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Pregnant Women's Autonomic Responses to an Infant Cry Predict Young Infants' Behavioral Avoidance During the Still-Face Paradigm

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Research suggests that women's autonomic nervous system responses to infant cries capture processes that affect their parenting behaviors. The aim of this study was to build on prior work by testing whether pregnant women's autonomic responses to an unfamiliar infant crying also predict their infants' emerging regulation abilities. Participants included 97 women in their third trimester of pregnancy, located in the United States. Most participants identified as White/non-Hispanic (48%) or Hispanic (30%), their mean age was approximately 30 years, and the modal family income was $40,000–$79,999. Pregnant women's respiratory sinus arrhythmia (RSA) and skin conductance levels (SCL)—which are thought to capture emotional engagement and behavioral inhibition, respectively—were measured while the women watched a relaxing video and a video of an unfamiliar infant crying. Approximately 7 months later, women and their infants completed the still-face paradigm (SFP). Infants' avoidance and resistance behaviors during the SFP reunions were rated. Pregnant women's RSA and SCL responses to the infant cry video uniquely predicted infants' avoidance (but not resistance) during the SFP. Infants displayed higher levels of avoidance when their mothers exhibited lower levels of RSA reactivity or when their mothers exhibited higher levels of SCL activity in response to the infant cry video. Maternal sensitivity during mother–infant free-play interactions did not mediate the associations between pregnant women's autonomic responses to the cry video and infants' avoidant behavior during the SFP. Discussion focuses on potential mechanisms underlying associations between pregnant women's autonomic responses to infant distress and infants' socioemotional development.

Public Significance Statement

Autonomic markers of pregnant women's emotional responses to an unfamiliar infant crying collected before the birth of their child could predict their young infants' later socioemotional behaviors. Because infant development provides a foundation for later social and emotional development, these findings suggest that interventions targeting pregnant women's emotional responses to infants' distress cues may lead to improvements in children's socioemotional outcomes.

Keywords: infant cry, respiratory sinus arrhythmia, electrodermal activity, still-face paradigm, maternal sensitivity

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Crying is a social communication signal commonly expressed by infants during the first year of life (Esposito & Bornstein, 2019; Vermillet et al., 2022). Infants cry when they feel discomfort, and the cry serves the purpose of eliciting a parental response (Bell & Ainsworth, 1972; Bowlby, 1969/1982). Parents' behavioral responses to infants' cries and other distress signals are theoretically expected to

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shape children's socioemotional development by scaffolding the development of self-regulation and contributing to a positive representation of the self and others (Leerkes et al., 2009; Sroufe, 1997; Thompson, 1997). Indeed, empirical data indicate that parental sensitivity in response to infant distress predicts infant–parent attachment security, child social competence, and fewer child behavior problems (Bornstein & Tamis-Lemonda, 1997; Leerkes, 2011; Leerkes & Zhou, 2018; Leerkes et al., 2009, 2011; McElwain & Booth-LaForce, 2006; Wright et al., 2018).

Parents' autonomic nervous system responses to their infants' distress are also associated with infants' early socioemotional development (Groh et al., 2019; Hill-Soderlund et al., 2008; Leerkes et al., 2017). For example, Groh et al. (2019) reported that a lesser degree of maternal respiratory sinus arrhythmia (RSA) withdrawal during a distressing caregiving task when infants were 6 months old predicted greater infant avoidance when infants were 12 months old. One possible explanation for these findings is that parent's autonomic responses to infant cries capture psychological processes that shape how parents interact with their infants and therefore their infants' development. An alternative possibility is that infants elicit different autonomic responses from their parents. In the current study, we attempt to address this issue by assessing whether pregnant women's autonomic responses to unfamiliar infant cries predict their infant's later regulation abilities. Autonomic responses in this context are thought to reflect emotional responding to infant distress cues, and are expected to affect infant regulation indirectly via differences in parenting behaviors. Capturing parents' emotional responding prior to the birth of the child will clarify the role of parents' autonomic responses in potentially shaping children's developmental outcomes. In addition, a better understanding of the predictive power of maternal responses to infant cry signals during the prenatal period will help with earlier identification of risk factors for problems related to infants' regulatory outcomes even before the child is born.

Adults' Autonomic Responses to Infant Cries

Measures of individuals' autonomic nervous system responses to stimuli are commonly used to capture cognitive and emotional reactions that may be automatic and less susceptible to response biases than are self-report questionnaires and behavioral observations (Dennis et al., 2012; Raby et al., 2015). One commonly investigated measure of parasympathetic nervous system activity is RSA. RSA refers to the heart rate accelerations and decelerations as a function of respiration via the vagus nerve (Shaffer et al., 2014). According to polyvagal theory (Porges, 2007), engagement in social relationships is supported by increased vagal influence on the heart. From this perspective, decreases in RSA in response to a challenging interpersonal situation reflect emotional engagement and coping with the demands of the social task. Likewise, a lack of RSA decreases in these situations is thought to reflect difficulties in social and emotional regulation (Porges, 2007). It is important to note that the implications of RSA reactivity appear to vary based on the nature of the task (Beauchaine et al., 2019). However, within the context of caring for a young child, decreases in RSA are generally thought to facilitate a parent's capacity to sensitively respond to their child's emotional signals (e.g., Mills-Koonce et al., 2007; Moore et al., 2009; Xu & Groh, 2023).

