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Infant physiological response to the still-face paradigm: Contributions of maternal sensitivity and infants' early regulatory behavior

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ABSTRACT

The current study examined the independent and additive contributions of maternal sensitivity measured prior to and following a social stressor, and infant behaviors to infants' physiological response to the still-face paradigm (SFP) in a sample characterized by poverty-related environmental risk. Ninety-one mother/infant dyads participated in the SFP when their infants were 5 months old. Maternal sensitivity was coded during the play and reunion episodes. Infant behaviors were coded during the reunion episode of the SFP while measures of heart rate (HR) and Respiratory Sinus Arrhythmia (RSA) were collected from the infants at baseline and across the SFP. Maternal sensitivity during the reunion episode predicted infants' biobehavioral reactivity and regulation, over and above maternal sensitivity during the play episode. Infants' HR decreased, and RSA increased, with greater levels of maternal sensitivity during the reunion episode. Infants also exhibited greater attentional engagement and fewer resistant behaviors with greater levels of maternal sensitivity during the reunion episode. Finally, infant behaviors predicted change in HR and RSA from the still-face to the reunion episode, above and beyond that of maternal behaviors. These findings further our understanding of the dyadic basis for the development of emotion regulation in infancy.

The capacity to regulate emotion effectively in response to stress is an important developmental objective of the first year of life, the ontogeny of which occurs at both biological and behavioral levels. In keeping with Fox and Calkins (Calkins & Fox, 2002; Fox & Calkins, 2003), it follows that to study emotion regulation there is a need to apply integrated developmental models across multiple, reciprocally interacting levels; specifically, those that incorporate the transaction between intrinsic (e.g., physiological, attentional) and extrinsic (e.g., parental characteristics, including parental sensitivity) factors. The development of adaptive emotion regulatory processes, in particular, the capacity to modulate, inhibit, and enhance emotional experiences and expressions (Calkins & Hill, 2007), develops in the context of the caregiving relationship (Calkins & Hill, 2007; Cohn & Tronick, 1989). Maternal sensitivity, or a mother's ability to detect and respond to the child's cues in a warm, responsive, and accurate manner (Ainsworth, Blehar, Waters, & Wall, 1978; Pianta, Sroufe, & Egeland, 1989), has been identified as a particularly important caregiver characteristic that supports infants' emotion regulatory capacities (Crockenberg & Leerkes, 2000; de Wolff & van Ijzendoorn, 1997). Important questions remain, however, about the actual contexts in which early emotion regulation might develop. For instance, not clear is the extent to which maternal sensitivity in response to infant distress versus non-distress most directly supports the development of emotion regulation during infancy. Although there is some evidence that maternal sensitivity to infant distress but not non-distress is more predictive of important socio-emotional outcomes (Leerkes, Blankson, & O'Brien, 2009; McElwain & Booth-LaForce, 2006), links to infants' emerging regulatory capacities have not been explored. The central aim of the present study was to investigate the degree to which maternal sensitivity to distress and non-distress were differentially related to individual differences

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in 5-month-old infants' physiological and behavioral regulation during the still-face paradigm (SFP; Tronick, Als, Adamson, Wise, & Brazelton, 1978).

1. The still-face paradigm

The SFP has become a standard laboratory procedure for evaluating infant emotion regulatory strategies and dyadic interactive characteristics by assessing the infant's response to violations of expected social norms. The SFP comprises three episodes: a face-to-face play episode; a still-face episode, during which the caregiver does not respond to the infant while holding a neutral expression; and a reunion episode, when the caregiver resumes interaction with her infant, often with a distressed child. In a recent narrative review and meta-analysis, Mesman and colleagues demonstrated that some infants respond to the stress of the still-face by engaging in emotion regulatory behaviors; specifically, they avert their gaze from the caregiver, and increase their self-soothing behaviors (Mesman, van Ijzendoorn, & Bakermans-Kranenburg, 2009). The SFP is a unique task that allows for investigations of maternal sensitivity in response to infant non-distress (during the play episode) as well as to infant distress (during the reunion episode). One overarching aim of this study was to examine whether maternal sensitivity prior to and following a stressful still-face episode was associated with infant physiological and behavioral reactivity and regulation upon reunion. There has been little research examining the reunion episode of the SFP despite evidence that it might provide insights into the processes by which mother–infant dyads repair, reorganize, and regulate following this social challenge (Cohn, 2003; Weinberg & Tronick, 1996). Thus, a second aim of the present study was to investigate the degree to which maternal sensitivity during the reunion episode of the SFP might be related to individual differences in 5-month-old infants' physiological and behavioral response to the stresses of the procedure, while controlling for maternal sensitivity during the play episode.

2. Maternal sensitivity and infant behavioral responses during the SFP

In Tronick's (Gianino & Tronick, 1988; Tronick, 2007) Mutual Regulation Model, it is hypothesized that sensitive caregivers, who recognize infant coping signals (e.g., looking away or protesting) during a dyadic interaction, and who respond to them in an appropriate manner, have infants who develop a sense that they can both help to regulate the dyadic exchange and, eventually, themselves. The ultimate goal of early mother–infant face-to-face interactions is to achieve mutual regulation, or a state of reciprocity, which is seen as an important foundation for the development of effective self-regulation. When the infant can initiate reparation by communicating to the partner using affective signals, and when the partner is appropriately responsive and sensitive to these signals, the infant begins to develop self-regulatory skills needed to cope with longer periods of interactive perturbations, such as the one induced experimentally in the SFP (Gianino & Tronick, 1988; Tronick, 2007). As such, infant behavioral responses to the SFP are seen as reflective of a history of dyadic sensitive interactions.

Early work on the SFP focused on recording behaviors during the still-face episode when infants confront mothers' non-responsiveness (Adamson & Frick, 2003). Infants typically attempt to signal caregivers by smiling and orienting toward them at first, but then tend to increase their crying and protesting as these efforts prove unsuccessful (Mesman et al., 2009). When these bids fail, many infants will altogether avoid looking at the caregiver (Adamson & Frick, 2003). Researchers have found that infants as young as 4 months of age engage in a variety of self-regulatory behaviors during the still-face episode, including, self-soothing (e.g., thumb sucking), distraction (e.g., focusing on an object), and orienting toward the parent (Braungart-Rieker, Garwood, Powers, & Notaro, 1998). Following the acute stress of the SFP, researchers have found that infants exhibit regulatory behaviors, such as attention seeking and avoidance behaviors (e.g., gaze aversion), during the reunion episode (Bazhenova, Plonskaia, & Porges, 2001; Kogan & Carter, 1996; Miller, McDonough, Rosenblum, & Sameroff, 2002; Rosenblum, McDonough, Muzik, Miller, & Sameroff, 2002).

