Getting to the Heart of the Matter:

The Role of Infants' Vagal Tone in Emotion Regulation and Coregulation During Mother-Infant Interactions

by

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ABSTRACT

Examining processes that characterize the ebb and flow of emotions offers insight into how infants modulate their own emotional experience as well as how both mothers and infants jointly regulate their emotional states. Drawing from polyvagal theory, which posits that vagal tone supports the capacity to quickly, flexibly, and adaptively respond to contextual demands (Porges, 2003, 2007), I hypothesized that infants with greater vagal tone (indexed by respiratory sinus arrhythmia; RSA) would show stronger evidence of emotion regulation and coregulation processes during free play and a frustrating task at 24 weeks child age. To evaluate these hypotheses, I used dynamic structural equation modeling (DSEM; Asparouhov, Hamaker, & Muthén, 2018) to examine biologically-based differences in second-by-second infant emotion regulation (equilibria, volatility, carryover, and feedback loops in positive and negative affect engagement) and mother- and infant-driven coregulation processes, among a sample of 210 low-income, Mexican-origin mother-infant dyads. Results offered evidence of both mother-driven and infant-driven emotion coregulatory processes during free play, which did not differ based on infant RSA. Results offered limited support for RSA-based differences in infant self-regulation processes during the teaching task, such that infants with below average RSA tended to respond to increased negative affect with subsequent increases in positive affect engagement. Prenatal maternal depressive symptoms also accounted for greater infant emotional volatility and weaker mother-driven emotion coregulation. Results highlight the unique roles mothers and infants play in achieving emotion regulation, as well as between-dyad differences in these processes, suggesting multiple pathways towards resilience among low-income, Mexican-origin families.

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INTRODUCTION

Emotion regulation supports children's acquisition of myriad positive developmental outcomes, including academic achievement, social competence, and psychological adjustment (Blandon, Calkins, Keane, & O'Brien, 2008; Cole, 2016; Denham, 1998). Longitudinal studies suggest that children who do not acquire competent emotion regulation by the preschool years have more mental health problems later in life, especially in the presence of socioeconomic and environmental adversities (Cole, 2016). By school entry, low-income Mexican-American children exhibit poorer self-regulation and interpersonal skills relative to their White peers (e.g., Galindo & Fuller, 2010). Early problems can cascade into other domains and across development; Mexican-American children and adolescents exhibit more internalizing and externalizing symptoms than do non-Hispanic youth (Avila & Bramlett, 2013; Bird, Canino, Davies, Zhang, Ramirez, & Lahey, 2001; CDC, 2006; Joiner, Perez, Dineen, Berenson, & Marquina, 2001). However, the risks associated with socioeconomic adversity and ethnic minority status may be mitigated by supportive, nurturing mother-child relationships (Fuller & García Coll, 2010; Luthar, 2006; Miller & Chen, 2013). The development of effective infant emotion regulation depends not only on infants' own abilities but also on coregulatory processes, such as synchronous (e.g., bidirectional and coordinated) caregiver-child interactions that maintain optimal affective states (Butler, 2011; Butler & Randall, 2013; Feldman, 2003; Tronick, 1989). Here, I sought to evaluate whether infants' biological functioning contributes to differences in emotion regulation and coregulation, which I conceptualized as temporally-based, dynamic processes that unfold in the context of bidirectional mother-child interactions.