A growing number of studies appear to support the idea that RSA reductions in response to infant distress reflect psychological processes that support responsive caregiving. For example, blunted maternal RSA reductions in response to their own infants' displays of negative emotions have been associated with less maternal sensitivity (Mills-Koonce et al., 2007; Moore et al., 2009; cf. Leerkes et al., 2017). Likewise, pregnant women who exhibit minimal changes in RSA levels in response to audio- or video-recorded cries of unfamiliar infants tend to report more negative perceptions of infants' cries and lower levels of observed maternal sensitivity (Ablow et al., 2013; Joosen, Mesman, Bakermans-Kranenburg, Pieper, et al., 2013; Leerkes, Su, et al., 2016). To the best of our knowledge, there are no data that relate pregnant women's RSA responses to an unfamiliar infant cry and their infants' later social and emotional outcomes. However, a lack of RSA decreases while interacting with one's own distressed infant is associated with infant attachment insecurity (Groh et al., 2019; Hill-Soderlund et al., 2008).

A second commonly investigated measure of parents' autonomic nervous system activity is skin conductance levels (SCL). SCL is driven by sympathetic nervous system arousal (Dawson et al., 2017), and increases in SCL in response to a stressful task may reflect attempts to inhibit emotional expressions or behavior (Fowles, 1980, 1988). Based on this perspective, increases in SCL in response to infant crying may be associated with less sensitive parental responses to infant distress, which in turn will fail to support young children's emerging abilities to effectively regulate their own emotions and behaviors. Indeed, SCL increases in response to audio-recordings of an unfamiliar infant crying have been associated with more negative emotional reactions to the infant cry, more harsh discipline practices, and less sensitive parenting (Emery et al., 2014; Joosen, Mesman, Bakermans-Kranenburg, & van IJzendoorn, 2013), although null findings have also been reported (Leerkes et al., 2023, Leerkes, Gedaly, & Su, 2016). Although these findings may suggest that increases in SCL in response to infant cries are associated with parenting-related emotions and behaviors, we are not aware of any studies testing whether increases in SCL in response to unfamiliar infants' crying are associated with infants' later socioemotional outcomes.

In considering to consider potential main effects of RSA and SCL responses to unfamiliar infant cries, Leerkes et al. (Leerkes et al., 2015; Leerkes, Gedaly, & Su, 2016) have proposed that parents' RSA and SCL responses to infant distress signals may interact with one another to predict parent and infant outcomes. According to this perspective, it is the combination of both high physiological arousal (as indexed by SCL increases) and high physiological regulation (as reflected by RSA decreases) in response to infant distress that supports appropriate parental responses. Indeed, RSA and SCL responses to unfamiliar infant cries interacted in this manner to predict mothers' empathetic assessments of the unfamiliar infant's cry as well as maternal sensitivity when interacting with their own infants (Leerkes et al., 2015, 2023; Leerkes, Gedaly, & Su, 2016). Moreover, infants were less likely to develop secure attachments and more likely to develop a disorganized attachment if their mothers exhibited both high SCL reactivity and a lack of RSA declines in response to their own infants' distress (Leerkes et al., 2017; Leerkes, Su, et al., 2016).

Altogether, these findings suggest that adults' autonomic responses to an unfamiliar infant's crying reflect emotional processes that may contribute to how they will ultimately interact with their own infants. It remains unclear, however, if adults' autonomic responses to videos of unfamiliar infants also shape infants' socioemotional development. As previously noted, existing research in this area has focused on parents' autonomic responses during parent–infant interactions (e.g.,

Groh et al., 2019; Hill-Soderlund et al., 2008; Leerkes et al., 2017). However, given the transactional nature of parent–child interactions, it is possible that parents' autonomic responses in these contexts may be due to child-driven effects on parents' autonomic responses (e.g., DePasquale, 2020; Gao et al., 2022; Ostlund et al., 2017). Controlling for infant characteristics in analyses is an imperfect solution due to measurement error and the inability to assess all relevant infant characteristics. The present study more directly addresses this issue by testing whether women's responses to infant distress while they were pregnant predicted their infants' socioemotional outcomes at age 7 months. By assessing women's autonomic responses to infant cry stimuli prior to the birth of their child, this approach eliminates the possibility that variability in parents' emotional responses during the cry are due to individual differences in their own infant's characteristics or behavior. As previously noted, we are not aware of any studies that have utilized this type longitudinal design to assess whether women's autonomic responses to infant cry stimuli while they are pregnant predict later infant outcomes. Addressing this gap will help us clarify the predictive nature of parents' responses to infant distress.

Infant Behavior During the Still-Face Paradigm

The still-face paradigm (SFP; Tronick et al., 1978) is a well-validated, structured laboratory task for assessing infants' early socioemotional development. During the SFP, the parent is first instructed to first sit across from their infant and play with them as they normally would for 2 min. Then, the parent is asked to display a neutral facial expression, remain still, and not respond to the infant for 2 min. Most infants respond to the psychological separation from the parent during the still-face episode with decreases in positive affect and increases in negative affect (Mesman et al., 2009). Finally, the parent is instructed to resume normal interaction with the infant for an additional 2 min.

During the reunion episode of the SFP, infants, and parents engage in a mutually regulated process to repair the disruption in the interaction and reestablish harmonious, back-and-forth interactions. Parents typically comfort their infants and encourage them to resume play interactions (e.g., Mesman et al., 2009, 2013), but infants are also engaging in self-regulation during the reunion episodes of the SFP. Kogan and Carter (1996) created a system for coding these self-regulation behaviors and strategies during these distressing parent–child interactions. The attention maintenance rating captures the degree to which infants look at, reach toward, and respond to their parents with positive affect during the SFP reunion. Alternatively, the avoidance rating measures the degree to which infants withdraw from the parent and actively disengage from interactions, and the resistance rating reflects the degree to which infants display high levels of distress and anger in response to the parent's attempts to interact with them (Kogan & Carter, 1996). These three behavioral rating scales are thought to capture strategies for self-regulation that are shaped by prior parent–infant interactions. The ratings of infant avoidance and resistance during the SFP reunion episodes, in particular, are thought to represent maladaptive self-regulation strategies that develop in the context of insensitive care. Indeed, infants' self-regulation behaviors during the SFP reunion episodes are associated with parents' caregiving behaviors (Conradt & Ablow, 2010; Kogan & Carter, 1996). These early emerging strategies for regulating one's behavior during distressing parent–child interactions have been shown to predict later attachment behaviors during the Strange Situation (Kogan & Carter, 1996; see also Barbosa et al., 2021).