Importantly, these regulatory behaviors have been related to maternal sensitive responses (Kogan & Carter, 1996; Rosenblum et al., 2002). For instance, in a sample characterized by economic disadvantage, mothers who were more sensitive prior to the still-face episode had infants who showed more attention seeking behaviors (e.g., looking at her, smiling, reaching) and less resistance to their mothers' attempts at reconnection (Kogan & Carter, 1996). Tarabulsy and colleagues (2003) examined maternal sensitivity in unstructured observations during a home visit prior to assessing infant behavioral responses to the SFP; they found that maternal sensitivity was predictive of lower levels of negative affect and greater levels of self-soothing behavior during the SFP. In a recent narrative review, it was found that maternal sensitivity during the play episode was predictive of greater positive affect during the still-face episode (Mesman et al., 2009) and more infant attention-seeking and less resistance during the reunion (Kogan & Carter, 1996). Together, these data suggest that the infants of more sensitive mothers attempted to use their caregiver as an external source of regulation during the reunion episode of the SFP. Moreover, these data also raise the possibility that it is how mothers respond to their infants during times of little or no stress that shapes how infants will utilize their mothers for external regulation during or after a stressor.

No studies that we know of have compared maternal sensitivity to distress and non-distress using the SFP. In the one study that examined maternal sensitivity solely during the reunion episode of the SFP, the authors found that mothers who displayed sensitive, infant-focused behaviors during the reunion episode had infants who expressed more attention seeking behaviors during this phase (Rosenblum et al., 2002). Other findings examining maternal sensitivity during a free play suggest that it may be maternal sensitivity during distress that is equally or more important to infant socio-emotional development. In these studies, stronger relations have been found between maternal sensitivity and later outcomes, includ-

ing attachment security, problem behavior, and affect regulation, when maternal sensitivity is assessed following a stressful context compared with a less stressful context, such as a free-play (Leerkes et al., 2009; McElwain & Booth-LaForce, 2006). Findings of this sort have prompted some to speculate that maternal behaviors that serve a protective function during and following times of stress, might be more predictive of socio-emotional outcomes than maternal sensitivity during times of lower stress, such as during a play context (Goldberg, Grusec, & Jenkins, 1999; Thompson, 1997). Miller et al. (2002) have even argued that the quality of the mother–infant relationship must be assessed when emotional demands are high. Presumably, during high-stress interaction, a caregiver's ability to respond sensitively is challenged, and thus individual differences in maternal behavior emerge. Reflecting Bowlby (1969/1982), who viewed the early caregiver/infant relationship as a "biobehavioral safety-regulating system" during times of distress, our goal in the present study was to evaluate the extent to which maternal sensitivity prior to and during the challenges associated with the SFP were related to 5-month-old infants' physiological and behavioral regulation.

3. Infant biobehavioral responses to the SFP

Beyond the role played by maternal sensitivity, the development of emotion regulation is also shaped by infants' biobehavioral responses to stress (Cole, Martin, & Dennis, 2004). By the end of their first year, most infants have begun the process of managing their own emotional reactions to their environment, including aspects that can be experienced as stressful. Extant theoretical models (Cole et al., 2004; Fox & Calkins, 2003; Propper & Moore, 2006) posit that the capacity to regulate one's self-emotionally occurs at multiple levels, with physiological processes and regulatory behaviors interacting in complex ways. Studies examining the link between cardiovascular activity and the behavioral concomitants of emotion regulation in infancy have found that individual differences in heart rate variability can be identified by 3 months of age. Cardiovascular activity is related to behavioral expressions of interest, negativity, and positive emotionality (Fox, Schmidt, & Henderson, 2000). By 5 months of age, associations between infant heart rate variability and self-regulation have been identified; specifically, infants with greater heart rate variability respond to an arm restraint procedure by looking to the mother and increasing motor movement more than infants with lower heart rate variability (Fox, 1989).

Individual differences in cardiovascular reactivity and regulation have been predictive of later cognitive and behavioral functioning (Fox et al., 2000). Thus, understanding infant cardiovascular responses to stress in infancy is important as these early attempts at regulation lay the foundation for later, more complex methods of regulating and responding to stress. In general, higher heart rate (HR) relative to a baseline is thought to index periods of greater cardiac arousal in response to stress. Respiratory Sinus Arrhythmia (RSA), which is related to the rhythmic increase and decrease of the heart that coincides with respiration, is used as an index of parasympathetic regulation (Beauchaine, 2001). In infancy, higher baseline or tonic levels of RSA are thought to reflect the infant's adaptive engagement with the environment (Beauchaine, 2001). Under conditions of stress, however, parasympathetic withdrawal, or a decrease in RSA relative to a baseline, allows for sympathetic activation and mobilization of the organism to respond to the stressor.

Although limited, existing research provides some evidence that the SFP elicits physiological responses from the infant. Like their behavior, individual differences in infants' physiological response to the SFP provides insights into infants' nascent regulatory capacities as well as the dyadic interactive history between caregiver and infant that has helped to program infants' regulatory patterns. Relative to tonic levels or in response to the play episode, infants typically exhibit greater cardiac arousal to the still-face episode in the form of increased heart rate (Bazhenova et al., 2001; Haley & Stansbury, 2003; Moore & Calkins, 2004; Weinberg & Tronick, 1996). Infants also exhibit a decrease in RSA from baseline (Bazhenova et al., 2001; Moore & Calkins, 2004) or the first play episode (Weinberg & Tronick, 1996) to the still-face episode, indicating that infants are attempting to cope during this episode. How infants' physiology changes from the still-face to reunion episodes is less clear, however. Whereas some researchers have found that HR (Bazhenova et al., 2001; Weinberg & Tronick, 1996) and RSA (Moore & Calkins, 2004; Weinberg & Tronick, 1996) return to baseline or play episode levels during the reunion episode, others have found evidence of greater cardiac arousal in the form of shorter heart period (Moore & Calkins, 2004). That some infants become less aroused and other infants become more aroused during what is putatively the recovery phase of the SFP, points either to different regulatory strategies or constraints (e.g., temperament), the possible moderating role of external factors, or to both.

Calkins and Fox (2002) have noted that individual differences in the behavioral expression of emotion may contribute to physiological functioning, and that in certain contexts, infant's behavior and physiology are coordinated (see Haley & Stansbury, 2003). For instance, greater attention has been associated with higher levels of RSA, and greater behavioral indices of distress are related to greater HR (Beauchaine, 2001; Haley & Stansbury, 2003). Interestingly, Field (1981) demonstrated that, during face-to-face interactions with the mother, infant's HR increases prior to gaze aversions, and HR decreases while infants avert their gaze. This finding suggests both that avoidant behavior and HR are related and, possibly, that avoidance for some infants is emerging as a means to dampen cardiac arousal. If so, we can speculate about the long-term benefits of such a strategy.

It is also possible that infant's nascent temperamentally related behavioral capacities for self-regulation may aid in their recovery following a social stressor. Infants vary in the intensity and affective expression of their arousal, as well as their success at managing this emotional response (Fox, 1989). Researchers suggest that individual differences in reactivity and attentional control are related to children's tendency to display over-arousal in emotionally stressful contexts (Eisenberg & Fabes, 2006; Rothbart & Bates, 2006). Rothbart and colleagues have demonstrated that individual differences in reactivity

and regulation are observable in the early months of life and that higher levels of attentional control are negatively associated with distress and negative affect (Rothbart & Bates, 2006). Because differences in biobehavioral regulation might be attributable to factors related to temperament, we sought to examine how temperament is related to maternal and infant behaviors during the SFP.