Overview

Early developmental milestones include learning to effectively regulate emotions and their expression in response to contextual demands (Cole, Michel, & Teti, 1994; Demos, 1986). Emotion regulation, or an individual's ability to modulate emotional experiences and expressions in response to contextual demands, includes tolerance of high levels of arousal associated with positive affect and management of negative affect (Kopp, 1989), which requires flexibility or "switching out of" negative affective states (Beebe & Steele, 2013). From a functionalist perspective, emotions must be managed as soon as they are generated, rendering emotion and emotion regulation "part and parcel of the same fundamental process" (Cole, 2016, p. 289). For infants, changes in affect allow infants to signal their needs to caregivers and organize their behavior, which may include implementing regulatory behavioral strategies (Buss & Goldsmith, 1998); infants' emotions can be regulated by infants' and caregivers' behaviors and can regulate infants' interactions in the social environment (Buss & Goldsmith, 1998). As a primary goal of emotion regulation is to modulate infants' emotional experience and its expression, dynamic changes in infants' affect over time offer a window into processes by which infants self-regulate their internal emotional state (Buss & Goldsmith, 1998; Haviland & Lelwica, 1987; Kuppens & Verduyn, 2015). Although the definition and operationalization of emotion regulation varies according to different research traditions, methods that consider the dynamic *processes* by which emotion expression changes over time are aligned with a functionalist approach to emotion regulation and have become increasingly popular in recent years (e.g., Beebe et al., 2010).

For infants, emotional communication is especially important for survival and organizing attachment ties (Bretherton, 1985; Sroufe & Fleeson, 1986; Sroufe, Schork, Motti, Lawroski, & LaFreniere, 1984). Emotion expression has regulatory potential in that it not only guides infants' own behaviors but also typically evokes the attention and guides the behavior of caregivers and others in infants' environment (Cole, 2016; Tronick, 1989). Leading theories of children's socioemotional development, such as Feldman's biobehavioral synchrony model (e.g., Feldman, 2003; Feldman, 2012) and the mutual regulation model (e.g., Tronick, 1989), converge on the notion that emotion coregulation is based on the capacity for bidirectional coordination (i.e., synchrony) between caregivers and their children, such that both interaction partners actively contribute to constructing an optimal affective state during their interactions (Butler & Randall, 2013; Feldman, 2007). Notably, whereas some researchers distinguish between synchrony and coregulation, others use terms such as synchrony, contingency, coordination, and coregulation interchangeably (Beebe & Steele, 2013). Consistent with claims that coregulation is captured by the time-lagged influences of each individual's affect on their partner's affect within a stable emotional system (e.g., Beebe et al., 2010; Butler & Randall, 2013), I operationalize emotion coregulation as affect synchrony between mothers and their infants.

Traditionally, emotion regulation and coregulation have been examined within two distinct theoretical and research traditions: Temperament researchers have focused on endogenous, biological predictors of emotion reactivity and regulation during infancy (e.g., Rothbart & Bates, 1998; Rothbart & Derryberry, 1981) and attachment researchers have focused on exogenous predictors, such as maternal sensitive care, of children's emotion regulation and coregulation. Infants' autonomic maturity, including cardiac vagal tone, may contribute to individual differences in infants' emotional reactivity and regulation (Beauchaine, 2001; Calkins, Dedmon, Gill, Lomax, & Johnson, 2002), although recently there has been increased recognition of the interacting influences among genetic, biological, and environmental factors on temperament (Crockenberg & Leerkes, 2003; Shiner, Buss, McClowry, Putnam, Saudino, & Zentner, 2012). A central component of temperament is negative emotional reactivity, which refers to individual differences in the frequency and intensity of negative emotion (Eisenberg, Fabes, Murphy, Maszk, Smith, & Karbon, 1995; Rothbart & Bates, 1998), including how regularly the infant displays negative affect (Derryberry & Rothbart, 2001). Infants who are high in negative affectivity tend to exhibit more frequent, intense, and prolonged displays of negative affect (e.g., Calkins et al., 2002). In addition, infant temperament encompasses dispositional differences in infants' styles of regulation, which is often operationalized in terms of the timing and/or degrees of reductions in infant emotional expression (Crockenberg & Leerkes, 2003; Demos, 1986; Stifter & Braungart, 1995).

