Trajectories of Maternal Behavior, Infant's RSA, and Emotional Recovery Following the Still Face Paradigm

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Abstract

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The development of emotion regulation is integral to children's socioemotional adjustment. Respiratory Sinus Arrythmia (RSA) reflects parasympathetic regulation of cardiac arousal and is an indicator of emotion regulation. However, it is unclear how changes in RSA are associated with positive maternal behaviors and infant emotional recovery throughout the reunion following a social stressor. Using a series of autoregressive latent trajectory models, the current study aimed to elucidate the associations among maternal warmth, infant RSA, and infant negative affect across a 5-minute observation. Mothers and their 5-6 months old infants (N = 143) completed the Still Face Paradigm. Cross-lagged effects indicated that increases in RSA precede decreases in NA during the first 2.5 minutes of the reunion. Change in maternal warmth was associated with change in RSA partially supporting our hypothesis that maternal warmth supports infant physiological, and in turn, emotional recovery.

Trajectories of Maternal Behavior, Infant's RSA, and Emotional Recovery Following the Still Face Paradigm

The development of emotion regulation is integral to children's socioemotional development. Caregivers play a primary role in infants' emotion regulation until around three years of age when children begin to increase in self-initiated regulation (Kopp, 1982). Indeed, early emotion regulation is thought to be learned through repeated one-on-one interactions with caregivers (Calkins & Hill, 2007). Thus, much of the research examining the development of emotion regulation in infancy has focused on regulation in the context of dyadic tasks (e.g., interactions involving mother and infant).

Growing interest in dyadic regulation at the physiological level has led researchers to examine the relations among infants' and mothers' physiological (e.g., parasympathetic and sympathetic) and emotion regulation during commonly used dyadic tasks. One such task is the Face-to-Face Still Face Paradigm (SFP, Tronick et al., 1978). The SFP has been extensively utilized to examine ways infants and their mothers regulate in response to a social stressor. The established literature detailing infants' and mothers' behavioral and physiological responses during and following the SFP (e.g., Bazhenova et al., 2001; Busuito & Moore, 2017; Conradt & Ablow, 2010; Mesman et al., 2009; Moore et al., 2009; Moore & Calkins, 2004) makes this task particularly well suited for examining the relation between physiological arousal and infant emotion regulation. Thus, the proposed study aims to describe the associations among physiological reactivity (i.e., parasympathetic regulation), maternal behavior, and infants' emotion regelation in the interactions between mothers and infants following the Still Face procedure, that is, during the recovery period.

Respiratory sinus arrhythmia (RSA) is a measure of vagal tone reflecting parasympathetic regulation of cardiac arousal to facilitate engagement with the environment (Porges, 2007). Porges' (2007) Polyvagal theory asserts that parasympathetic regulation plays an important role in emotional arousal and social engagement in particular. Previous research suggests that higher resting RSA is associated with infants' responsiveness to environmental demands (Beauchaine, 2001; Calkins, 1997). However, during challenging or upsetting situations, RSA withdrawal (i.e., decrease or suppression) is thought to be adaptive and is associated with higher global ratings of social engagement and approach (Calkins, 1997; Stifter & Corey, 2001).

Infants' physiological and behavioral responses to the SFP are well documented. Infants typically show RSA withdrawal during SFP relative to baseline levels (e.g., Bazhenova et al., 2001; Moore & Calkins, 2004). During the reunion, previous research has found that, on average, infants' RSA returns to near baseline levels as there is no longer a need for infants to engage in active coping (Bazhenova et al., 2001; Moore & Calkins, 2004). Additionally, one study found that infants who showed RSA withdrawal during SF episode and a return to baseline RSA (i.e., RSA augmentation) during the reunion episode also exhibited behavioral regulation (i.e., reduced negative affect and positive social engagement strategies) during the reunion. Infants who did not follow the same pattern of withdrawal during the SF episode and augmentation during the reunion did not exhibit a decrease in negative affect during the reunion episode (Bazhenova et al., 2001). Furthermore, other studies have found that infants who do not show RSA withdrawal during SF episode continue to show negative affect, less positive engagement, and more cardiac arousal during reunion (Moore & Calkins, 2004; Provenzi et al., 2015).

Given the role of caregiver interactions in children's development of regulation, previous research has investigated the effects of maternal behavior on infant's regulation during SFP. However, these studies have found mixed patterns of association. For example, higher maternal sensitivity (indexed as a composite score of five aggregated subscales including sensitivity/responsiveness, positive regard, stimulation of cognitive development, etc.) was associated with continued decrease in infant RSA during the reunion (Moore et al., 2009). The authors suggested that these infants may have been as equally engaged as their mother in the reunion and, therefore, showed matched direction of RSA with their mothers as mothers typically show lower RSA during this period. However, another study showed higher maternal sensitivity (indexed by mother's ability to be appropriately responsive) was associated with RSA augmentation during the reunion (Conradt & Ablow, 2010), which appears more compatible with previous research suggesting RSA augmentation is a sign of adaptive regulation following the Still Face procedure (Bazhenova et al., 2001; Moore & Calkins, 2004). The same study also found lower maternal sensitivity was associated with infant resistance (i.e., fussing) during the reunion and higher maternal sensitivity was associated with greater infant engagement with mothers during reunion (Conradt & Ablow, 2010).