As it relates to contextual factors such as maternal sensitivity, Moore and Calkins (2004) found no differences in maternal affective behavior, as coded during the play and reunion episodes, between infants who exhibited vagal withdrawal between normal play and the still-face episode when compared to infants who did not exhibit a decrease in RSA during the still-face episode. However, they did find that infants in the former group were part of a dyad characterized by greater dyadic coordination. Ham and Tronick (2006) and Haley and Stansbury (2003) both examined the relation between maternal responsiveness and infant physiological response during the SFP. Both studies provide evidence of an association between maternal sensitivity and physiological regulation during the SFP. For example, Haley and Stansbury (2003) found that infants of mothers who were more responsive during normal play and the first of two reunion episodes of their modified SFP expressed less negative affect and had lower heart rates during the second reunion.

In sum, previous research supports the premise that the SFP elicits a behavioral and physiological response from infants, and that individual differences in the nature and intensity of this response are associated with the quality of the mother–infant dyad's interactive history. It also is thought that mothers who are more sensitive have infants who orient to their mother more and who exhibit less behavioral and physiological distress during the reunion episode relative to the infants of less sensitive mothers. We know that infant's own behaviors work in concert with their physiology to aid in regulation during face-to-face interactions. However, the important question of how maternal sensitivity in different contexts, and infants' own behavioral attempts at regulation, work together to regulate physiological levels of distress following a dyadic disruption lacks a clear answer.

4. The current study

The aim of the present study was to investigate the extent to which observed maternal sensitivity prior to and following distress was related to individual differences in 5-month-old infants' biobehavioral reactions to, and recovery from, the demands of the SFP. Although one study has examined maternal responsiveness aggregated in both play and reunion (Haley & Stansbury, 2003), no studies that we know of have examined maternal sensitivity during both contexts, nor tried to understand the differential contributions to infants' emotional functioning of maternal sensitivity during distressed and non-distressed interaction. By assessing the extent to which maternal sensitivity to distress versus non-distress are separate (or redundant) precursors of infants' nascent emotion regulation strategies, theoretical predictions concerning the contributions of our earliest caregiver relationships may be sharpened. Likewise, greater specificity in delineating the interpersonal processes that foster emotion development may enable family interventionists to design more effective therapeutic and preventive interventions for families of young infants (McElwain & Booth-LaForce, 2006).

We explored this question by examining infants' behavioral and physiological responses to the still-face in a sample of low-income primiparous women. Few studies have examined infant physiological and behavioral responses to mothers of varying degrees of sensitivity in samples of risk (for exceptions see, Kogan & Carter, 1996). Because conditions of poverty have been shown to contribute to some parents' difficulties providing their offspring with warm and supportive parenting (Duncan, Brooks-Gunn, & Klebanov, 1994; Repetti, Taylor, & Seeman, 2002), the results form the current investigation may help with generalizability as well as to broaden our knowledge of how emotion regulation develops.

Based on previous research and theory, we hypothesize that maternal sensitivity measured following the stress of the still-face will be more predictive of infant physiological and behavioral responses to the SFP than maternal sensitivity measured during a play episode. Specifically, we hypothesize that infant HR will decrease and infant RSA will increase, suggesting active attempts at regulation, as mothers exhibit greater sensitivity during reunion. Second, we hypothesize that infant behaviors; specifically, the extent to which infants resist and protest during the reunion episode, or the degree to which infants attend to their mothers during the reunion episode, will be related to maternal sensitivity during reunion. Based on previous work (Kogan & Carter, 1996), we hypothesize that infants who protest more will have mothers who are less sensitive, while infants who attend to their mothers more will have mothers who are more sensitive. Finally, we also investigated the independent and joint contributions of maternal sensitivity examined in different contexts, and infant behaviors to changes in infant HR and RSA from the still-face to reunion episodes of the SFP. Based on prior evidence that outward rather than inward directed attention under conditions of stress are related to physiological calming (Cacioppo & Sandman, 1978; Gill & Calkins, 2003), we hypothesize that infants who exhibit higher levels of mother-directed attention-seeking behaviors during reunion will show greater evidence of cardiac deceleration and parasympathetic regulation relative to infants who show higher levels of resistance of their mother.

5. Method

5.1. Participants

Participants were recruited during their third trimester of pregnancy at local childbirth education classes, hospitals, and public assistance organizations as part of a longitudinal effort to identify psychobiological markers of risk for insensitive

or unresponsive parenting ($n = 105$). Participants were screened using the Screening Scale for Problems in Parenting (SSPP; Avison, Turner, & Noh, 1986) and a 9-item version of the Center for Epidemiological Studies-Depression scale (CES-D; Radloff, 1977). Participants who scored 11 or above (out of a possible 25) on the SSPP and those who scored a 12 and above (out of a possible 36) on the CES-D were invited to participate in the prenatal laboratory visit. Participants ($n = 95$) returned to the laboratory again when their infants were 5 months old ($M = 20.99$ weeks, $SD = 2.55$). Of the 10 participants who did not complete the 5-month visit, one mother's baby died, two moved, four could not be reached, two had infants who were too fussy to complete the SFP, and one had volunteered for the prenatal assessment alone, so she was not contacted for the postnatal assessment. There were no differences in participant age, marital status, education, or household income between participants who completed the 5-month assessment and those who did not.

At the 5-month assessment, infants ranged in age from 16 to 32 weeks ($M = 20.99$ weeks, $SD = 2.55$). There were 42 males and 53 females. The mother's mean age was 24.11 years ($SD = 4.77$, range = 18–38). Approximately 93% of the sample had a personal income of less than $20,000. Approximately 80% attended some college or received a 2-year degree. Most of the mothers were either living with their partner (43.5%), or they were married (37.6%). Mothers were primarily European-Americans (81.0%), with 2.9% African American, 5.8% Hispanic, 3.8% American Indian, 1% Asian, and 5.7% identifying themselves as "another group."

5.2. Procedures

When infants were 5 months, they and their mothers came into the laboratory as part of a larger assessment of dyadic interactions. The infants were first assessed with the Bayley Scales of Infant Development while their mother filled out questionnaires. Experimenters then attached heart rate and respiration monitoring equipment (described below) to both mothers and infants prior to the baseline episode. Although we collected physiological data on both mothers and infants, only the infant physiological data will be reported. Mothers then dressed their infants in a white sleeper so that the infant could not pull on the electrodes, and so the clothing would be gender-neutral. It was important to use gender-neutral clothing to avoid any bias the coder might have with regard to male and female behavior. The dyads then watched a 2-min Baby Einstein video (© 2002, The Baby Einstein, LLC) while the infant sat on the mother's lap. This baseline physiology assessment was used to examine infant's heart rate and RSA while in a neutral state.

5.2.1. Mother–infant SFP

Following the baseline, infants were placed in a high chair approximately 18 in. across from their mother. Experimenters introduced the mother to the SFP by explaining that they were interested in how babies behave when their parents are playing with them, and how they react when their parents are not responding to them. The experimenter then left the room, and communicated the specific procedures of the SFP over an intercom from a separate filming room. Specifically, mothers were asked to play with their babies (with no toys) for 2 min. Following SFP procedures, mothers were then signaled to turn to their left for 15 s, and then signaled to turn around with a neutral face for 2 min. Following this still-face episode, mothers were signaled to turn around to their left for 15 s, and then signaled to play with their baby again for 1 min. This last episode constituted the reunion episode. This slightly modified version of the SFP was adapted from Lewinsohn (1996) as reported in Forbes, Cohn, Allen, and Lewinsohn (2004). If the infants were fussy for more than 15 s at the start of the procedure, the interaction was stopped and the SFP was attempted again after the baby was soothed.

