, which reflected the extent to which infants and mothers shared the same type of affective expression across a period of time, appeared to be related only to dyadic interaction in the reunion episode, when mothers and infants were engaged in a process of interactive repair. For example, synchrony and infants' physiological responses were correlated only in normal play and matched affect and infants' physiological responses were correlated only in the reunion episode. Furthermore, infants who did not suppress RSA in response to mothers' still-face were in dyads that showed lower levels of synchrony only in normal play, suggesting that ineffective vagal regulation is related to lower mother–infant dyadic coordination in normal social play interactions.

Results for the effects of maternal depression reflected the divergent role that synchrony and matched affect may play in distinct interactive contexts. Mothers with high levels of depressive symptoms and their infants showed lower levels of synchrony in normal play but higher levels of matched affect in the reunion episode. Results regarding synchrony are consistent with prior research that has also documented decreased synchrony or maternal contingency in depressed mothers' facial and vocal expressions when interacting in normal play with their infants (Cohn et al., 1990; Zlochower & Cohn, 1996). Results regarding matched affect may also be consistent with earlier research. Infants of depressed mothers have been found to be less distressed by mothers' still- face than infants of nondepressed mothers (Field, 1984). Because infants of mothers with high levels of depression in the current study showed physiological signs of lower arousal during the reunion episodes, their higher levels of matched affect in the reunion episode may reflect that lack of distress.

This pattern of findings suggested that level of matched affect may be a reflection of the quality of dyadic interaction, whereas synchrony may reflect a more active process that mothers use to regulate and maintain optimal interaction. This theory would predict the current findings of an increase in mean levels of synchrony between normal play and the reunion, during which infants typically are more reactive and distressed, and a decrease in matched affect between normal play and reunion.

Future longitudinal research that measures outcomes and correlates of individual differences in infants' RSA regulation in the SFP and dyadic coordination will be particularly important. Although we found that lower levels of dyadic synchrony in normal play were related to higher reactivity and a failure to suppress RSA in response to the still-face, it is unclear that lower dyadic synchrony will systematically predict negative outcomes for infants. One possibility is that mothers of infants that showed higher levels of reactivity in normal play may have allowed infants to attempt to self-regulate rather than intervene by increasing synchronization. Over time, allowing infants opportunities to self-regulate when they do not seem unduly distressed may result in more positive developmental outcomes for emotion regulation. This idea is consistent with recent research finding that moderate, rather than high, levels of synchrony are optimal in mother–infant interaction (e.g., Jaffe et al., 2001; Moore et al., 2004) and with research finding that mothers who engaged in higher levels of preemptive control of their toddlers' behavior had toddlers who showed lower levels of self-control (Calkins & Johnson, 1998).

Another important direction for future research would be to follow the developmental trajectories of infants with suppressor and nonsuppressor patterns of RSA regulation across the SFP to see if some infants "outgrow" the nonsuppressor pattern. Although stable individual differences have been found in RSA functioning (e.g., Stifter & Fox, 1991) and RSA regulation is a reliable predictor of later behavioral outcomes (Porges, 1996), it is possible that a subgroup of infants would eventually show the putatively more effective pattern of RSA suppression and that a distinct subgroup of infants would maintain nonsuppressor patterns across development. As our results suggest, dyadic synchrony may be an important mediator of developmental change in patterns of physiological regulation. In addition, factors such as infant temperament may be important moderators of the relation between dyadic coordination and infants' physiological regulation. Future research should add measures of infant temperament or study groups of infants selected for extremes of temperament to explore this question further.

There were several limitations of the current study. One was that our methods for assessing dyadic coordination did not indicate the extent to which mothers and infants were each responsible for synchronizing or matching affect to the other. Earlier research has found that 3-month-old infants were likely to follow the organization of the interaction determined by mothers' expressions (Cohn & Elmore, 1988) whereas older infants were more independent and active in structuring social interactions with their mothers (Cohn & Tronick, 1987). Therefore, it is likely that mothers were the more active partners in synchronizing and matching affect. Future research could add measures or methods that are sensitive to direction of effects from one partner to the other, including sequential analyses of change in behavioral and physiological responses. Because RSA is calculated in 15- to 30-s epochs, however, only the HP data would be appropriate for time-series methods.

Another limitation of the current research was that the relatively small sample size did not allow us to discriminate more than two patterns of RSA regulation. That about half of the infants were categorized into the nonsuppressor group suggests that this pattern of vagal regulation is not necessarily associated with impairment. Additional research examining outcomes associated with the non- suppressor pattern of regulation would help to clarify the issue of whether this is one of various developmentally normal patterns or whether it represents an atypical pattern. It may also be that the suppressor and nonsuppressor groups were actually composed of smaller sets of infants with distinct types of emotion regulation profiles. Longitudinal research with a larger sample of infants would allow an exploration of prototypical clusters of infants who vary in the extent to which they develop successful behavioral and physiological emotion regulation strategies.

The current study was conducted with a fairly homogeneous sample with respect to ethnicity and socioeconomic status. Research in this area needs to be extended to a more diverse sample, including groups that may use different emotion socialization strategies with their infants. Longitudinal research with various infant and parent at-risk populations, such as clinically depressed parents, may elucidate mechanisms by which dyadic synchrony supports infants' developing physiological and behavioral regulation of emotion.

The current study was the first to examine qualities of mother– infant dyadic coordination in relation to infants' vagal regulation across the SFP. Taken together, findings regarding mean differences, individual differences, and maternal depression converged on the conclusion that dyadic coordination supported effective emotion regulation in response to social engagement and disengagement. Continued research is needed to identify optimal levels of parental support for infants' emotion regulation and to examine developmental outcomes for infants who vary in patterns of RSA regulation and mother–infant dyadic coordination.

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