Mothers' engagement and sensitive responses to infants in distress, compared to situations not characterized by distress, may be particularly important for children's development (McElwain & Booth-LaForce, 2006). Thus, maternal behaviors during the SFP reunion period may capture aspects of emotion socialization that have a unique impact on infant's regulation. In fact, previous research has found that maternal sensitivity during the SFP reunion episode uniquely predicted children's change in heart rate from SF to the reunion; whereas, there was no effect of maternal sensitivity during the play episode on infant's arousal during the reunion

(Conradt & Ablow, 2010). Additionally, higher dyadic flexibility (i.e., a measure of infant-mother interaction quality in response to the situational stressor) during the reunion episode has been found to be positively associated with infants' RSA augmentation during the reunion episode (Busuito & Moore, 2017). Regarding infants' behavior, maternal responsiveness (measured using a composite score of maternal responsiveness during play and reunion, given the high correlation between the two observations) was associated with infants' regulation of negative affect during reunion (Haley & Stansbury, 2003). Given the research demonstrating the importance of parent-child dynamics during the reunion episode, the proposed study will focus on observed maternal behaviors, specifically maternal warmth, during the reunion episode following the SF episode.

Current Study

Despite the extensive use of the SFP to assess physiological and behavioral regulation, there remains a gap in the literature directly addressing the time-specific associations between RSA during the reunion episode and behavioral signs of regulation. The literature examining the differences in behavioral regulation between infants who show RSA withdrawal compared to no-withdrawal during the Still Face episode suggests that infants vagal regulation supports their initiating engagement and eliciting responsiveness from mothers and aids in recovery and behavioral regulation following the challenge (Bazhenova et al., 2001; Moore & Calkins, 2004). However, to our knowledge, previous research has not directly examined the time-specific associations between RSA and observed emotion regulation (i.e., changes in negative affect) during the reunion episode. Additionally, given the evidence suggesting the importance of maternal behavior in supporting infants' physiological and regulation, the role of concurrent maternal behavior (e.g., warmth) may be particularly relevant to both physiological and emotion regulation, and must also be considered during the reunion episode.

The current study addresses this question by describing the associations among maternal behaviors, infant RSA, and infant's negative affect (NA) using auto-regressive latent trajectory (ALT) models (Bollen & Curran, 2004). First, we established the association between mothers' warmth and infant's NA during the reunion episode by modeling the linear changes and mean level of maternal warmth and observed infant NA. Additionally, we examined the time-specific associations between maternal behavior and infant's NA to better understand the timing and directionality of the association between maternal behavior and NA. We then tested the associations between maternal warmth and infant RSA, and finally, the associations between infant RSA and infant NA using the same design described above. Our hypotheses were as follows: 1) Higher initial levels and increases in maternal warmth during the reunion episode would be related to greater decreases and lower ultimate levels of infant NA, whereas lower or decreasing maternal warmth would be related to smaller decreases and higher ultimate levels of infant NA. In addition, there would be epoch specific effects, with the residual variance of each 30-sec epoch of maternal behavior predicting the unique variance in the subsequent epoch of infant NA, above the variance accounted for by the slope and intercept factors. 2) Increasing or higher levels of maternal warmth during the reunion episode would be related to greater increases and higher ultimate levels of infant RSA, whereas lower or decreasing maternal warmth would be related to smaller increases and lower ultimate levels of infant RSA. Again, we expected time specific associations to emerge with changes in maternal warmth predicting changes in infant RSA in subsequent epochs. 3) Finally, increasing or higher levels of infant RSA during the reunion episode would be related to greater decreases and lower ultimate levels of infant NA, whereas lower or decreasing infant RSA would be related to less decrease and higher ultimate levels of infant NA. Time specific associations were expected to emerge such that changes in infant RSA would predict changes in infant NA in the subsequent epoch.

Method

Participants

Participants were 143 mother-infant dyads who participated in the Still Face Paradigm at the third assessment of an ongoing longitudinal study, when infants were 5-6 months of age. Participants were recruited while pregnant with their first child from a metropolitan county in the Pacific Northwest region of the United States. The original study aimed to understand how low income and its associated adversity impact infant development, thus families recruited had an annual income below $45,000 (2x below the national poverty line). Infants were roughly evenly distributed with regard to gender (52% girls, 48% boys). Infants were identified by their mothers as 34% Black/African American, 25% White, 17% Latinx/Hispanic, 12% Asian American, 6% Native American, 4% Multi-racial, and 2% Hawaiian/Pacific Islander.

Procedure

The original study featured an intervention component. Upon enrollment in the study, participants were assigned to one of four groups (i.e., three different intervention programs and a control group). The intervention programs include: 1) a mindfulness-based childbirth class, 2) a program incorporating mindfulness-based stress management and self-care practices, and 3) a program providing mindfulness and parenting practices to support positive parenting. The control group received a book on child development. Therefore, we explored whether participation in an intervention was significantly related to the study variables and should be included as a covariate. The original study consisted of four assessments with the first occurring during the mothers' pregnancy, and the subsequent assessments when the infants were two to three months, five to six months, and ten to twelve months. Measures of cardiac arousal and RSA were collected during the SFP episodes at the second assessment post-partum (i.e., infants aged five to six months).

Collecting physiological data. Infants and their mothers were each situated with a set of physiological sensors and, once the mother and child were comfortable, a baseline measure of RSA was recorded.