The SFP was video-recorded with one camera on the mother and one on the infant. A split-screen generator combined the images so that the mother and infant behaviors could be observed simultaneously. A time code was added to the recording so that physiology and behavior could be examined simultaneously in a second-by-second manner.

5.2.2. Coding of maternal behaviors

Maternal sensitivity was assessed during the play and reunion episode of the SFP using the Global Ratings of Mother–Infant Interaction (Murray, Fiori-Cowley, Hooper, & Cooper, 1996). Coders examined five dimensions of maternal behavior, coded on a scale from 1 to 5. Higher scores represented higher levels of the following five dimensions: warmth, acceptance, responsiveness, demandingness (reversed), and sensitivity. *Warmth* was defined as the degree to which the mother expressed love and affection toward her baby; *acceptance* included the willingness and ability of the mother to follow the infant's lead; *responsiveness* was operationalized as both the mother's awareness of her infant's signals and response to them (regardless of the appropriateness of the response); *demandingness* was defined as the degree to which the mother required the infant to behave in a certain way; and *sensitivity* included the ability of the mother to identify her infant's signals and vary behavior appropriately.

A subset of tapes (15% during play; 32.6% during reunion) was coded by two different teams of coders to evaluate interrater reliability. One team of two coders observed maternal sensitivity during the play episode and a separate team of two coders observed maternal sensitivity during the reunion episode. Intraclass correlations between both coders for each of the five dimensions coded during play were, .89 (warmth), .77 (accepting), .81 (responsive), .94 (demanding, reversed), and .88 (sensitivity). Intraclass correlations between both coders for each of the five dimensions coded during reunion were, .89 (warmth), .88 (accepting), .91 (responsive), .91 (demanding, reversed), and .93 (sensitivity). Because these five scales were highly intercorrelated, *mean* $r_{play} = .51$ (range = .24–.74), *mean* $r_{reunion} = .71$ (range = .46–.91), we averaged each woman's score on all five dimensions, creating a single measure of maternal sensitivity during play and a single measure during reunion.

5.2.3. Coding of infant behaviors

An independent team of coders examined infant behavior during the reunion episode of the SFP. Behaviors were coded on a scale from 0 to 3 based on dimensions developed by Kogan and Carter's (1996) Post-Still-Face Reengagement Behavior Codes. In order to identify infants' behavioral reengagement and engagement strategies with their mothers, coders rated infant behaviors during the first 20 s of the reunion and then for the remainder of the reunion. The scores were then averaged to obtain infant behavioral scores for the entire reunion episode, as a paired samples *t*-test revealed there were no differences between scores coded in the first 20 s and those coded during the remainder of the reunion episode (all $ps > .19$). These behaviors included avoidance, resistance, and attention-seeking strategies. *Avoidance* was defined as the degree to which the infant actively turned away from and tried not to look at the mother; higher avoidance scores reflected increased avoidance. *Resistance* included the extent to which the infant fussed and protested while looking at the mother, as well as squirming and arching behaviors; higher resistance scores indicated greater resistance. *Attention-seeking* behaviors included the degree to which the infant tried to engage the mother by making eye contact and reaching toward her; higher attention-seeking scores reflected greater attention-seeking behaviors. Consistent with previous research (Kogan & Carter, 1996) we found a strong, significant, negative correlation between infant avoidance and attention-seeking, $r(85) = -.871$, $p < .001$. We therefore reverse-scored avoidance and aggregated the two variables into a single measure, which was conceptualized as attention to mother.

A subset of 15 tapes (16% of the sample) was randomly selected for double coding. Intraclass correlations between coders were .930 (avoidance), .949 (resistance) and .961 (attention-seeking).

5.2.4. Infant distress

Infant distress was coded during the play and reunion episodes in order to determine whether infants were indeed more behaviorally distressed during the reunion. Distress was coded using Weinberg and Tronick's (1994) Infant Engagement Phases, based on Tronick's Monadic Phases Scoring System. Specifically, infant distress was coded if the infant protested, cried, or fussed. Following Moore and Calkins (2004), infant distress was coded in 1-s intervals. Percentage scores of infant distress were calculated for both the play and reunion episode by summing the total number of seconds in each episode that distress occurred. This sum was then divided by the total interaction time per episode.

An independent team of coders were first trained on a large pool of pilot tapes until reliability was achieved. A random subset of tapes (21%) were then double-coded at various times throughout the coding process to insure reliability and prevent coder drift. Agreement was achieved when both coders observed the same behavior within 1-s of each other. Coders reliability observed infant distress ($\kappa = .81$).

5.2.5. Infant temperament

The Infant Behavior Questionnaire-Revised (IBQ-R; Gartstein & Rothbart, 2003) was used to assess, via maternal report, the infant's temperament. The IBQ-R is a 191-item questionnaire comprising 14 scales. Following Haley and Stansbury (2003) we computed negative temperament as: (Activity Level + Distress + Fear of Novelty) minus (Smiling + Soothability).

5.2.6. Infant heart rate, RSA, and movement measures

Infant physiological responses were collected with a 21-channel Bioamplifiers (model JCA-09). Film electrodes connected via alligator-clip electrode leads were used. Oil was removed from the skin with an alcohol wipe in order to improve electrode impedance. The experimenter placed electrodes axially on the left-rib and right-rib at the same elevation as the heart while the infant was seated on the mother's lap. The ground electrode was placed on the middle of the infant's back. The electrode lead was affixed using surgical tape so that an extra inch of slack was left to prevent from tugging of the electrode. The infant was then fitted with a gender-neutral color sleeper so that, although the infant's hands were free, she or he could not pull on the leads.

During the experimental session, physiological channels were sampled continuously with low-pass filtering at 1000 Hz. High pass filtering was recorded at .03 Hz. Artifactual epochs were edited manually for each channel. Consistent with previous research (Moore & Calkins, 2004), editing the files included the identification of outlier points relative to adjacent data and replacing them by determining the time between successive interbeat intervals. Data files that required editing more than 2–3% of the data were not included in the analyses. The data were then scanned graphically using the Statistical Analysis System (version 9.1) and outliers were removed. In addition, outliers that were more than 3 standard deviations above or below the mean were removed and replaced with the mean of the episode. Continuous measures of temperature and whole-body activity were also monitored, as movement could affect heart rate.

In order to obtain heart rate (HR) data, interbeat interval was first computed as the interval (in milliseconds) between successive R waves in the electrocardiogram (ECG). IBI was converted to instantaneous heart rate after editing R–R interval outliers due to movement artifacts or ectopic myocardial activity. RSA was computed using respiration and interbeat interval (IBI) data as outlined by Grossman's peak-valley technique (Grossman, 1983; Grossman, Karemaker, Wieling, 1991). The difference between the minimum IBI during inspiration and the maximum IBI during expiration, in seconds, was used to calculate RSA. The difference was computed twice for each respiration cycle; once for each inspiration and once for each expiration. Using this method, RSA was computed without being impacted by arrhythmia due to baroreceptor, thermoregulation, and tonic shifts in heart rate.