Infant negative emotionality is generally considered an impediment to the development of effective emotion self-regulation (Calkins et al., 2002; Cole, 2016) and is associated with longer-term deficits in socioemotional functioning, including internalizing and externalizing behavior problems and impaired social competence (Cole, Martin, & Dennis, 2004; Eisenberg et al., 2001; Eisenberg et al., 2005; Hagan, Luecken, Modecki, Sandler, & Wolchik, 2016; Mesman et al., 2009; Rothbart & Bates, 2006; Rydell, Thorell, & Bohlin, 2007; Stifter & Dollar, 2016). However, there may be differences in the consequences of negative emotionality depending on the type of eliciting stimuli, and researchers have argued for distinguishing between fearful reactivity to novel stimuli and angry reactivity to limitations (Crockenberg & Leerkes, 2003). Further, some studies have demonstrated that temperamentally negative infants benefit the most from positive parenting (Slagt, Dubas, Dekovic, & van Aken, 2016), suggesting negative reactivity may facilitate infants' engagement in their social environment and may only be associated with poor outcomes in the context of insensitive or unresponsive caregiving. Similarly, prior work suggests that negative reactivity is only associated with problem behavior when children are unable to engage in appropriate regulatory strategies (e.g., Santucci et al., 2008), which may depend on the maturation of children's regulatory capacity as well as the abilities of children's interaction partners to offer external regulation (Cole, 2016).

Attachment researchers have long argued the origins of emotion regulation can be traced back to qualities of the parent-child relationship (Beebe & Steele, 2013; Cassidy, 1994; Feldman, 2004). Infants depend on parent-child interactions to supplement their rudimentary regulatory capacities and to develop more sophisticated self-regulation (Feldman, 2009). Adults' contingent responsiveness to infants' signals is thought to facilitate infants' understanding that their feelings matter and have an impact on others' thoughts and feelings (Beebe et al., 2010, 2012; Tronick & Beeghly, 2011), and infants' perception of their mothers' positive and negative affect strongly influences infants' own emotional state (Haviland & Lelwica, 1987; Tronick, 1989). By three-to-four months, infants are able to sustain long periods of face-to-face engagement (Beebe & Steele, 2013), are sensitive to changes in adults' facial and vocal expressions (Gusella, Muir & Tronick 1988; Haviland & Lelwicka, 1987; Montague & Walker-Andrews, 2002; Muir &

Hains, 1993), and expect adults to mirror their behaviors (Beebe et al., 2010, 2012; Tronick & Beeghly, 2011). Around three months of age, infant and mothers show affect synchrony in their face-to-face interactions (Beebe et al., 2010; Cohn & Tronick, 1988; Feldman, 2007; Gordon & Feldman, 2015; Malatesta, Culver, Tesman, & Shepard, 1989; Messinger, 2002; Stern, 1985; Tronick, 1989), such that infants and mothers change their affect in temporal coordination with each other, which is typically measured at a lag of a second (e.g., Beebe et al., 2010; Feldman & Eidelman, 2007; Weinberg, Beeghly, Olson, & Tronick, 2008). In short, coordinated changes in infants' and their mothers' affect reflect an important coregulatory process.

Although synchrony occurs across numerous behavioral channels (e.g., facial affect, gaze, touch, vocalizations), affect synchrony has retained a privileged position in theoretical and empirical work. Affect synchrony is one of the "building blocks of behavioral synchrony" (Gordon & Feldman, 2015), shapes the parent-infant "relational system" (Feldman & Eidelman, 2007), and supports organized and secure attachment (Beebe et al., 2010, 2012; Cole, Michel, & Teti, 1994). Affect synchrony may be assessed within a specific modality (e.g., facial affect, vocal affect), although research on face-to-face mother-infant interaction has often adopted Tronick's (1989) multimodal perspective that affect is expressed not only facially, but also expressed vocally and bodily (e.g., affect engagement: Beebe et al., 2010; Cohn et al., 1990; Feldman, 2003, 2006; Weinberg et al., 1999, 2008). Affect synchrony promotes coregulation through direct transmission of maternal emotional states to the child, and also through indirect means, such as physiological attunement, as the infant may "sense" changes in maternal internal states, which in turn influence the infant's inner emotional state (similar to the concept of hidden regulators; Hofer, 1995). Through establishing affect synchrony, mothers and infants are able to develop reciprocal, well-regulated interactions (e.g., Feldman, Bamberger, & Kanat-Maymon, 2013).