Current Study

The primary aim of the current study was to test whether pregnant women's autonomic responses to a video of an unfamiliar infant crying predict their young infants' later self-regulation behaviors during the SFP. This study is unique because infants' self-regulation strategies were observed during the reunion episodes of the SFP approximately 7 months after the assessment of parents' autonomic responses. To the best of our knowledge, this is the first study to examine the potential intergenerational associations between pregnant women's autonomic nervous system responses to infant cries and later infant socioemotional outcomes.

Our first hypothesis was that minimal RSA reductions in response to the infant cry would predict infants' use of maladaptive regulation strategies (i.e., avoidance and/or resistance) during the SFP. This is based on the idea that a lack of RSA reductions reflects emotional disengagement with the task (Porges, 2007) as well as evidence that a lack of RSA reductions to infant cry stimuli may be associated with insensitive parenting (e.g., Ablow et al., 2013; Joosen, Mesman, Bakermans-Kranenburg, Pieper, et al., 2013; Mills-Koonce et al., 2007; Moore et al., 2009). Our second hypothesis was that increases in pregnant women's SCL in response to the infant cry would predict their infants' use of behavioral avoidance and resistance during the SFP. This is based on the idea that SCL increases reflect emotional inhibition (Fowles, 1988) as well as evidence that SCL increases in response to infant cry stimuli may be associated with negative emotional reactions to the cry and harsh parenting (e.g., Emery et al., 2014; Joosen, Mesman, Bakermans-Kranenburg, & van IJzendoorn, 2013). Based on the evidence from Leerkes et al. (Leerkes et al., 2023; Leerkes, Gedaly, & Su, 2016), we also explored the possibility that pregnant women's RSA and SCL responses to an unfamiliar infant's cry interacted with one another to predict infant avoidant and resistant regulation strategies.

A secondary aim of this study was to test whether associations between pregnant women's RSA and SCL responses to infant cry stimuli and their infants' later self-regulation behaviors were mediated by observed maternal sensitivity. We expected that pregnant women who exhibited minimal reductions in RSA or greater increases in SCL activity in response to the infant cry stimuli would interact with their infants in a less sensitive manner, and this in turn would be associated with infants' avoidance and resistance behaviors during the reunion episode of the SFP.

Method

Participants

This study used data from a longitudinal study of 162 women and their children. Pregnant women were recruited through flyers, brochures, and social media posts. Because the area in which the data were collected consists of predominantly non-Hispanic, White individuals, women of color were intentionally oversampled in an effort to maximize the likelihood that the findings from this study generalize to individuals that are more racially and ethnically diverse than the demographics of our study location. In addition, women with high and low scores on the Difficulties in Emotion Regulation Scale (Gratz & Roemer, 2004) were intentionally oversampled to achieve a uniform distribution on levels of emotion dysregulation. This is in alignment with the overarching aims of the study to understand the processes underlying intergenerational transmission of

emotion dysregulation. Additional eligibility criteria for the study included participants being ages 18–40 at the time of their pregnancy, no reported pregnancy complications such as preeclampsia or gestational diabetes, no reported substance use during pregnancy, anticipated delivery of a singleton, and planned delivery at a participating hospital. Individuals interested in participating in the study first completed a screener questionnaire to determine their eligibility for the study, and eligible individuals were contacted to complete additional questionnaires and laboratory visits. Eligible women participated in a laboratory visit during their third trimester of pregnancy and then returned to the lab when their infants were approximately 7 months old (average age = 6.6 months). This time point was selected because this is the age that the SFP is most commonly conducted (Jones-Mason et al., 2018; Mesman et al., 2009). All mothers completed informed consent prior each visit, and this study was approved by the University of Utah's Institutional Review Board. In addition, individuals were compensated $50 for their participation in the prenatal visit and $50 for their participation in the 7-month visit. Mothers were also provided with a list of local and national resources relevant to the transition to parenthood.

Because this specific study is focused on infant self-regulation behaviors during the SFP reunion, mother–infant dyads were included in the analyses if ratings of infant behavioral self-regulation during the 7-month visit were available. Forty-eight dyads were excluded because they did not participate in the 7-month lab visit (29 indicated they were too busy to participate, 13 could not be contacted, four withdrew from the study, one participant moved, and one experienced a fetal demise). Of the remaining 114 participants, 17 were excluded because it was not possible to rate the infant's self-regulation behaviors during the lab visit (10 due to video error, three mothers blocked the view of the infant, two infants were too distressed to complete reunion episodes, and two mothers deviated from protocol, such as providing the infant with a pacifier). This resulted in a sample of 97 mother–infant dyads. Table 1 contains demographic information for these dyads. The median income for this sample of 97 mothers was comparable to the median income in the Salt Lake County area ($82,206; U.S. Census Bureau, 2021). Demographic variables (e.g., maternal age, educational attainment, and race/ethnicity) were significantly associated with attrition from the prenatal to the 7-month visit, but none of these variables were significantly correlated with missing the ratings of infant self-regulation behaviors at the 7-month visit. With a sample of 97 dyads, the analyses had 80% statistical power to detect an effect of $r = .28$.