Face-to-Face Still Face Paradigm (Tronick et al., 1978). The SFP is comprised of three episodes: 1) face-to-face play episode (2 minutes), 2) face-to-face still face episode (2 minutes), and 3) reunion episode (5 minutes). During the still face episode, mothers were instructed to stop responding to their child and maintain a neutral expression. During the reunion episode, the mother is told she may resume interaction with her child.

Coding Procedures. Coders trained to 90% agreement with experts on the coding manual. ICCs will be calculated for a percentage of videos coded for all measures included in the proposed study to assess reliability. Behavioral coding entailed providing a rating for each 30-sec epoch of the SFP (four ratings per episode). The average across these four ratings for the SFP and reunion episode will be used for analyses.

Measures

Infant RSA. Using BIOPAC's Acqknowledge software (BIOPAC Systems Inc.), infant's electrocardiograph (ECG) recordings were collected at a 1kHz sampling rate from three disposable cardiac electrodes placed over the infant's chest. ECG data were then loaded into custom Matlab software to detect R-wave peaks and screen for artifacts. R-wave peaks were initially located by identifying the local maxima of the ECG waveform above a voltage threshold set to the 98th percentile of all ECG observations. Inter-beat intervals (IBIs) were plotted as a function of the time of the R-peak that concluded the current interval. Trained technicians used the screening program to identify signal interference. Technicians visually inspected time-synchronized ECG and IBI series and identified segments in which distortions in ECG data coincided with sudden large deflections in the IBI series, indicating a false or missed R-peak.

Technicians corrected erroneously detected or missed R peaks if the ECG distortion fell into one of three categories. 1) The R-peak fell below the 98th percentile threshold used to identify peaks due to slow deflection of ECG baseline and thus were missed. In these cases, the technician manually adjusted the threshold level so the automatic peak detection algorithm would capture the missed peaks. 2) High-frequency interference distorted the shape of the ECG wave components resulting in additional peaks that interfered with the R-peak detector. If the ECG waveform for a missed heart cycle could be clearly identified by visual inspection, the R-peak was automatically detected by local adjustment of the detection threshold. If the heart cycle waveform was not clearly identifiable during the period of interference, but the interference spanned less than two heart cycles as indicated by adjoining, undistorted IBI data, then interference peaks were used as proxies for R-peaks. The proxy R-peak was always chosen to fall halfway between two adjacent, clearly legitimate R-peaks. If there were no proxy peaks at this halfway point, the distorted segment will be excluded from analyses. 3) Poor contact of the cardiac electrode with skin caused sustained intervals of low signal-to-noise ratio resulting in attenuated ECG waveform amplitude and added 60-cycle environmental noise. Heart cycles remained clearly identifiable, but the reduced R-wave amplitude resulted in peaks below the peak detector threshold. Additionally, the environmental noise added multiple local maxima to the R-waves resulting in multiple erroneously detected peaks as the threshold of the peak detector adjusted to the reduced signal amplitude. In these cases, the technician manually selected the R-wave peaks.

Data screening and editing were completed by one trained technician and reviewed by another. Cases of distorted ECG signals that did not fall into one of the above categories were excluded from analyses. Clean intervals less than 20 seconds in duration were also excluded to maintain a minimum of 0.05 Hz frequency resolution for spectral analysis of IBI data.

Cleaned intervals of IBI data were categorized by the behavioral assessment episode in which they were acquired (i.e., baseline, free play, Still Face, and reunion). If a behavioral assessment episode contained multiple clean IBI intervals, descriptive statistics were calculated for each interval and then averaged with weights proportional to the duration of the intervals. For baseline and each episode of the Still Face procedure, the mean and standard deviation of the IBIs were computed and the reciprocals of these IBI values were used to compute the mean and standard deviation of heart rate. The IBI data were interpolated onto a time scale that sampled at 2Hz, and then Fourier transformed to compute respiratory sinus arrhythmia (RSA). RSA was defined as the log of average power density from frequency components in the band falling between 0.33 and 0.42 Hz (Litvack et al. 1995), which corresponds to the range of respiration rates reported for infants 6-12 months (Behrman et al., 2002). Finally, the average RSA across every 30-second segment within a behavioral assessment episode was computed.

Infant Baseline RSA: Baseline RSA was collected from infants during a three-minute, relaxed, and naturalistic resting episode with their mother present. The experimenter instructed the mother to sit quietly with her child on her lap before leaving the room and then returned three minutes later.

Infant RSA during the SFP: Infant's RSA was computed for each episode of the SFP (i.e., two-minute free play, two-minute Still Face, and five-minute reunion).

Infant Negative Affect and Rejection. Infant negative affectivity and rejection during the reunion episode were coded from video recordings of parent-infant interactions and included frequency and intensity displays of negative affect, distress, and hostility directed at the mother, including verbal (e.g., crying) and nonverbal displays (e.g., frowning, grimacing, turning away, arching back) (Lengua et al., 2014). Ratings reflect infants' overall negative tone, overstimulation (e.g., gaze aversion), and rejection of their mother. Rejecting behaviors directed at the mother are reflected in higher scores on the scale. The scale ranged from 0 (no negativity) to 5 (two or more episodes of moderate-to-high intensity negativity or rejection). The intraclass correlation (ICC) for the infant negative affect code was .88.