Whereas the biological basis of infants' dispositional styles of emotional reactivity and regulation (i.e., temperament; Rothbart & Bates, 1998) has garnered considerable attention, there is a paucity of information regarding factors, especially infant characteristics, which account for between-dyad differences in affect synchrony. Recent neurobiological models of the ontogeny of emotion regulation posit that brainstem-limbic processes (e.g., vagal functioning) support the development of self-regulation and social engagement (Feldman, 2015), suggesting these processes may also support children's ability to tap into the coregulatory potential of caregiver-infant interaction. Here, I propose to evaluate whether infants' biological characteristics contribute to temporal processes of infant emotion regulation and coregulation.

Infant Vagal Tone and Emotion Regulation

Autonomic nervous system (ANS) functioning may be an infant factor that contributes to differences in emotion regulation and coregulation. ANS functioning is involved in the generation and regulation of emotions (Porges, Doussard-Roosevelt, & Maiti, 1994; Thompson, Lewis, & Calkins, 2008). Research on the contributions of ANS functioning to emotion regulation has focused primarily on the role of the parasympathetic nervous system (Perry, Nelson, Swingler, Leerkes, Calkins, Marcovitch, & O'Brien, 2012), and more specifically, on vagal tone, which reflects the ebb and flow in heart rate during a respiratory cycle that is mediated by the vagus nerve. According to Porges' polyvagal theory (e.g., Porges, 1995, 2001, 2003, 2007), the myelinated vagus nerve acts like a “brake”; during resting conditions, this break inhibits activation of more resource-intensive sympathetic influences and supports physiological homeostasis, whereas release of the vagal break during challenges supports adaptive behavioral and emotional responses. Further, polyvagal theory describes an integrated system that links the myelinated vagus with muscles in the face and head. This social engagement system provides a “biobehavioral platform” for socioemotional behavior (e.g., facial expressions and vocalizations) during face-to-face interactions (Porges, 2001, 2003; Porges & Furman, 2011). Thus, vagal tone is a putative marker of an individual’s capacity to quickly, flexibly, and adaptively respond to the social environmental context (Beauchaine, 2001; Obradović, 2012; Porges, 2003, 2007). Consistent with theory that higher vagal tone facilitates contingent and appropriate emotion expression, social engagement and attachment formation, and effective emotion regulation (Beauchaine, Gatzke-Kopp, & Mead, 2007; Porges, 2007; Porges et al., 1994; Porges & Furman, 2011), across the lifespan, high resting respiratory sinus arrhythmia (RSA), an index of parasympathetically-mediated vagal tone (Porges, 2007), is associated with more effective emotion regulation, empathy, social competence, and psychological well-being (Appelhans & Luecken, 2006; Beauchaine, 2001, 2015; Propper, 2012; Shader et al., 2018).

Parasympathetic nervous system functioning rapidly matures over the first few months of life (Quigley & Moore, 2018), and vagal tone achieves moderate rank-order stability by four to six months, among ethnic majority children as well as among low-income Latino children (e.g., Alkon, Boyce, Davis & Eskenazi, 2011). Low infant vagal tone and low vagal withdrawal in response to stressors have been associated with subsequent deficits in self-regulation and social, emotional, and behavioral problems in childhood (Porges, 2001; Porges, Doussard-Roosevelet, Portales, & Greenspan, 1996; Feldman, 2009; Field & Diego, 2008). However, among low-income, Mexican-American children, low infant vagal tone also has been related to higher subsequent behavioral competence and fewer behavior problems when infants are reared in highly supportive contexts (Somers, Jewell, Ibrahim, & Luecken, 2018; Somers, Luecken, Spinrad, & Crnic, 2018). Further, empirical associations between vagal tone in infancy and emotion regulation are inconsistent, raising questions about the implications of vagal tone for emotion regulation early in life.