Movement was collected by placing a piezo-electric accelerometer (one axis) to the infant's high chair. The gain was adjusted to take into account stiffness of chair and the weight of participant. The average movement score was .0301 (range = 0–.12), with higher scores indicating greater movement. A score of 0 indicated that no movement was detected.

5.3. Missing data

Of the 95 dyads that participated in the 5-month assessment, 3 infants could not complete the SFP as they became too fussy, and subsequently more than 3% of the physiological data were lost. There were no differences in infant age, sex, infant avoidance, resistance, or attention-seeking, between infants with complete physiological data and those with missing data. One additional videotape was lost because of video problems. In all, data were available for $n = 91$ infants. With α set to .05, 91 infants provided power of .90 or greater to detect medium effect sizes, and .75 or greater to detect a small effect sizes in either GLM or multivariate regression analyses with up to 5 predictors (Cohen, 1988).

6. Results

6.1. Preliminary analyses

Prior to conducting our main analyses, we evaluated our central variables for demographic effects to determine whether covariates would be needed. The means and standard deviations of all variables tested are presented in Table 1. There were no significant associations between maternal sensitivity (observed during play or reunion), infant physiology, and infant behavior during the SFP and demographic variables that comprised maternal age, household income, ethnicity, marital status, child age, and child gender ($ps > .29$). Using repeated measures ANCOVAs, we also examined whether there were

Table 1
Descriptive information of variables of interest for sample.

Variable	*M* (%)	*SD*
Maternal age (years)	24.11	4.77
Maternal household income	3.30	1.52
Maternal ethnicity		
European American	81%	
African American	2.9%	
Hispanic	5.8%	
American Indian	3.8%	
Asian	1%	
Another group	5.7%	
Maternal marital status		
Living with partner	43.5%	
Married	37.6%	
Infant age (weeks)	20.99	2.55
Gender		
Boys	$n = 42$	
Girls	$n = 53$	
Infant negative temperament (IBQ)	.067	2.37
Infant movement	.03	.018
Maternal sensitivity during play	3.69	.67
Maternal sensitivity during reunion	2.99	.95
Infant HR (bpm)		
Baseline	137.95	9.74
HR 1	138.23	11.08
HR 2	149.10	13.25
HR 3	150.11	17.32
Infant RSA		
Baseline	.0142	.0174
RSA 1	.0170	.0130
RSA 2	.0141	.0067
RSA 3	.0141	.0064
Infant attention	1.26	.79
Infant resistance	1.14	1.14

Note: Maternal household income (3 = $10,000–20,000); HR = heart rate; RSA = Respiratory Sinus Arrhythmia; HR (RSA)1 = heart rate (RSA) during the face-to-face play episode; HR (RSA)2 = heart rate (RSA) during the still-face episode; HR (RSA)3 = heart rate (RSA) during the reunion episode.

Table 2
Correlations between maternal sensitivity, infant behavioral, and infant physiological variables.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Maternal sensitivity during play	–													
2. Maternal sensitivity during reunion	.448**	–												
3. HR baseline	−.193	−.155	–											
4. HR play	−.237*	−.274**	.210*	–										
5. HR still-face	−.163	−.264**	.072	.677**	–									
6. HR reunion	−.189	−.396**	.104	.615**	.823**	–								
7. RSA baseline	.079	−.123	−.225*	.088	−.038	−.026	–							
8. RSA play	.048	−.050	.013	−.144	.050	−.080	.043	–						
9. RSA still-face	−.011	−.132	−.014	−.090	−.089	−.124	.086	.861**	–					
10. RSA reunion	.010	.028	−.052	−.126	−.074	−.232*	−.056	.706**	.760**	–				
11. Infant attention	.248*	.485**	−.068	−.226*	−.349**	−.528**	.115	.079	.054	.150	–			
12. Infant resistance	−.257*	−.382**	.001	.280**	.574**	.721**	−.149	−.042	−.081	−.144	−.577**	–		
13. Infant movement	−.144	−.179*	.149	.372**	.275**	.222*	.100	−.018	−.057	−.103	−.075	.296**	–	
14. Infant negative temperament	.005	−.248*	−.030	.060	.057	−.011	.045	−.032	.038	−.008	−.026	−.001	.081	–

Note: $n = 91$, HR = heart rate, RSA = Respiratory Sinus Arrhythmia.
* $p < .05$.
** $p < .01$.

differences in infants' physiological responses across the SFP episodes while covarying our different demographic variables. None of the main or interaction effects were significant ($ps > .10$).

Pair *t*-tests did reveal, however, that the SFP generally produced the expected change in infants' HR and RSA (physiological means presented in Table 1). Specifically, whereas there was no significant change in mean HR between baseline and play, there was a significant increase in HR from the play to the still-face episode, $t(89) = -9.07$, $p < .001$. This change is consistent with increased cardiac arousal typically seen during the SFP. However, contrary to prediction, there was no significant difference in HR between the still-face and reunion episodes, suggesting that infants typically did not recover physiologically once their mothers were able to resume unconstrained interaction.

A similar pattern emerged for infant RSA. Specifically, there was a significant increase in RSA from the baseline to the play episode, $t(89) = -2.83$, $p = .006$. Infants' RSA decreased significantly between the play and still-face episodes, $t(89) = 3.27$, $p = .001$, which is consistent with parasympathetic withdrawal during distress. As with HR, there was no significant difference in RSA between the still-face and reunion episodes.

We next compared the mean levels of distress during the play and reunion episodes in order to provide a validity check and to confirm that infants did indeed exhibit more distress during the reunion episode as compared to play. Consistent with results from a recent meta-analysis (Mesman et al., 2009), pair *t*-tests revealed that infants exhibited significantly more distress during the reunion episode ($M = 23.04$, $SD = 32.64$) as compared to the play episode ($M = 5.92$, $SD = 10.58$), $t(89) = -5.11$, $p < .001$.

Table 2 presents the correlations among all study variables. As temperament-linked differences in negative reactivity might account for observed differences in physiological reactions during the SFP (Rothbart & Bates, 2006), following Haley and Stansbury (2003) we examined correlations between infant negative temperament and our major study variables. We found that maternal sensitivity during reunion was inversely related to infant negative temperament ($r(89) = -.248$, $p = .016$). Consequently, we control for infant negative temperament in our multivariate regression models. Infant movement during the SFP might also account for observed differences in physiological reactions during the SFP. We found that infant movement during the still-face paradigm was positively associated infant HR during the play ($r(89) = .372$, $p < .001$), still-face ($r(89) = .275$, $p = .007$), and reunion ($r(89) = .222$, $p = .033$) episodes, but was uncorrelated with RSA. Infant movement was also significantly correlated with infant behavioral resistance, $r(89) = .296$, $p = .004$. Following recommendations by Bazhenova, Plonskaia, and Porges (2001), we also control for movement in subsequent analyses.