Table 1
Demographic Characteristics of Mothers and Infants at the 7-Month Time Point

Demographic characteristic	Mothers	Infants
Average age (*SD*)	29.7 years (4.6)	6.6 months (0.5)
Sex assigned at birth		
Female (%)	100.0	47.4
Male (%)	0.0	52.6
Race/ethnicity		
White (%)	47.9	50.5
Hispanic (%)	30.3	26.8
Multiracial (%)	10.4	16.5
Asian (%)	9.4	3.1
Black (%)	1.0	1.0
Other (%)	1.0	2.0
First-time parent (%)	48.9	—
Relationship status		
Married (%)	76.0	—
Single and never married (%)	17.7	—
Separated or divorced (%)	6.3	—
Educational attainment		
Less than high school degree (%)	2.1	—
High school degree or GED (%)	13.7	—
Some college (%)	31.6	—
Baccalaureate degree (%)	31.6	—
Postbaccalaureate degree (%)	21.1	—
Household income		
<$9,000 (%)	4.2	—
$9,000–$14,999 (%)	4.2	—
$15,000–$24,999 (%)	11.4	—
$25,000–$39,000 (%)	12.5	—
$40,000–$79,999 (%)	37.5	—
$80,000–$99,999 (%)	13.5	—
>$100,000 (%)	12.5	—

Note. GED = general educational development.

Procedure

At the prenatal lab visit, women were fitted with electrodes used to collect electrocardiogram and skin conductance data. They completed a 10-min resting baseline, followed by the Trier Social Stress Test (Kirschbaum et al., 1993) and a 9-min resting recovery period. This extended resting recovery period was intended to allow women's physiological responses to recover after the Trier Social Stress Test. After the recovery period, a research assistant returned to the room and told the women they would be watching a series of video stimuli. The women were not given any additional instructions. The women watched a 1-min seascape video baseline intended to elicit a relaxed state. They then watched a 1-min video of an infant girl playing with an adult woman, followed by a 1-min video of the infant girl sitting alone on the floor crying. Finally, the women watched an additional seascape video intended to serve as a recovery period.

At the 7-month visit, mothers and their infants were fitted with electrodes. Mothers and infants watched a 2-min Baby Einstein baseline video, which was intended to induce a neutral and calm state, and mothers then completed a brief writing task. Afterward, mother–infant dyads participated in the extended version of the SFP. This task consisted of a 2-min play interaction where dyads were seated across from one another, followed by a 2-min still-face episode where the mother was instructed to remain affectively neutral, followed by a 2-min reunion episode where the mother was instructed to reengage the infant in play. In the extended SFP procedure, there was a second 2-min still-face and 2-min reunion episode immediately following the first reunion. This five-episode task was selected because it elicits a stronger emotional response from infants than the traditional three-episode still-face (Haley & Stansbury, 2003; Jones-Mason et al., 2018). After the SFP, electrodes were removed and the mother–infant dyads completed a free-play interaction.

Measures

Maternal RSA

At the prenatal lab visit, electrocardiograph data were continuously collected during all four videos using a standard three-lead spot electrode placement on the women's torsos (i.e., right clavicle and lowest

left rib). The data were sampled at 500 Hz using MindWare Technology mobile devices (MindWare Technologies Ltd.; Biolab software Version 3.1), and electrocardiograph activity was monitored throughout the task to ensure accurate data collection. Later, MindWare Technology's heart rate variability analysis was used for scoring the data. MindWare's software automatically identified R peaks within the QRS complex, which were visually inspected and corrected if needed by trained research assistants. Using MindWare's software, spectral analysis was used to decompose the variability in beat-to-beat intervals in 60-s intervals into very low-frequency (0.003–0.04 Hz), low-frequency (0.04–0.12 Hz), and high-frequency power (0.12–0.60 Hz; MindWare Technologies, 2014). RSA was calculated as the natural log of the high-frequency power spectrum. After data were cleaned and scored, boxplots were run to check for outliers, which were flagged as needed. Infants whose data were flagged were examined an additional time to check for scoring errors, which were corrected if identified.

Maternal Electrodermal Activity

At the prenatal lab visit, SCL data were continuously collected during all four videos by placing two skin conductance electrodes with 0.5% NaCl solution to the thenar and hypothenar eminences of each participant's nondominant hand. The data were sampled at 500 Hz using MindWare Technology's mobile devices (MindWare Technologies Ltd.; Biolab software Version 3.1). The SCL data were monitored throughout the task to ensure accurate data collection. Later, MindWare Technology's electrodermal activity analysis was used for scoring the data. MindWare's software automatically flagged peaks and troughs in the electrodermal signals and these flagged peaks and troughs were visually inspected by trained research assistants. Using MindWare's software, SCL was calculated by averaging the SCL, in microsiemens, across each 30-s epoch. The data were manually reviewed for outliers, and participants whose data were flagged were examined an additional time to check for scoring errors, which were corrected if identified.

Infant Regulation Behaviors

Infant regulation behaviors during the two reunion episodes of the SFP were rated using the coding system designed by Kogan and Carter (1996). During each reunion episode, infants' attention maintenance, avoidance, and resistance were rated using a set of 3-point scales. Examples of attention maintenance included eye contact with the mother, reaching for the mother, and responsiveness to the maternal bids for engagement. Examples of infant avoidance included gaze aversion, attempting to turn the body away from the mother, and delayed or no response to maternal bids for attention. Examples of infant resistance included continued and persistent fussing, protesting while looking at the mother, and angrily pulling away from the mother's touch. Previous studies using this coding system have reported that these ratings are concurrently correlated with maternal behaviors during the SFP (Conradt & Ablow, 2010; Kogan & Carter, 1996; Rosenblum et al., 2002) and predict infant attachment classifications during the Strange Situation Procedure (Kogan & Carter, 1996).