Among infants from ethnic majority, middle-class families, higher vagal tone has been associated with less observed infant negative emotion reactivity to novel sensory and social situations. Huffman et al. (1998) found that 12-week old infants with higher baseline cardiac vagal tone showed fewer negative behaviors during the Behavioral Response Paradigm (BRP), a laboratory assessment of infant temperament that exposes infants to novel social and sensory stimuli. Similarly, in addition to these cross-sectional studies, higher neonatal vagal tone prospectively predicted less negative emotionality, based on the proportion of time the infant spent in crying or fussing states during the BRP, at three months child age (Feldman, 2006). Additionally, in response to a novel person, five-month old infants with higher RSA exhibited more joy and interest expressions than did their lower RSA counterparts (Stifter, Fox, & Porges, 1989).

On the other hand, among typically developing infants, higher resting RSA also has been associated with exaggerated emotion reactivity, assessed via physiological and behavioral reactivity, to a range of stressors (Beauchaine, 2001; Porges, Doussard-

Roosevelt, Portales & Suess, 1994). Higher neonatal vagal tone has been related to more infant negative emotion reactivity to stressful medical procedures, including more emotion reactivity to the gavage method of feeding (DiPietro & Porges, 1991), higher fundamental cry frequencies and autonomic reactivity to unanaesthesized circumcision (Porter, Porges, & Marshall, 1988), and exaggerated cortisol reactivity to a heel stick blood draw (Gunnar, Porter, Wolf, Rigatuso, & Larson, 1995). Infant vagal tone has been positively associated with more negative emotionality (including longer duration of crying and higher odds of crying) in response to everyday tasks designed to elicit frustration, such as pacifier withdrawal or arm restraint (Fox, 1989; Stifter & Fox, 1990; Stifter, Fox & Porges, 1986). Using a selected groups approach among a sample of six-month olds from predominantly Caucasian, middle-class families, Calkins et al. (2002) demonstrated that infants who were more easily frustrated (based on behaviors during laboratory-based tasks designed to elicit frustration [e.g., plastic barrier task, arm restraint, maternal prohibition] and maternal report of distress to limitations) had higher baseline RSA than their less easily frustrated counterparts.

Consistent with predictions borne from polyvagal theory, some investigators, using predominantly ethnic majority, middle-class samples have found that higher RSA was not only associated with more infant frustration, but also with greater infant regulatory efforts. For example, although Calkins et al. (2002) found that higher infant RSA was associated with increased frustration, in their study, higher RSA infants also more frequently sought support from their mothers. Similarly, although Fox (1989) found infants who had higher vagal tone were more likely to cry upon arm restraint and were more likely to exhibit more negative reactivity, infants with higher vagal tone also displayed more regulation of distress (including looks to mother and averting gaze). Other work has demonstrated positive associations between infant vagal tone and emotion regulation. Twelve-week old infants with higher vagal tone required less soothing/calming during the BRP (Huffman et al., 1998). Among a small sample of preterm infants, infants' observed self-consoling behaviors (e.g., non-nutritive sucking, grasping, hand/foot clasp) in response to caregiving procedures on the neonatal intensive care unit on days four to five of life were positively associated with infants' observed HF-HRV, suggesting that infants' vagal functioning is related to behavioral regulation (Gardner et al., 2018). In sum, vagal tone has been interpreted as both an index of negative emotion reactivity and of emotion regulation in infancy (e.g., Beauchaine, 2001; Porges et al., 1994).