Observed Maternal Warmth and Responsiveness. Maternal warmth and responsiveness during the reunion was coded from video recordings of parent-infant interactions (Lengua et al., 2014). Maternal warmth will be calculated as an average of maternal interactiveness and positive affect for each epoch. Maternal positive affect assesses the positive quality of the parent emotional expressiveness toward their infant, including tone of voice, facial expressions, and body language. The scale ranges from 0 (none) to 5 (high). The low end of the scale reflects a lack of positive expressions (not necessarily negative expressions) and the high end of the scale reflects positive affect (e.g., smiling, verbal warmth, affection) expressed at a high frequency and intensity during the segment. ICC for maternal positive affect was .88. Maternal interactiveness captures parent's verbal and non-verbal engagement with and attentiveness to their infant during the reunion episode. The scale ranges from 0 (the parent does not engage with their infant) to 5 (parent consistently initiates and responds enthusiastically to infants). The ICC for maternal interactiveness was .75

Data Analysis

First, descriptive statistics and bivariate correlations among study variables were examined. Next, after examining unconditional growth models to determine if there was significant variability to be predicted, we ran three parallel process models and three ALT models using overall model fit (indicated by RMSEA< .05 and CFI>.90) to indicate adequacy of the model in reproducing the observed data. The first parallel processes model examined maternal behavior warmth slope and intercept predicting infant NA slope and intercept. The first model included intercept and linear slope growth factors for maternal warmth and infant NA specified by the 10 observations across the reunion for each variable. The intercept for maternal warmth indicated the initial level of maternal warmth at the start of the reunion, whereas the intercept for infant NA (and infant RSA in other models) indicated infant's average level of NA (or RSA) at the end of the 5-minute reunion. The corresponding ALT model also included autoregressive paths in which each observation predicted the subsequent epoch to account for relative stability in observations across the 5 minutes, cross-lagged paths were estimated to examine time-specific bidirectional effects of maternal warmth and infant NA from one 30-sec observation to the next. The second and third parallel process models examined maternal warmth and infant RSA, and infant RSA and infant NA, respectively. The second and third corresponding ALT models included autoregressive and cross-lagged components as described above (see Figure 1). Analyses were conducted in R using the lavaan package (Rosseel Y, 2012).

Analyses were preregistered on OSF (https://osf.io/hjurz) before data were analyzed. Given that models ran when all 10 observations were included and negative affect did not appear to subside within the first 2 minutes, observations were not averaged into 1-minute epochs and the full 5-minute reunion was included, which differed from the pre-registered analysis plan. Pre-registered analyses included covariates (e.g., still face negative affect, still face RSA, baseline RSA, and intervention group); however, models did not converge when covariates were added. Thus, models presented here do not include the covariates. Given that we included all 10 epochs in the models, still face carry over effects may have been captured in first 30-sec observation. RSA baseline is not accounted for in the models; therefore, we do not make inferences about RSA levels, rather our focus is on the associations among changes in RSA, infant negative affect, and maternal behaviors. Additionally, receiving any intervention and specific intervention group status were not significantly associated with study variables and were therefore not included as covariates. Models including quadratic terms did not fit the maternal warmth data well, and did not converge for one of the three ALT model, thus quadratic terms were not included in the final analyses. In line with the pre-registration, next steps include examining maternal responsiveness in addition to warmth, and examining infant self-soothing in addition to infant nefative affect.

Results

Descriptive statistics show average levels of infant negative affect, infant RSA, and maternal warmth across the 10 30-second epochs of the reunion and across the entire 5-minute reunion (see Table 1). Bivariate correlations among variables at average levels across the 10 epochs suggest a moderate negative association between infant's negative affect and maternal warmth during reunion ($r = -.35$, $p < .001$; see Table 2). Correlations did not reveal any significant (at $\alpha < .05$) associations among infant's average level of RSA across the reunion episode and other study variables (i.e., maternal warmth and infant negative affect) at the epoch-average level.

Missing Data

It is worth noting that the number of children for whom RSA data were available in the last epoch (38) is notably lower than the first (109). A series of *t*-tests revealed no significant differences in mean levels of NA during still face or reunion for infants missing more than 25% of RSA data, suggesting that infants missing RSA data were not significantly more aroused by the task resulting in disruptions in electrocardiography recording. T-tests revealed no significant difference in mean levels of Still Face NA (t = -1.77, df = 15.03, p = .096) or Reunion NA (t = 0.87, df = 13.97, p = .399) among infants missing 3 or more epochs of RSA data compared to those with more complete RSA data (at least 75%). Therefore, all available data were used in analyses and the use of missing data estimation (e.g., Full Information Maximum Likelihood Estimation) was deemed appropriate for all subsequent models.

Unconditional growth models

The unconditional growth model of maternal warmth demonstrated an inadequate fit to the data ($\chi 2$ [50] = 106.261, RMSEA = 0.093, CFI = 0.918). The intercept for maternal warmth (M = 3.540, SE = 0.055, $p < .001$) was significantly different from 0, and variance in the intercept suggested significant variability in initial levels of warmth (σ^2 = 0.311, SE = 0.001, p < .001). Maternal warmth also demonstrated significant linear change (M = -0.030, SE = 0.007, p < .001) and variance in this change (σ^2 = 0.004, SE = 0.001, p = .001) across the reunion episode.

The second unconditional growth model examining infant RSA demonstrated adequate fit to the data ($\chi 2$ [50] = 58.116, RMSEA = 0.038, CFI = 0.980). The intercept for infant RSA (M = 3.494, SE = 0.091, $p < .001$). was significantly different from 0, and variance in intercept suggested significant variability in infant's ultimate levels of RSA (σ^2 = 0.643, SE = 0.131, p <

.001). Infant RSA also demonstrated significant linear change (M = -0.023, SE = 0.011, p = .045) and variance in this change (σ^2 = 0.005, SE = 0.002, p = .007) across the reunion episode.