Twenty-four percent of cases were double-coded, and the intraclass correlations were between .93 and .97. An exploratory factor analysis (principal axis factoring, oblique rotation) of the six ratings of infants' behaviors during the two reunion episodes of the SFP identified two factors. The first factor included the ratings of infant avoidance during the two reunions as well as infant attention maintenance during the first reunion. The second factor included the two ratings of infant resistance as well as infant attention maintenance during the second reunion. Because infant attention maintenance ratings cross-loaded on the two factors, they were excluded from analyses. Infant avoidance was calculated by averaging the ratings of avoidance during the two reunions ($r = .56$, $p < .001$), and infant resistance was calculated by averaging the ratings of infant resistance during the two reunions ($r = .67$, $p < .001$).

Maternal Sensitivity

Mothers' behavior during the two, 2-min reunion episodes of the SFP were coded using an adapted version of the Observational Record of the Caregiving Environment (NICHD Early Child Care Research Network, 1996). During both episodes, mothers' behaviors were rated using five rating scales: maternal sensitivity to infant distress, maternal sensitivity to infant nondistress, intrusiveness, positive regard, and detachment. All ratings were assigned using a 5-point scale (1 = *not at all characteristic* to 5 = *highly characteristic*). All observations were double-coded by research assistants, and disagreements in coding decisions greater than a half point were conferenced. Intraclass correlation estimates for the 10 sets of ratings were between .42 and .80 (average intraclass correlation coefficient = .73). For the purposes of this study, the ratings of maternal sensitivity to infant distress and nondistress were used. Indicators of maternal sensitivity to infant distress include the proportion of distress signals responded to, the latency of response, and the appropriateness of response. Maternal sensitivity to nondistress was assigned when infants did not display overt distress during the reunion portion of the SFP, and was defined as following the child's lead during the parent–infant interaction. This rating was considered conceptually relevant because it was assigned during the reunion episode of the SFP, which is potentially distressing context. Maternal sensitivity to infant nondistress was significantly correlated with maternal sensitivity to infant distress during both reunion episodes ($r = .46$, $p = .043$ and $r = .54$, $p = .009$). Therefore, the four ratings of maternal sensitivity during the two SFP reunion episodes were averaged to create an overall score of maternal sensitivity in the context of infant distress ($\alpha = .74$).

Covariates

Five covariates were considered for all analyses, including parity (1 = *first-time parent*, 0 = *otherwise*), family socioeconomic status, which was calculated by standardizing and averaging measures of women's household income, educational attainment, and household occupational prestige (Hout et al., 2016; $\alpha = .79$), infant race/ethnicity, infant biological sex (1 = *male*, 2 = *female*), and infant age in months at the time of the SFP. These covariates were considered because they have been reported to be associated with parents' autonomic responses to infant distress as well as infants' socioemotional development (e.g., Groh et al., 2019; Leerkes, Su, et al., 2016). Preliminary analyses indicated that only infant race/ethnicity was significantly correlated with either the measures of mothers' RSA or SCL responses to the infant cry video or the measures of infant regulation behaviors during the SFP. Therefore, only infant race/ethnicity ultimately was included as a covariate in our analyses. This was represented with two binary variables: one representing whether infant was Hispanic or not (the most

common marginalized group in our sample) and the other indicating whether the infant was a non-Hispanic person of color (e.g., Black/African American, Asian American, or multiracial) or not.

Analytic Plan

Prior to the main analyses, a series of paired-samples *t* tests were conducted to assess whether pregnant women's average RSA and SCL levels changed across the videos. Then, a measure of RSA reactivity to the infant cry video was created by subtracting mothers' average RSA levels during the video baseline from their average levels during the infant cry video. Similarly, a measure of SCL reactivity to the cry video was created by subtracting mothers' average SCL during the video baseline from their average levels during the infant cry video. Next, we examined the bivariate correlations among the measures capturing women's autonomic responses to the infant videos, maternal sensitivity, the potential covariates, and infant regulation behaviors.

In order to test whether pregnant women's autonomic responses to a video of an unfamiliar infant crying predict young infants' self-regulation behaviors, we conducted two hierarchical linear regression analyses. One focused on predicting infant avoidance behaviors during the SFP, and the other predicted infant resistance behaviors. For each model, maternal RSA and SCL reactivity to the infant crying videos were included as predictor variables along with covariates.

The indirect effects of maternal RSA and SCL reactivity to the infant cry on infants' regulation behaviors via maternal sensitivity during the SFP reunion were tested in Mplus. Maternal RSA and SCL reactivity to the infant crying video were included as predictors, along with the covariates, and maternal sensitivity in response to infant distress was entered as a mediator. Additional preregistered analyses, which assess maternal sensitivity in a free-play context as a potential mediator of the association between women's autonomic responses and infants' regulatory behaviors, are reported in the online supplemental materials of this article.

Missing Data

Of the 97 dyads included, 4% of mothers were missing SCL data during the baseline video, 6% were missing SCL data during the play video, 2% were missing SCL during the cry video, and 1% were missing SCL data during the recovery video. Additionally, 3% of mothers were missing RSA data during the baseline video, 3% were missing RSA data during the play video, 1% were missing RSA during the cry video, and 2% were missing RSA data during the recovery video. Approximately 4% of infants were missing avoidance data but not resistance, and 1% were missing resistance data but not avoidance. No mothers were missing maternal sensitivity data. Missing data were handled using Full Information Maximum Likelihood in Mplus (Muthén & Muthén, 2017) for the bivariate correlations and focal analyses. The overall research design and hypotheses for this study were preregistered with the Open Science Framework (Speck et al., 2023). The current study differs from the initial preregistration with regard to the variables used for covariates and mediators, and these differences have been highlighted. Hypotheses and methods pertaining to the main effects of mothers' autonomic responses to the video of an unfamiliar infant crying and their own infants' self-regulatory behavior during the SFP were consistent with the initial preregistration. Data and code for this study are not publicly available online but can be made available upon request.