Following a functionalist view of emotion (Cole, 2016), these findings may be reconciled by conceptualizing emotion expression in its context and considering the social meaning of emotion expression. Polyvagal theory (e.g., Porges, 2001; Porges et al., 1994) adopts a similar approach to the model of vagal regulation. According to polyvagal theory, the myelinated vagus supports communication with the environment via facial expressions and vocalizations (e.g., crying and grimacing to signal negative states, and positive vocalizations and smiles to signal more positive states; Porges, 2001). Higher infant resting RSA may reflect infants' capacity to actively engage with their environment and exhibit appropriate affective responses, which may take different forms depending on environmental conditions (Beauchaine, 2001; Blandon, Calkins, Keane, & O'Brien, 2010; Stifter & Fox, 1990; although other explanations aligned with a differential susceptibility framework have been proposed, e.g., Conradt, Measelle, &

Ablow, 2013). Especially during novel, frustrating tasks (e.g., arm restraint, medical procedures), negative affect is an appropriate regulatory strategy for infants (Stifter & Fox, 1990), as it may guide infants' attention toward their caregivers and the broader social environment and may capture caregivers' attention (Perry et al., 2018). However, it remains to be tested whether infants with higher RSA also differentially respond to fluctuations in their caregivers' emotional expressions, which provide meaningful cues about the environment.

Further, whereas existing research has relied on ethnic majority, middle-class families, understanding early emotion regulation and coregulation among vulnerable dyads (e.g., dyads from low-income, ethnic minority backgrounds) may shed light on how children adapt to their environments in ways that either promote adjustment or confer risk. Low-income Mexican-American children are at higher risk for future regulatory and interpersonal skills deficits and emotional and behavioral problems relative to their White counterparts (e.g., Avila & Bramlett, 2013; Bird et al., 2001; Galindo & Fuller, 2010; Grant et al., 2004; Joiner et al., 2001). Low-income, Latina women also experience numerous stressors that impact their own self-regulatory and coregulatory capacities, including elevated rates of postpartum depressive symptoms (Chaudron et al., 2005; Howell, Mora, & Leventhal, 2005; Kuo et al., 2004). Thus, their children are at-risk for being unable to elicit effective coregulatory responses from their caregivers. When children are not able to elicit effective responses to their emotional distress from their caregivers, they may engage in dysregulated (either minimized or exaggerated) emotion expression, which is ineffective at obtaining the additional regulatory support children require to cope with the challenges in their environment

(Cole, 2016). Over time, repeated failure to elicit effective coregulation may contribute to children's subsequent regulatory deficits.

Yet children who are able to reap the benefits of maternal nurturance and support are more likely to experience resilience to the risks associated with low socioeconomic and ethnic minority status (Fuller & García Coll, 2010; Luthar, 2006; Miller & Chen, 2013). Consistent with multifinality, a central tenet of developmental psychopathology (Richters & Cicchetti, 1993; Sroufe, 1997), it is particularly important to understand factors that increase risk for poor coregulation or confer resilience among high-risk populations, in order to understand processes underlying individual pathways to adaptive or maladaptive outcomes (Cicchetti & Toth, 2009; Sroufe, 2007). Children's internal, biological rhythms may facilitate children's flexible behavioral and physiological responses to stress (Quigley & Moore, 2018), and may promote overall engagement and contingent responsiveness in caregiver-child interactions, which in turn facilitate fluency in these interactions. Overall, children's biological characteristics may buffer against broader environmental risks by promoting emotion regulation and coregulation during dynamic mother-child interactions. Further, whereas most extant research has adopted a developmental time scale to understand processes of multifinality, investigation of micro-level processes offers an entrée into potentially causal mechanisms through which parent-child interactions support or hinder development. Thus, it is particularly important to evaluate the role of infants' resting RSA in the dynamic temporal processes of emotion regulation and coregulation among high-risk families.