The final unconditional growth model examining infant negative affect (NA) demonstrated poor fit to the data ($\chi2$ [50] = 131.087, RMSEA = 0.113, CFI = 0.890). The intercept for infant NA (M = 1.857, SE = 0.162, $p < .001$) was significantly different from 0, and variance in intercept suggested significant variability in infant's ultimate levels of NA (σ^2 = 2.776, SE = 0.442, $p < .001$). Infant NA also demonstrated significant linear change (M = 0.072 , SE = 0.019, $p < .001$) and variance in this change (σ^2 = 0.029, SE = 0.006, $p < .001$) across the reunion episode.

Parallel Process Models

To test the first part of our hypotheses, three parallel process models examined separately the associations among growth factors for (1) maternal warmth and infant NA, (2) maternal warmth and infant RSA, and (3) infant RSA and infant NA. The first model including maternal warmth and infant NA demonstrated poor fit to the data ($\chi2$ [196] = 346.517, RMSEA = 0.077, CFI = 0.896. The slope of infant NA was positively associated with ultimate levels of NA (β= .185, SE = .044, $p < .001$); and the ultimate level of infant NA was marginally associated with the initial level of maternal warmth (β= -0.195, SE = 0.104, p = 0.060). There were no other significant associations between the ultimate level of infant NA and the slope of maternal warmth, or slope of infant NA and maternal warmth levels or growth.

The second model including maternal warmth and infant RSA demonstrated adequate fit to the data ($\chi2$ [196] = 280.823, RMSEA = 0.057, CFI = 0.924). The ultimate level of infant RSA was positively associated with the slope of maternal warmth, indicating that higher levels of RSA were related to greater increases in warmth (β= 0.018, SE = .008, p = .023).

Additionally, the slope of infant RSA was positively associated with the slope of maternal warmth, indicating that increases in RSA were related to increases in maternal warmth (β= .003, SE = 0.001, p = 0.009). There were no significant associations between the ultimate level or slope of infant RSA and the initial level of maternal warmth.

The third parallel process model including infant RSA and infant NA demonstrated poor fit to the data ($\chi 2$ [196] = 329.271, RMSEA = 0.072, CFI = 0.888). The ultimate level of infant RSA was positively associated with the slope of infant RSA (β= 0.030, SE = .015, p = .05). The ultimate level of infant NA was positively associated with the slope of infant NA (β= 0.193, SE = .045, $p < .001$). The ultimate level of infant RSA was negatively associated with the ultimate level of infant NA, indicating that higher RSA was related to lower infant NA at the end of the reunion (β= -0.777, SE = 0.212, $p < .001$). The ultimate level of infant NA was negatively associated with the slope of infant RSA, such that infants whose RSA increased over the course of the reunion episode also had lower levels of NA in the final epoch (β= -0.082, SE = 0.027, p = .002), and similarly, the ultimate level of infant RSA was negatively associated with the slope of NA, such that infants whose NA decreased over the course of the reunion episode also had higher levels of RSA in the final epoch (β= -0.058, SE = 0.022, p = .009). The slopes of infant RSA and infant NA were not significantly associated.

Autoregressive Latent Trajectory (ALT) Models

To test the time-specific and directional hypotheses, the three autoregressive latent trajectory (ALT) models examined the associations between (1) maternal warmth and infant NA, (2) maternal warmth and infant RSA, and (3) infant RSA and infant NA across the reunion episode. The time-specific results of the ALT models are presenting in Table 3. The first model including maternal warmth and infant NA demonstrated adequate fit the data ($\chi 2$ [160] =

225.978, RMSEA = .056, CFI = 0. 954), and $\chi 2$ difference tests suggest fit was significantly improved from the parallel process model without the autoregressive and cross-lagged components ($\chi 2$ [36] = 120.54, $p < .001$). Over and above the variance accounted for by the growth factors and autoregressive effects, maternal warmth predicted subsequent levels of infant NA across the first 3 epochs (90 seconds) (β= -0.212, SE = .050, $p < .001$; β= -0.144, SE = .048, $p = .003$; and β= -0.162, SE = 0.051, $p = .002$, respectively). There were no significant cross-lagged effects in the opposite direction (i.e., infant NA predicting subsequent levels of maternal warmth).

The second model examining time-specific associations between maternal warmth and infant RSA fit was acceptable ($\chi 2$ [160] = 200.743, RMSEA = 0.044, CFI = 0.964). Again, this model fit the data significantly better than the model predicting infant RSA without autoregressive and cross-lagged effects ($\chi 2$ [36] = 80.08, $p < .001$). Only one cross lagged effect emerged with initial levels of infant RSA predicting subsequent levels of maternal warmth from the first epoch to the second (β= -0.102, SE = .038, $p = .008$).