We next focus on associations among maternal sensitivity, observed in both contexts, and infant bio-behavioral responses across the SFP. Notably, there was moderate concordance between maternal sensitivity during play and reunion ($r(89) = .448$), providing support for the validity of our measure of sensitivity as well as evidence of moderate continuity of maternal behavior across context. Different associations between maternal sensitivity and infant physiology emerged depending upon physiological system and context in which maternal sensitivity was observed. Maternal sensitivity during play and reunion was not significantly related to infants' baseline HR or RSA. Maternal sensitivity in both contexts was not related to infant RSA during any of the SF episodes. Only one significant correlation emerged between maternal sensitivity during play and infant HR: maternal sensitivity during play was significantly and negatively correlated with infant HR during play. Maternal sensitivity during reunion was significantly and negatively correlated with infant HR during all three episodes of the SFP. Women observed as more sensitive during the reunion had infants who demonstrated lower HR during these episodes, suggesting a decrease in cardiac arousal during reunion. With regard to infant behavior, we found that women who

exhibited more sensitivity during the play and reunion episodes had infants who resisted their mothers less, and exhibited greater levels of attention toward their mothers.

Infants also exhibited concordance in behavior and physiology during the SFP, depending on physiological system. Infant attention and resistance were not significantly related to infant RSA during baseline or the SFP. Both forms of infant behavior showed fairly similar though reversed patterns of association with infant HR during each of the SFP episodes. Specifically, infant's attention and resistant behavior to the mother were not related to baseline HR, but were related during subsequent episodes, such that infants who directed greater attention to their mothers had lower HR during the still-face and reunion episodes, and infants who exhibited higher resistant behavior demonstrated higher HR during these episodes. Notably, infant negative temperament was not correlated with the infant behaviors during the reunion episode. Thus, other factors, such as the behavioral interactions between mother and infant, might be affecting the degree to which the infants are displaying attention toward the mother and resistance behaviors during the reunion.

6.2. Is maternal sensitivity during play and reunion related to change in infant physiology during the still-face paradigm?

6.2.1. Infant heart rate

We used hierarchical regression models to examine the independent and joint contributions of maternal sensitivity during the play and reunion episodes to changes in infant HR from the still-face to the reunion episode of the SFP. Infant HR during the still-face episode, infant movement, and infant negative temperament were entered as controls on the first step of a hierarchical regression model. Infants' HR during reunion served as criterion. Maternal sensitivity during play and reunion was added to the model on the second step. As shown in Table 3 (Model 1), infant HR during the still-face episode and maternal sensitivity during reunion significantly predicted change in infant HR from the still-face to the reunion episode. Infant HR increased across the still-face to the reunion episode with decreased levels of maternal sensitivity during reunion. Infant negative temperament was a marginally significant predictor of change in infant HR from the still-face to the reunion episode. Interaction terms were also tested, but were dropped because they were non-significant.

6.2.2. Infant RSA

The same analysis was repeated with infant RSA during the still-face included in the first step and infant RSA during reunion as criterion. As shown in Table 3 (Model 2), infant RSA during the still-face and maternal sensitivity during reunion were significantly predictive of change in RSA from the still-face to the reunion episode. Infant RSA increased with greater

Table 3
Maternal sensitivity during play and reunion and associations with infant physiology and behavior.

Model 1	Infant HR during reunion				
	B	(SE)	*β*	*t*	*p*
HR during still-face	1.01	.08	.78	12.83	.001
Infant movement during SFP	−38.73	57.21	−.04	−.68	.50
Infant negative temperament	−.82	.42	−.12	−1.94	.06
Maternal sensitivity during play	.976	1.64	.038	.60	.55
Maternal sensitivity on reunion	−4.37	1.23	−.24	−3.57	.001
Model 2	**Infant RSA during reunion**				
	B	(SE)	*β*	*t*	*p*
RSA during still-face	.54	.07	.67	8.29	.001
Infant movement during SFP	−.02	.03	−.04	−.50	.62
Infant negative temperament	.00	.01	.02	.20	.84
Maternal sensitivity during play	.00	.00	−.06	−.62	.54
Maternal sensitivity on reunion	.00	.00	.19	1.96	.05
Model 3	**Infant attention to the mother**				
	B	(SE)	*β*	*t*	*p*
Infant movement during SFP	.65	4.12	.02	.16	.87
Infant negative temperament	.03	.03	.10	1.02	.31
Maternal sensitivity during play	.03	.12	.03	.26	.79
Maternal sensitivity on reunion	.41	.09	.50	4.61	.001
Model 4	**Infant resistance during reunion**				
	B	(SE)	*β*	*t*	*p*
Infant movement during SFP	14.02	6.10	.22	2.30	.02
Infant negative temperament	−.05	.05	−.10	−1.05	.30
Maternal sensitivity during play	−.13	.18	−.08	−.74	.46
Maternal sensitivity on reunion	−.40	.13	−.33	−3.00	.004

levels of maternal sensitivity during reunion, suggesting that these infants were making active attempts at coping. Interaction terms were also tested, but were dropped because they were non-significant.

6.3. Is maternal sensitivity during play and reunion predictive of infant behaviors during the reunion episode?

6.3.1. Infant attention to the mother

Hierarchical regression models were used to examine the independent contributions of maternal sensitivity during play and reunion to infant behaviors during the reunion episode. Infant movement was entered on the first step as a control, followed by infant negative temperament. Maternal sensitivity during the play and reunion episodes was entered on the second step. As shown in Table 3 (Model 3), only maternal sensitivity during reunion significantly predicted infant attention to the mother during the reunion episode; higher levels of maternal sensitivity during the reunion episode was associated with greater infant attention to mother.

6.3.2. Infant resistance

The same analyses were repeated using infant resistance as the criterion. As shown in Table 3 (Model 4), both infant movement and maternal sensitivity during reunion significantly predicted infant resistance during the reunion episode; more movement and lower levels of maternal sensitivity during the reunion episode were associated with greater infant resistance of mother on reunion.

In sum, these analyses suggest that there is something unique about maternal sensitivity in response to infant distress as it relates to physiological and behavioral regulation following a social stressor, above and beyond maternal sensitivity exhibited while mothers interact with their infants while at play.

6.4. Are infant behaviors on reunion related to changes in infant physiology during the still-face paradigm?

The correlations discussed above provide an initial picture of the association between infants' physiology and their behavior. However, we wanted to explore whether changes in infant physiology from the still-face to the reunion episode were associated with the infants' behavior during reunion. We tested separate regression models, one using infants' HR, one using infants' RSA as criterion during reunion. In the first model, infant HR during the still-face episode, infant negative temperament, and infant movement were entered on the first step of a hierarchical regression model. Infant attention to the mother and resistance were both included in step 2 as predictors. In these models, infant movement was unrelated to changes in HR or RSA. However, as shown in Table 4 (Model 1), infants' resistance and attention were each associated with significant change in HR from the still-face to the reunion episodes. Specifically, greater infant resistance during reunion was associated with a significant increase in the mean HR levels from still-face to reunion, whereas greater attention to mother was associated with a significant decrease in mean HR levels from still-face to reunion. As shown in Table 4 (Model 2), infant attention was associated with significant change in RSA from the still-face to the reunion episode. Greater attention to the mother was associated with an increase in RSA from still-face to reunion. Infant resistance, however, did not contribute significantly to changes in infant RSA from still-face to reunion.

6.5. What are the contributions of maternal sensitivity and infant behavior to changes in infant physiology from still-face to reunion?