Moment-to-moment Emotion Dynamics During Mother-infant Interactions

Emotion regulation is not a static process, but “is an ongoing process of the individual's emotion patterns in relation to moment-by-moment contextual demands" (Cole, Michel, & Teti, 1994, p. 74). According to Tronick & Reck’s (2009) mutual regulation and Feldman’s biobehavioral synchrony (e.g., Feldman, 2003) theories, infants and mothers participate in an emotional communication system, characterized by moment-to-moment coordination in mothers’ and infants’ affective states, which functions to regulate infants’ states of arousal and emotions. Infants’ expressions of emotions act as signals within dynamic parent-child interactions, capturing mothers’ attention and guiding both infants’ and mothers’ regulatory behaviors, and offer a window into understanding the critical temporal aspects of infant emotion regulation (Cole, 2016; Fox, Kirwan, & Reeb-Sutherland, 2013). Fluctuations over time in infants’ emotional signals can index the dynamic *processes* of emotion regulation and coregulation, offering an important complement to research that has globally evaluated behaviors employed in regulatory efforts (Feldman, 2003).

Evaluating between-dyad differences in second-by-second changes within infant affect offers a lens for understanding infant emotion regulation. Infants experience both internal (e.g., hunger) and external (e.g., too much or too little stimulation) regulatory challenges. In contrast to global observations that capture qualitative features of behavior, micro-level observations highlight fine-grained patterns of how mothers and infants manage emotions online and offer insight into the dynamic aspects of emotion regulation and coregulation processes, as they unfold over time (Beebe et al., 2010; Feldman, 2009;

Granat et al., 2017). Specifically, time series analyses using micro-level observations of affect can capture the within-person variability in affect, which fluctuates over time (i.e., a person's affect at any given point in time may be higher or lower than his or her mean level of affect), allowing for examination of specific parameters that characterize the "momentary dynamics" (McNeish & Hamaker, 2018, p. 16) of emotion regulation and coregulation *processes*. Overall, my aim is not to compare microanalytic and macroanalytic approaches to the study of emotion regulation and coregulation, but rather to use a microanalytic approach to evaluate biologically-based differences in the dynamic processes of infant emotion regulation and coregulation that unfold over time during mother-infant interactions.

Emotion processes can be captured by several parameters derived from time series analyses. Time series model assume each person has a stable (mean) level of affect around which he or she fluctuates. Infants' mean level of positive and negative affect is conceptually related to temperamental negativity, especially how regularly the infant experiences negative emotions (Derryberry & Rothbart, 2001). Examining fluctuations in infant's and mother's affect around his or her mean offers insight into infants' emotion regulation and coregulation processes, which can be indexed through several parameters derived from time series models, such as the volatility in positive and negative affect over time as well as moment-to-moment carryover in and transactions between one's affect states. Although we know little about variability in infants' emotions (Cole, 2016), evidence suggests by six months of age, infants demonstrate decreased emotional lability (based on the average number of changes in their facial expressions) and greater attenuation of negative affect (based on the average frequency of affect expression;

Malatesta & Haviland, 1982). Despite the paucity of empirical literature, infants' affect variability is thought to be an integral component of emotional competence (Cole, 2016). Although excessive variability may indicate emotion dysregulation (Maher et al., 2018), examination of the temporal dynamics of adolescents' and adults' emotional states generally suggests that emotion variability reflects appropriate responding to changes in environmental/task demands whereas restricted emotion variability (i.e., emotional inertia or resistance of emotional states to change) is a hallmark of psychological maladjustment (e.g., Koval, Kuppens, Allen, & Sheeber, 2012; Kuppen, Allen, & Sheeber, 2012).