The final ALT model tested the time-specific associations between infant RSA and infant NA. For the final ALT model, including infant RSA and infant NA, fit was acceptable ($\chi 2$ [160] = 214.173, RMSEA = 0.050, CFI = 0.955). The model fit significantly improved with the addition of the autoregressive and cross-lagged components ($\chi 2$ [36] = 115.1, $p < .001$). In partial support of our hypotheses infant's RSA predicted change in infant NA across the first 5 epochs (150 seconds) of the reunion episode. Specifically, infant's RSA was negatively associated with infant NA in the subsequent epoch (β= -0.245, SE = .048, $p < .001$; β= -.214, SE = .044, $p < .001$; β= -.244, SE = .043, $p < .001$, β= -.150, SE = .052, $p = .004$; β= -.170, SE = .058, $p = .004$, respectively). Only one cross-lagged association in the opposite direction (i.e., infant NA predicted subsequent levels of infant RSA) emerged. Specifically, infant's NA during the third epoch predicted infant's RSA in the subsequent, fourth, epoch (β= -0.168, SE = .063, p = .008).

Discussion

Results from the current study detail time-specific associations among infant negative affect, infant RSA, and maternal warmth across a 5-minute reunion episode following a stressor. A series of autoregressive latent trajectories models revealed that changes in infant RSA predicted changes in infant negative affect in the subsequent epoch. Additionally, changes in infant negative affect were predicted by changes in maternal warmth. Contrary to our hypothesis, no associations emerged when examining epoch to epoch associations between maternal warmth and infant RSA, although parallel process models indicated an association between the slope of maternal warmth and the slope of infant RSA across the reunion.

In line with hypothesis, the study adds to the evidence that an increase in RSA following a stressor is associated with emotional recovery (i.e., decreased negative affect) (e.g., Bazhenova et al., 2001; Conradt & Ablow, 2010). Specifically, although the slopes of infant NA and RSA were not associated, the ultimate levels of NA and RSA were negatively associated suggesting that infants with higher RSA had lower levels of NA at the end of the reunion episode. Additionally, both of the ultimate levels of NA and RSA were explained by the slopes of RSA and NA respectively, such that a decrease in NA was associated with higher ultimate RSA and an increase in RSA over the course of the reunion were associated with lower ultimate NA.

The final ALT model revealed cross-lagged associations in primarily one direction suggesting that changes in RSA preceded changes in infant NA. Notably, these associations were observed in the first 2.5 minutes of the reunion episode, suggesting that most of the variation in infant's emotional recovery occured during the first few minutes. Although descriptive statistics indicate that NA did not drastically change after the first 5 epochs, there is significant individual variability in the level of NA epoch to epoch. These effects could be stronger for some children compared to others. Future research may consider potential moderators of this association.

Similarly, results indicated that higher maternal warmth was associated with lower infant NA in the subsequent epoch during the first 1.5 minutes of the reunion episode. Maternal behaviors immediately following the Still Face stressor may have the greatest impact on infant emotional recovery, whereas the physiological support (i.e., increases in RSA) of infant's emotion regulation may be a slightly more protracted process. Indeed, previous literature indicates that carryover effects from the Still Face episode may play a role in the first couple of minutes of the reunion (e.g., Suurland et al., 2017). Maternal behaviors during this period could, thus, be particularly important. It is also possible that maternal warmth and RSA contribute to infant emotion regulation additively, with maternal behaviors initially serving to sooth the infant, and RSA reflecting infants' individual differences emotion regulation capacity that continues to regulate infant NA beyond maternal effects.

It is important to note that the overall slope of RSA was negative. Although the negative slope was relatively small (M = -0.023, SE = 0.011, $p = .045$), on average infant RSA slightly increased at the sample level. This finding is somewhat in line with recent literature which also found that infant's RSA levels did not significantly increase following the Still Face stressor, suggesting that physiological recovery may take longer than the reunion episode allows (Gao et al., 2022). Studying temporal dynamics may capture subtle processes that are otherwise lost at the episode average level. For instance, Gao et al. (2022) found that while arousal measured shortly after birth was not associated with mean changes of RSA from Still Face to reunion, newborn arousal was associated with infant's slower decrease in RSA. Taken together, findings from previous research and the present study underscore the value of examining RSA's relation to other indicators of regulation using a fine-grained approach rather than using average RSA levels across a task.

Additionally, although the unconditional model fit is poor, the overall slope of infant NA was positive (M = 0.072 , SE = 0.019, $p < .001$) suggesting that infants did not decrease in their negative affect over the course of the reunion. Both of these growth factors for RSA and NA were characterized by significant variability. Individual differences in physiological regulation and recovery following the stressor could potentially explain these overall effects, as well as the mixed findings in the literature. Indeed, previous literature has found interactive effects of infant irritability and maternal sensitivity on infant's emotional recovery following the Still Face (Gunning et al., 2013). Furthermore, a person-centered approach such as growth mixture modeling or latent class analysis may help elucidate the individual differences and unique patterns of emotion recovery. Additionally, the trajectory of emotional and physiological recovery during the reunion may take a curvilinear shape that is not captured by the linear models tested in the current study.

Limitations to the current study must be considered when interpreting the results. First, although the final models indicated adequate fit to the data, the unconditional growth models for maternal warmth and infant NA did not fit the data well. The trajectories of maternal behaviors and emotions and physiological recovery during the reunion may be better described by a nonlinear shape that is not captured by the linear models tested in the current study. Additionally, we did not control for baseline levels of RSA or participants intervention group in the current study. Our main hypothesis concerned associations in the trajectories of maternal warmth, infant

RSA, and infant NA within the reunion episode, thus infant's arousal immediately following the Still Face episode was accounted for by the first epoch in our analyses. However, controlling for baseline levels may have accounted for individual differences in RSA that are not accounted for in the current models (Graziano & Derefinko, 2013). The original study included three intervention groups (i.e., a pre-natal mindfulness group, a post-natal mindfulness group, and a post-natal mindfulness and parenting group) and one control group (e.g., received a book on parenting). Participants were randomly assigned to groups and group assignment was not accounted for in this study; however, there may be intervention effects on parenting behaviors, such as maternal warmth.