In a final set of analyses, we examined the simultaneous contributions of maternal sensitivity and infant behavior to changes in infant HR and RSA from the still-face to the reunion episode. Given our theoretical interest in the predictive power of maternal sensitivity measured during two different contexts (low distress and higher distress contexts), we first examined maternal sensitivity during the play in two separate models, one for HR and one for RSA. In our first two hierarchical regression models, infant physiology during the still-face episode, infant movement, and infant negative temperament were entered as controls on the first step, with maternal sensitivity during play, infant resistance and attention to the mother entered on a second step. Maternal sensitivity during play did not significantly predict change neither in HR nor in RSA from the still-face to the reunion episode. Infant resistance significantly predicted change in HR, but not change in RSA, from the still-face to the reunion episode; greater levels of infant resistance predicted an increase in HR from the still-face to the reunion episode. Infant attention to the mother was a significant predictor of change in HR and change in RSA from the still-face to the reunion episode. Greater levels of attention predicted an increase in RSA from the still-face to the reunion episode, reflecting infants' attempts at coping.

In our final two models, we include maternal sensitivity during play and reunion to examine whether sensitivity measured in different contexts is predictive of change in physiology from a stressful episode to a reunion episode. We also were interested in the unique contributions of maternal sensitivity and infant behavior to change in HR and RSA from the still-face to the reunion episode. In separate hierarchical regression models for HR and RSA, we entered infant physiology during the still-face, infant movement, and infant negative temperament in step 1 as controls, and infant attention to the mother, infant resistance, and maternal sensitivity during play and reunion in step 2. Infant HR or RSA during reunion served as criterion in their own models, the results of which are presented in Models 3 and 4 of Table 4. In the first model, infant HR during still-face, infant resistance, and maternal sensitivity during reunion each predicted significant change in infant HR

Table 4
Change in infant physiology from still-face to reunion and associations with maternal sensitivity and infant behavior.

Model 1	Infant HR during reunion				
	B	(SE)	*β*	*t*	*p*
HR during still-face	.803	.08	.62	10.12	.001
Infant movement during SFP	−58.03	50.34	−.06	−1.15	.25
Infant negative temperament	−.30	.36	−.04	−.86	.39
Infant attention to the mother during reunion	−3.16	1.36	−.14	−2.32	.023
Infant resistance to the mother during reunion	4.60	1.08	.303	4.25	.001
Model 2	Infant RSA during reunion				
	B	(SE)	*β*	*t*	*p*
RSA during still-face	.52	.06	.64	8.13	.001
Infant movement during SFP	−.02	.03	−.06	−.70	.49
Infant negative temperament	.00	.00	−.02	−.30	.76
Infant attention to the mother during reunion	.00	.00	.22	2.35	.02
Infant resistance to the mother during reunion	.00	.00	.02	.18	.86
Model 3	Infant HR during reunion				
	B	(SE)	*β*	*t*	*p*
HR during still-face	.80	.08	.62	10.12	.001
Infant movement during SFP	−64.00	50.75	−.07	−1.26	.21
Infant negative temperament	−.53	.37	−.07	−1.42	.16
Maternal sensitivity during play	1.71	1.42	.07	1.20	.23
Maternal sensitivity during reunion	−2.32	1.17	−.13	−1.98	.05
Infant resistance to mother during reunion	4.55	1.09	.30	4.18	.001
Infant attention to mother during reunion	−2.22	1.46	−.10	−1.52	.13
Model 4	Infant RSA during reunion				
	B	(SE)	*β*	*t*	*p*
RSA during still-face	.53	.07	.65	8.04	.001
Infant movement during SFP	−.02	.03	−.05	−.60	.55
Infant negative temperament	.00	.00	.00	−.02	.99
Maternal sensitivity during play	.00	.00	−.06	−.68	.50
Maternal sensitivity during reunion	.00	.00	.09	.86	.39
Infant resistance to mother during reunion	.00	.00	.02	.24	.81
Infant attention to mother during reunion	.00	.00	.20	1.90	.06

from still-face to reunion. Specifically, infants' HR increased from still-face to reunion at higher levels of resistance and at lower levels of maternal sensitivity during the reunion episode. In a model with infant RSA during reunion as criterion, infant RSA during still-face was a significant predictor of change in RSA from still-face to reunion. Higher levels of RSA during the still-face episode predicted higher levels of RSA during reunion. Infant attention was a marginally significant predictor of change in RSA from still-face to reunion. Infant RSA increased from the still-face to the reunion episode as infant attention toward the mother increased during reunion. Again, follow-up interaction terms were included in the above models, none of which added significantly.

In sum, low maternal sensitivity and higher infant resistance during reunion were uniquely associated with further cardiac arousal during the reunion phase of the still-face. However, only infants' attention to mother, and not maternal sensitivity, was related to increased RSA or increased physiological regulation.

7. Discussion

Research has established that social regulation processes, particularly parent-infant interaction patterns during times of stress, and infants' own coping behaviors, typically attending to a caregiver early in life, are associated with infants' psycho-physiological functioning (Tronick, 2007). Less clear at this point, however, is the relative importance of these two factors, which may vary in salience depending on the nature of the infants' stressful experiences, the developmental state of the infant, and the specific physiological system (Spangler, Schieche, Ilg, Maier & Ackermann, 1994). The findings from the current study point to the regulatory importance of both maternal behavior and infants' nascent coping abilities in their psychophysiological response and recovery to a social stressor. The results also suggest, however, that the infants of mothers who are more sensitive following a stressful episode may already be expressing competent coping behaviors that are both independent of maternal effects and that have differential associations with specific aspects of psychophysiological regulation.

Consistent with our hypotheses, we found that maternal sensitivity during and following distress uniquely predicted infant physiological and behavioral reactivity and regulation, independent of maternal sensitivity during a play episode. These findings highlight the importance of studying maternal sensitivity in different contexts, as it may be predictive of differences in later adaptation (Bornstein & Tamis-LeMonda, 1997; Leerkes et al., 2009; McElwain & Booth-LaForce, 2006). For example, greater sensitivity to infant distress is uniquely predictive of security of attachment, fewer problem behaviors, greater social competence, and, as evidenced by this study, physiological and behavioral regulation. However, maternal sensitivity to non-distress also is predictive of important developmental outcomes. For example, Bornstein and Tamis-LeMonda (1997) found that maternal sensitivity during non-distress was uniquely predictive of infant cognitive development. Thus, there may be processes occurring during lower stress contexts that supports infant cognition, with different mechanisms influencing infant regulation during more emotionally charged contexts. Caregivers who are more sensitive during both contexts may be an important population worth examining further, as Leerkes et al. (2009) found that it was the toddlers of these caregivers who exhibited better affect regulation. Future research should investigate associations between caregiving sensitivity in multiple contexts, and diverse cognitive, social, and emotional outcomes.

These results also uniquely contribute to the literature on maternal sensitivity to distress and non-distress contexts by examining these relations in a paradigm designed to elicit a stress response from infants. A majority of the empirical work comparing maternal sensitivity during distress and non-distress has examined maternal sensitivity during a play period, during which infants were not as likely to be distressed for long periods of time, and thus, the validity of maternal sensitivity may be questioned (Leerkes et al., 2009). Our results extend these findings as we found that maternal sensitivity during and following distress to be associated with infant biobehavioral regulation following a context designed to elicit a more prolonged stress response from the infants.