Results

Preliminary Analyses

On average, RSA decreased from the seascape baseline video to the video of the mother–infant playing, $t(93) = -6.18$, $p < .001$, but did not significantly change from the mother–infant play video to the infant cry video, $t(93) = -1.0$, $p = .32$, or from infant cry video to the recovery video, $t(94) = 0.46$, $p = .64$; Figure 1.

SCL decreased from baseline to the mother–infant play video, $t(91) = -7.06$, $p < .001$, but then increased from the mother–infant play video to the infant cry video, $t(91) = 2.34$, $p = .02$. SCL decreased from the infant cry video to the recovery video, $t(94) = -3.81$, $p < .001$; Figure 2.

Descriptive statistics and correlations among study variables are presented in Table 2. In addition, there were no outlier values for any of the variables and skewness statistics were less than 0.92 for variables used in the analyses.

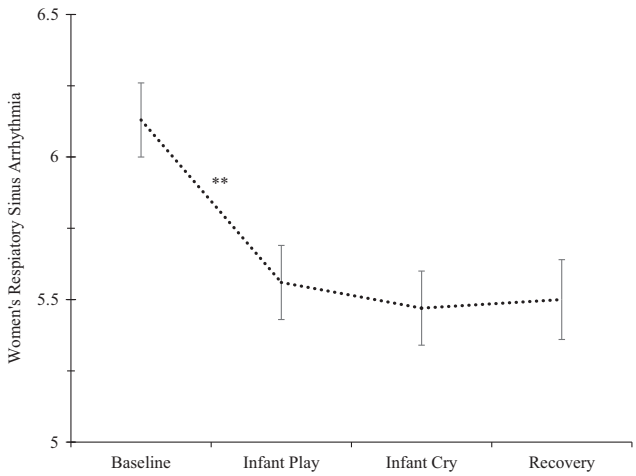
Do Maternal Autonomic Responses to the Infant Cry Predict Infant Regulatory Behaviors During the SFP?

Ordinary least squares regressions are presented in Table 3. Pregnant women's RSA reactivity to the cry video was positively associated with infant avoidance during the reunion episode of SFP. In other words, infants tended to display higher levels of avoidance when their mothers exhibited lower RSA reactivity to the task (i.e., had RSA reactivity values close to zero as opposed to a larger negative value). Women's SCL reactivity to the cry video was also positively associated with infant avoidance, which suggests that infants displayed higher levels of avoidance when their mothers exhibited higher SCL in response to the infant cry video. Neither RSA reactivity nor SCL reactivity was significantly associated with infant resistance.

A set of exploratory analyses were conducted to determine whether maternal RSA and SCL reactivity to the unfamiliar infant

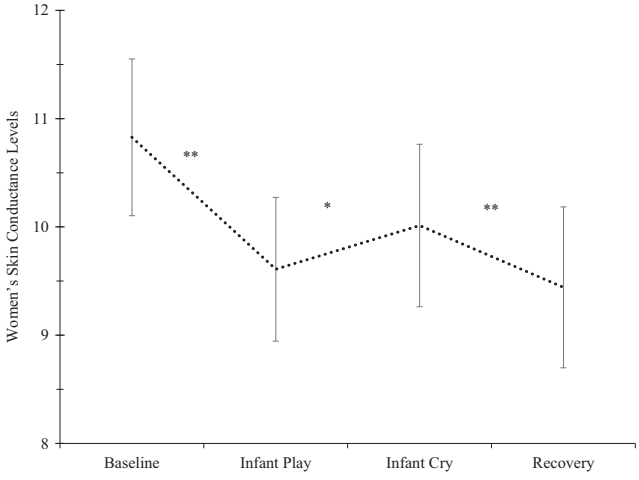
Figure 1

Pregnant Women's Average RSA Levels Across the Video Stimuli



Note. Error bars represent 1 standard error. RSA = respiratory sinus arrhythmia.
** $p < .01$.

Figure 2
Pregnant Women's Average SCL Across the Video Stimuli



Note. Error bars represent 1 standard error. SCL = skin conductance levels.
* $p < .05$. ** $p < .01$.

cry video interacted to predict infant regulation behaviors. The maternal RSA and SCL reactivity variables were mean-centered and then multiplied together to create an interaction term. This interaction term was included as a predictor variable along with the centered RSA and SCL reactivity variables and covariates. Results indicated that maternal RSA and SCL reactivity did not interact to predict infant avoidance behavior or resistance behavior ($\beta = .08$, $SE = 0.11$, $p = .45$, and $\beta = .06$, $SE = 0.12$, $p = .60$, respectively).

In order to test whether these associations were unique to mothers' autonomic responses to the infant cry video, measures of maternal RSA and SCL reactivity to the infant play video were calculated by subtracting mothers' average autonomic levels during the video baseline from their average levels during the infant play video. Two additional hierarchical linear regression analyses were conducted to test whether maternal autonomic responses to the infant play video predict young infants' self-regulation behaviors during the SFP. Once again, maternal RSA and SCL reactivity to the infant play videos were included as predictor variables along with covariates. Results indicated that neither pregnant women's RSA reactivity nor their SCL reactivity to the mother–infant play video significantly predicted infants' avoidance or resistance behaviors (p values between .15 and .55).

Does Maternal Sensitivity Mediate the Associations Between Maternal Autonomic Reactivity and Infant Avoidance?