Given that our sample consists of families living in low-income contexts, it is particularly important to view our findings in relation to the context of risk that poverty confers. In line with previous literature (e.g. Lengua et al., 2014), our results indicate that infants are supported by their mother's positive affect and interactiveness (i.e., "warmth") during the reunion. Thus, interventions, particularly in an infant's first year of life (McLaughlin et al., 2015), that support maternal warmth and overall mental health may be important for infant's development of emotion regulation. Although low-income contexts are generally indicative of the presence of other risk factors, other factors such as maternal educational achievement and occupational status may be important to consider (Duncan & Magnuson, 2002). Factors such as employment have been predictive of positive parenting practices and better mental health among other samples of mothers living in low-income contexts (e.g., Jackson et al., 2008).

Using a stepwise approach, the current study utilized three autoregressive latent trajectory (ALT) models to describe associations among infant negative affect, infant RSA, and maternal warmth across the reunion following the Still Face episode. In sum, cross-lagged effects indicated that increases in RSA precede decreases in NA during the first 2.5 minutes of the reunion episode. Although not a time specific association, change in maternal warmth was associated with change in infant RSA across the task, partially supporting our hypothesis that maternal warmth supports infant physiological, and in turn, emotional recovery following the Still Face stressor. The study detailed associations among maternal behavior, infant RSA, and infant negative emotionality across a recovery episode following the commonly used Still Face paradigm to better elucidate the time-specific relations among maternal warmth, infant RSA, and observed emotion regulation.

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Table 1. *Descriptive Statistics for Study Variables during Reunion*

Reunion 30-sec Epoch	**Infant Negative Affect** Mean (SD) [min, max]	**Infant RSA** Mean (SD) [min, max]	**Maternal Warmth** Mean (SD) [min, max]
1	1.81 (1.74) [0, 5]	3.76 (1.08) [1.21, 6.48]	3.63 (0.75) [1.5, 5]
2	1.23 (1.60) [0, 5]	3.65 (0.99) [1.26, 6.69]	3.50 (0.71) [1.5, 5]
3	1.20 (1.54) [0, 5]	3.74 (1.15) [1.10, 6.44]	3.45 (0.71) [2, 5]
4	1.15 (1.57) [0, 5]	3.64 (1.16) [0.10, 6.36]	3.41 (0.74) [1.5, 5]
5	1.46 (1.72) [0, 5]	3.66 (1.15) [0.12, 6.34]	3.44 (0.78) [1, 5]
6	1.42 (1.66) [0, 5]	3.46 (0.95) [1.10, 5.21]	3.38 (0.82) [0, 5]
7	1.53 (1.61) [0, 5]	3.65 (1.03) [1.40, 6.12]	3.35 (0.85) [1, 5]
8	1.63 (1.59) [0, 5]	3.62 (1.05) [1.14, 6.08]	3.33 (0.89) [1, 5]
9	1.62 (1.73) [0, 5]	3.56 (0.93) [0.99, 6.09]	3.30 (0.79) [1, 5]
10	1.71 (1.74) [0, 5]	3.37 (0.88) [1.34, 5.02]	3.35 (0.78) [1.5, 5]
Average	1.57 (1.34) [0, 5]	3.60 (0.85) [0.10, 5.40]	3.23 (0.65) [1, 4.6]

Note. Descriptive statistics during the 5-minute reunion episode following the Still Face episode presented in 10 30-second epochs and at average levels across all epochs. For infant negative affect and maternal warmth observational codes, possible range = 0-5. RSA= respiratory sinus arrythmia, SD = standard deviation, min = minimum observed score, max = maximum observed score. N = 131 for maternal warmth, 127 for infant NA, and 113 for infant RSA.

Table 2. *Bivariate correlations among study variables averaged across epochs.*

	Infant NA	Maternal Warmth
Infant Negative Affect	-	
Maternal Warmth	-0.34** ($p < .001$)	-
Infant RSA	-0.09 ($p = .096$)	0.16 ($p = .070$)

Note. **p < .001; two-tailed. NA = Negative Affect. RSA = Respiratory Sinus Arrhythmia. All variables averaged across 10 30-sec epochs across 5-minute reunion episode.

Table 3. *Standardized regression coefficient and standard error for the autoregressive and Cross lagged effects of maternal warmth and infant RSA predicting subsequent epochs of infant RSA and infant negative affect.*