Our finding that infants' physiological and behavioral response to the SFP was related to maternal sensitivity during reunion was both predicted and in keeping with prior work (Haley & Stansbury, 2003; Ham & Tronick, 2006; Mesman et al., 2009; Spangler et al., 1994). As has been demonstrated previously in primarily middle class samples, the infants of more as well as less sensitive mothers showed similar physiological response to the stress of maternal unavailability during the still-face episode in the form of increased heart rate and deceased RSA. The current results suggest that the procedure is sufficiently stressful for a sample of 5 months old whose mothers are living in poverty, and who had originally been screened into the study based on the assessed likelihood that their infants would be at increased risk of experiencing a broader range of contextual and, possibly interpersonal stressors.

A striking difference emerged between groups of infants in how they recovered from the stressful effects of maternal non-responsiveness. Specifically, once mothers were instructed to resume normative interaction, the infants of less sensitive mothers during the reunion manifested a pattern of physiological arousal that was characterized by greater cardiac arousal and lowered parasympathetic regulation. Consistent with a biobehavioral view of emotion regulation (Calkins & Fox, 2002), these infants also directed greater behavioral resistance toward and were less attentionally engaged with their mothers during the reunion phase, relative to the infants of more sensitive mothers during reunion. In general, the link between parental non-responsiveness and infants' negative affect has been found previously (Braungart-Rieker et al., 1998; Haley & Stansbury, 2003; Rosenblum et al., 2002). However, the current findings also suggest that some infants became more distressed when able to resume normative interaction with their mothers.

Two interrelated interpretations seem plausible here. The first emphasizes the quality of maternal care (Weinberg & Tronick, 1996), both historically and more immediately during the SFP reunion. Mothers who are less responsive and contingent when their infants are distressed miss the opportunity to provide their child with an external source of regulation which appears related to their infants' autonomic and behavioral distress. It also may be that these infants are developing less effective social regulatory strategies in the context of this early relationship. This pattern at 5 months portends the type of attachment pattern seen in anxious-resistant infants at 12 months and beyond (Cohn, Campbell, & Ross, 1991; Rosenblum et al., 2002; Spangler & Grossmann, 1993).

The infants of more sensitive mothers during reunion exhibited the opposite pattern, indicating increased physiological and behavioral regulation during the reunion episode. Consistent with prior research, we found that the infants of more sensitive mothers during reunion exhibited more attentional engagement behaviors, often referred to in the literature as social attend (Kogan & Carter, 1996; Rosenblum et al., 2002). These behaviors suggest that infants look to and utilize their mothers for soothing. In all likelihood, the infants of more sensitive mothers during reunion are developing the capacity to benefit from their mother as an external source of regulation. These behaviors also may be an early indication of competent autonomous self-regulation.

Attachment researchers (Cassidy, 1994; Schore, 2000, 2001) have proposed that attachment can be considered a regulatory theory, as, during times of stress, caregiver and infant are engaged in co-regulation to alleviate distress. For instance, infants who are secure use their caregiver to self-regulate and openly communicate their needs when distressed (Cassidy, 1994). The sensitive, responsive mother then is attuned to these cues and aids the infant in regulation. Infants who are insecurely attached, particularly avoidant infants, tend to restrict or minimize their outward expression of emotions during times of stress (Cassidy, 1994), although physiologically they may be just as aroused as secure infants (Spangler & Grossmann, 1993). Mothers of avoidant infants may be less sensitive and more intrusive (Isabella & Belsky, 1991). This theory is consonant with the differences we found in the infants' bio-behavioral regulation in response to mothers of varying degrees of sensitivity. Infants who demonstrated more avoidance had mothers who were less sensitive, and these infants also exhibited a continuous increase in HR from the still-face to the reunion, whereas infants whose mothers were more sensitive directed

their attention to the mother upon reunion. In the future, we plan to investigate whether differences in attachment security can be predicted from infant bio-behavioral regulation during the SFP, from as young as 5 months of age.

The finding that infants' physiological and behavioral regulation was highly associated contributes to current theories of the physiological underpinnings of social engagement and disengagement. Porges' Social Engagement System model (see Bazhenova et al., 2001) predicts that greater parasympathetic activity should be associated with more environmental engagement. Indeed, when Porges and colleagues examined infant parasympathetic regulation during the still-face episode with a stranger, followed by a reunion period, they found a relation between positive engagement (defined as looking at a stranger with an absence of negative affect) and an increase in RSA during the reunion episode (Bazhenova et al., 2001). These researchers hypothesized that RSA may "reflect an emotional aspect of positive engagement" (Bazhenova et al., 2001, p. 1324). Our findings replicate and extend this work as we found that infant attentional engagement behaviors predicted greater increases in RSA, not with a stranger, but with the infant's mother.

Perhaps most novel here are the specific patterns of association found between infants' different behaviors and cardiac arousal versus parasympathetic changes from still-face to reunion. Although maternal sensitivity during reunion predicted change in HR from the still-face to the reunion episode, infant resistance and less attentional engagement also uniquely accounted for increased cardiac arousal. In the absence of temporal precedence, we cannot be sure of the direction of effect-physiology predicting behavioral change or behavior predicting physiological change. Like others (Tronick, 2007), it may be that the infants' resistance is a behavioral response to current and/or prior patterns of mother–infant interaction that reflect some level of ineffectual, possibly disorganized self-regulatory behavior. Another view, however, is that, at 5 months, infants' resistance may be more proximal to their psychobiology than maternal behavior.

Although maternal sensitivity remained a marginally significant predictor of RSA change from still-face to reunion, infant attentional engagement but not resistant behavior was uniquely associated with increased parasympathetic regulation. If infant resistance can be conceptualized as a failure to use a social partner to help regulate one's response to a social stressor, infant attention toward the mother may reflect infants' capacity to engage and to use their mother to regulate following a stressor. Although this is a new finding and requires replication, it is compelling that 5-month-old infants' behavior may already play a unique role in physiological regulation following the still-face.

The current study is not without limitations. The regression analyses should be interpreted with caution, as we are unable to infer a causal direction with these data. Both mother and infant are contributing to the dyadic relationship and each other's behavior; there is a bi-directional association between infant regulation and maternal behavior. We believe our findings to be robust, however, as we tested change in infant physiology using strict, autoregressive models. In addition, although we controlled for infant temperamental distress, it is possible that alternative infant characteristics, such as positivity, could influence how sensitive a mother may appear to be. Finally, we identified significant associations between our predictors (e.g., sensitivity during play and reunion, infant resistance, and infant attention toward the mother). We must therefore be cautious not to over-interpret the uniqueness of any of our predictors.

Future studies could examine sensitivity during face-to-face interactions as well as maternal sensitivity in different contexts, including the home, so that our findings can be replicated using an independent measure of maternal sensitivity. Future research also could examine, in a time-series model, the physiological and behavioral synchrony among mothers and infants, as this may be related to the regulation of the dyadic interaction. In this manner one can infer direction of change; how maternal behavior affects infant physiology and behavior and vice-versa.

To our knowledge, our study is the first to find both unique relations between maternal sensitivity during and following distress and infant biobehavioral regulation in a sample characterized by poverty-related environmental risk. Our results highlight the importance of understanding how caregiving behaviors support the development of emerging emotion regulatory capacities in infancy, and how, already at 5 months, infants are expressing coordinated bio-physiological regulation. Our findings regarding the unique association between maternal sensitivity during and following distress and infant biobehavioral reactivity and regulation may inform and add specificity to interventions in infancy.

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