We tested whether maternal RSA and SCL reactivity were indirectly associated with infants' avoidance behaviors via maternal sensitivity (see Table 4). Neither RSA reactivity nor SCL reactivity to the infant cry were significantly associated with maternal sensitivity. RSA reactivity and SCL reactivity also did not have significant indirect effects on infant avoidance. Moreover, SCL reactivity continued to predict infant avoidance behaviors when maternal sensitivity was included as a potential mediator, and RSA reactivity became marginally significant when maternal sensitivity was included as a potential mediator.

Discussion

The primary aim of this longitudinal study was to test whether pregnant women's RSA and SCL responses to a video of an unfamiliar infant crying predict their infants' regulation behaviors during the reunion episode of the SFP. Our findings partially supported our hypotheses. Specifically, lower levels of maternal RSA reactivity and higher maternal SCL reactivity in response to the infant cry video were both uniquely associated with high levels of infant avoidance during the reunion episodes. These associations were specific to the video of an unfamiliar infant crying, as pregnant women's RSA and SCL responses to the video of the mother and infant playing did not significantly predict levels of infant avoidance. These findings extend earlier evidence indicating that parents' autonomic responses during parent–infant interactions are associated with parental sensitivity and infant behaviors (Groh et al., 2019; Hill-Soderlund et al., 2008; Mills-Koonce et al., 2007; Moore et al., 2009). To the best of our knowledge, this is the first study to provide evidence for an intergenerational association between pregnant mothers' RSA and SCL responses to an unfamiliar infant crying and their own infants' regulation behaviors.

Although we hypothesized that maternal responses would be associated with both infant avoidance and resistance, pregnant women's autonomic responses to the infant cry video were only significantly associated with levels of infant avoidance. Similar findings have been observed when assessing parents' RSA responses during parent–infant interactions. Specifically, mothers of infants who are classified as avoidantly attached (as opposed to secure or resistant) exhibit a lack of RSA reductions during both the SFP and the strange situation

Table 2
Descriptive Statistics and Correlations Among Variables

Variable	1	2	3	4	5	6	7
1. Maternal RSA reactivity to infant cry video	—						
2. Maternal SCL reactivity to infant cry video	.06	—					
3. Maternal sensitivity	.14	.02	—				
4. Infant avoidance behavior	.17	.22*	.18	—			
5. Infant resistance behavior	−.01	.03	−.31**	.03	—		
6. Infant Hispanic versus non-Hispanic	−.07	−.09	−.10	.15	.00	—	
7. Infant non-Hispanic POC versus other	.25*	.12	.02	−.16	−.03	−.33**	—
M or %	−0.64	−0.78	3.09	1.11	1.39	27%	23%
SD	0.85	2.09	0.61	0.87	0.99		

Note. $N = 97$. RSA = respiratory sinus arrhythmia; SCL = skin conductance levels; POC = person of color.
* $p < .05$. ** $p < .01$.

Table 3
Predicting Young Infants' Regulatory Behaviors During the SFP From Pregnant Women's Autonomic Responses to an Infant Cry Video

Predictor variable	Outcome: infant avoidance			Outcome: infant resistance		
	β	*SE*	*p*	β	*SE*	*p*
Maternal RSA reactivity	.21*	0.10	.04	−.00	0.11	.98
Maternal SCL reactivity	.25*	0.10	.01	.04	0.11	.74
Infant Hispanic versus non-Hispanic	.12	0.10	.25	−.00	0.11	.98
Infant non-Hispanic POC versus other	−.20	0.10	.05	−.03	0.11	.79

Note. $N = 97$. SFP = still-face paradigm; RSA = respiratory sinus arrhythmia; SCL = skin conductance levels; POC = person of color.
* $p < .05$.

procedure (Groh et al., 2019; Hill-Soderlund et al., 2008). Consistent with polyvagal theory (Porges, 2007), minimal reductions in RSA in the context of infant crying may reflect a lack of emotional engagement with the infant's distress, and this in turn could lead to the type of dismissing and rejecting caregiving behaviors that are thought to contribute to the development of infant avoidance (Ainsworth et al., 1978). In addition, changes in SCL in response to infant distress may reflect the effortful inhibition of behavior (Dawson et al., 2017; Fowles, 1980), which may also lead to parental disengagement or rejection during parent–child interactions.

In addition to our test of the main effects of pregnant women's RSA and SCL responses to the infant cry, we also explored the possibility that pregnant women's RSA and SCL responses interacted with one another to predict infant regulation outcomes. However, our analyses did not provide support for the idea that RSA and SCL responses interact to predict infant avoidance or resistance. That said, it is important to interpret these null findings with caution because the current study was not sufficiently powered to test for moderation effects (Whisman & McClelland, 2005). Therefore, additional research involving larger samples is needed to test whether pregnant women's RSA and SCL responses to infant distress interact to predict infants' later socioemotional development.

The second aim of this study was testing whether the associations between pregnant women's RSA and SCL responses to an unfamiliar infant cry video and infants' regulation behaviors were mediated by maternal sensitivity. The results of these analyses indicated that the indirect effects of RSA and SCL reactivity to the infant cry and infant avoidance via maternal sensitivity were not statistically significant. There are at least two possible explanations for these nonsignificant results. First, the fact that maternal sensitivity and infant regulation behaviors were concurrently assessed in the same context may have resulted in distortions in the associations between those variables. Measures of maternal sensitivity assessed in other distressing contexts may be more appropriate to test this association. Similarly, more ecologically valid measures of maternal sensitivity in day-to-day parent–infant interactions may be more central in mediating the association between maternal autonomic responses and infant outcomes. A second explanation is that the associations between parents' autonomic responses to cry stimuli and their infants' regulation behaviors are not mediated by caregiving behavior. While maternal sensitivity to infant distress is thought to reflect processes relevant to children's self-regulation outcomes (Del Carmen et al., 1993; Lee et al., 2022; Leerkes et al., 2009), other mechanisms explaining the association between parents' autonomic responses and infant behaviors have been proposed. These include shared genetics, dyadic autonomic synchrony, and emotional contagion (Leerkes, Gedaly, & Su, 2016). Testing these potential mechanisms represents a valuable direction for future research.