	Outcome								
	Infant Negative Affect								
Predictor (Epoch N – 1)	Epoch 2	Epoch 3	Epoch 4	Epoch 5	Epoch 6	Epoch 7	Epoch 8	Epoch 9	Epoch 10
Infant NA	.23(.08)***	.18(.08)*	.24(.07)***	.26(.08)**	.25(.06)***	.11(.08)	.25(.08)**	.21(.09)*	.16(.10)
Maternal Warmth	-.21(.05)***	-.14(.05)**	-.16(.05)**	-.02(.06)	-.02(.07)	.12(.08)	.13(.09)	.17(.11)	.25(.12)*
	Infant RSA								
Infant RSA	.07(.07)	.15(.08)	.11(.08)	.22(.08)**	.08(.06)	.20(.09)*	.20(.09)*	.14(.10)	.17(15)
Maternal Warmth	-.06(.07)	-.08(.09)	-.04(.09)	-.13(.09)	.01(.07)	-.04(.08)	-.02(.09)	.06(.10)	.00(.15)
	Infant Negative Affect								
Infant NA	.24(.08)**	.18(.08)*	.24(.07)***	.24(.07)**	.23(.06)***	.11(.08)	.26(.08)**	.19(.09)*	.14(.09)
Infant RSA	-.24(.05)***	-.21(.04)***	-.24(.04)***	-.15(.05)**	-.17(.06)**	-.10(.08)	-.12(.08)	-.10(.09)	-.06(.10)

Note. Results of autoregressive latent trajectory models reflecting autoregressive and cross-lagged effects predicting subsequent levels in outcome. RSA = respiratory sinus arrhythmia. NA = negative affect. N = 143, estimate (standard error), * $p < .05$, ** $p < .01$, *** $p < .001$.

Figure 1. Auto-Regressive Latent Trajectory Model testing Cross-Lagged Associations between RSA and NA

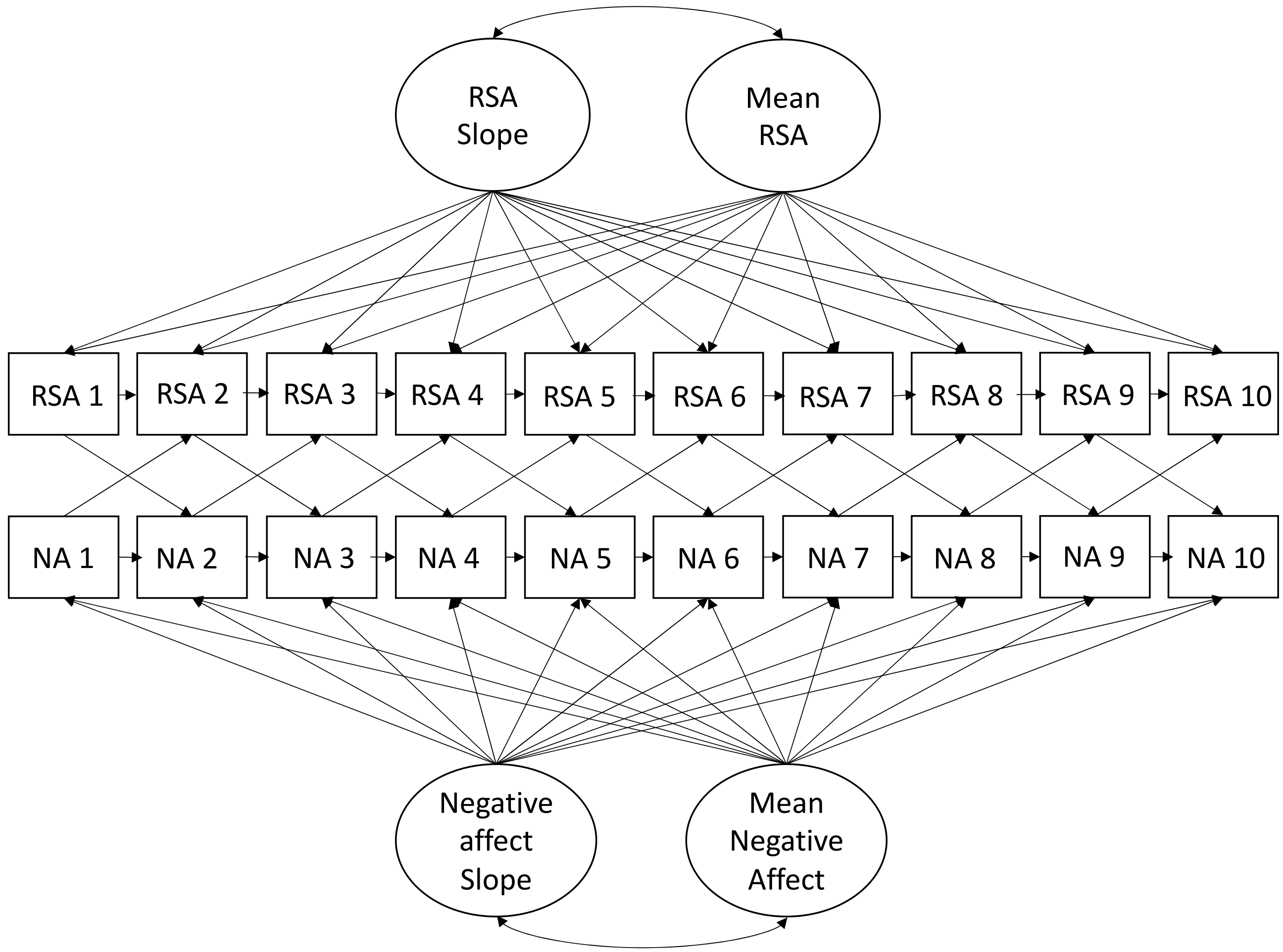

Figure 1 Note. NA 1-10 and RSA1-10 = levels of NA (negative affect) and RSA (respiratory sinus arrhythmia) in 30-epochs across 5-minute reunion episode following the still face episode. Intercepts for RSA and NA set to ultimate levels (for models that included maternal warmth – maternal warmth intercept set to initial level).