One of the strengths of this article is that mothers' autonomic responses to infant cries were assessed prenatally. This aspect of the research design removes the possibility that infant characteristics are eliciting this parental physiological response. At the same time, this study does necessitate a reliance on the use of video clips of an unfamiliar infant crying, as opposed to one's own infant. This has the potential to weaken the associations between pregnant women's autonomic responses and later parenting or infant outcomes, given that parents' autonomic responses to an unfamiliar infant crying may not generalize to their own infant. The fact that the current study provided evidence for intergenerational associations between pregnant women's autonomic responses to an unfamiliar infant crying and their infants' regulation behaviors despite this potential limitation speaks to the significance of these autonomic responses.

A potential limitation of the study is that women's average SCLs unexpectedly decreased across the entire series of infant videos. This may have been due to the structure of the laboratory visit. Prior to watching the infant videos, the pregnant women completed the trier social stress task (TSST). Although there was a 9-min resting

Table 4
Indirect Effects of Maternal Autonomic Responses on Infant Avoidance Behaviors During the SFP via Maternal Sensitivity

Model	β (*SE*)	*p*
Path A		
Maternal RSA reactivity → Maternal sensitivity	.14 (0.11)	.19
Maternal SCL reactivity → Maternal sensitivity	.01 (0.11)	.95
Path B		
Maternal sensitivity → Infant avoidance	.17 (0.10)	.08
Path C		
Maternal RSA reactivity → Infant avoidance	.19 (0.10)	.06
Maternal SCL reactivity → Infant avoidance	.24 (0.09)	.01
Indirect effects		
Maternal RSA reactivity → Maternal sensitivity → Infant avoidance	.02 (0.02)	.29
Maternal SCL reactivity → Maternal sensitivity → Infant avoidance	.00 (0.02)	.95

Note. $N = 97$. SFP = still-face paradigm; RSA = respiratory sinus arrhythmia; SCL = skin conductance levels.

recovery in between the TSST and the presentation of the infant videos, this task order may have nonetheless resulted in unusually highly SCLs during the baseline video administered immediately prior to the infant play and cry videos. That said, SCLs did significantly increase from the play to the cry video, and this was followed by a significant decrease from the cry to the recovery video. These changes across the tasks indicate that mothers were responding to the infant cry video with the anticipated increase in SCL, supporting the validity of our measure of SCL reactivity. Additionally, RSA levels exhibited the expected pattern of change across the videos. Specifically, RSA levels decreased from baseline to the infant play video with an additional (albeit nonsignificant) decrease during the infant cry video. Altogether this suggests that the videos were effective at eliciting autonomic responses from the pregnant women.

Future research may also benefit from the use of larger and more broadly representative samples. The current sample of 97 dyads included women who had relatively high levels of formal education, most of whom were married and had family incomes that were comparable to the median family income for the United States (Semega & Kollar, 2022). In addition, approximately half of the sample identified as White and non-Hispanic which is slightly lower than the United States (U.S. Census Bureau, 2022). Although the initial recruited sample was somewhat larger, attrition occurred between the prenatal and 7-month assessment largely due to mothers being too busy to participate after the birth of their child. Future research with larger samples will have more statistical power to precisely estimate the magnitude of the effect that women's autonomic responses have on infants' outcomes. Additionally, testing the presence of these associations in larger, more diverse, populations will help clarify how broader contextual characteristics, such as experiences of poverty or racial and ethnic discrimination, may affect the magnitude of the associations reported in the current study.

In the current study, the focal outcome was young infants' behaviors during the reunion episodes of the SFP, which is a well-validated task to assess young infants' emerging regulation strategies during parent–child contexts (Mesman et al., 2009). Parents' autonomic responses to an unfamiliar infants' cry may also predict infant mental health outcomes. Another fruitful direction for future studies may be to expand the scope of these initial findings to other infant socioemotional outcomes and potentially at later developmental time points. These research investments would also provide valuable information regarding opportunities for intervention.

In conclusion, the present longitudinal study provides novel evidence that lower levels of maternal RSA reactivity or higher levels of maternal SCL reactivity while pregnant and in response to an unfamiliar infant crying are associated with higher levels of infant avoidance behaviors during the SFP at age 7 months. To the best of our knowledge, this is the first known report of an intergenerational association between prenatal maternal autonomic responses to infant distress and later infant socioemotional outcomes. In this way, the results of this study suggest that parents' autonomic responses to infant distress capture emotional processes that may shape infant development. In addition to advancing our understanding the intergenerational effects of parents' emotional responding to infant cries, the results of this study can be applied toward developing novel interventions or modifying existing interventions that aim to alter infants' emerging regulation outcomes. Traditionally, interventions that focus on improving infants' social and emotional development have targeted parenting behaviors that occur soon after birth (Bakermans-Kranenburg et al., 2003; Jeong et al., 2021). Recently, efforts have been made to modify these programs to begin during the prenatal period and focus on preparing parents to sensitively respond to their infants' eventual cry signals (e.g., Labella et al., 2021). Our findings lend support to this idea and provide much needed evidence that intervention efforts can effectively begin prior to the birth of the child, thereby elongating the potential window for intervention opportunities.

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