In the limited extant literature that has employed time series analyses of infants' emotion regulation processes, emotion regulation has more often been operationalized in terms of carryover in affect from one time point to the next (i.e., self-contingency; Beebe et al., 2010, 2018). Consistent with the definition of self-regulation as the ability to activate and dampen arousal and the capacity to downregulate negative affect, researchers have suggested that carryover in affect is an important indicator of emotional wellbeing (Beebe & Steele, 2013; Kuppens, Allen, & Sheeber, 2012). However, there are differences in the interpretation of the carryover of affect state. Some argue it is an indicator of stability and predictability (e.g., Beebe et al., 2010), such that relatively higher self-contingency reflects well-organized, predictable behavior that facilitates smooth parent-child interactions. In contrast, others argue carryover is an indicator of emotional inertia and inflexibility, such that high absolute levels of self-contingency may reflect imperviousness to external, environmental influences (Kuppens, Allen, & Sheeber, 2012), suggesting an "optimal midrange" of self-contingency (Beebe et al., 2010). Consistent with speculation relatively higher self-contingency is adaptive, Beebe et al. (2010) demonstrated that relative to their insecurely attached counterparts, securely attached children showed greater self-contingency in affect engagement (Beebe et al., 2010).

The optimal level of self-contingency also may differ depending on affect valence. Prior research has suggested that a family intervention designed to help mothers form emotional connections with their preterm infants impacted infants' self-contingency, such that infants exhibited more carryover in positive vocal affect but were less likely to exhibit carryover in negative vocal affect (Beebe et al., 2018). Further, these infants were more likely to transition from negative to more positive vocal affect (Beebe et al., 2018), suggesting emotional self-regulation may also be indexed by the transactional relations between one's positive and negative affect over time (i.e., how well one's level of negative affect at one time point in time predicts one's level of positive affect at a subsequent point in time). These transactional relations among emotions *within* a person are thought to be an important component of emotion dynamics, reflecting feedback loops through which emotions can be regulated, although few researchers have evaluated transactional (cross-lagged) processes between a person's emotional states (Kuppens & Verduyn, 2015; Krone et al., 2018).

Relative to emotion regulation, more attention has been dedicated to the temporal dynamics of emotion coregulation (Beebe & Steele, 2013). Synchrony, or time-lagged influences of fluctuations in each partner's affect on the other's affect which serve to maintain a baseline affect state, has gained prominence as an index of interpersonal emotion regulation (e.g., Beebe et al., 2010; Butler & Randall, 2013; Feldman, 2006; although synchrony has also been used to refer to whether pairs of observed behaviors between partners follow each other sequentially at greater than chance rates; Butler, 2011). In response to extended maternal neutral affect and unresponsiveness in the still-face procedure, infants show a decrease in positive affect and an increase in negative affect (Cohn & Tronick, 1983; Tronick, Als, Adamson, Wise, & Brazelton, 1978). In addition, parents' positive affect plays a unique role in promoting infant positive affect (e.g., Tronick, 1989). Infants require caregivers' assistance to express and maintain positive affect through corresponding, moment-by-moment synchrony in parent and infant positive affect (Feldman, 2003). Mothers' positive affect expression may not only be mirrored by their infants, but may also be "state transforming," such that mothers' positive affect facilitates change in their infants' arousal and affect state (Beebe et al., 2010).

Research suggests that mothers and infants vary in their responsiveness to changes in each other's behavior (Cohn & Tronick, 1988). Among a sample of 54 mother-infant dyads, Cohn and Tronick (1988) coded mothers' and infants' affective engagement every quarter-second across a two-minute interaction and calculated cross-correlation functions for each dyad. Among six-month olds in the sample, 33 percent of infants and 67 percent of their mothers were responsive to changes in the other's behavior (i.e., exhibited a cross-correlation greater than two standard deviations from zero; Cohn & Tronick, 1988). Qualities of the caregiving relationship (e.g., maternal sensitivity, attachment quality) may account in part for these between-dyad differences in bidirectional influence (Beebe et al., 2010; Cohn & Tronick, 1988), although recent work has offered mixed evidence in support of this hypothesis. Whereas some studies have failed to demonstrate that maternal factors (e.g., maternal major depressive disorder or panic disorder) account for differences in the cross-correlation between each mother's and infant's time series (Weinberg, Beeghly, Olson, & Tronick, 2008), other work demonstrates that maternal depression is inversely related to the degree of synchrony, based on the largest cross-correlation coefficient between mothers' and infants' positive affective engagement time series (Feldman, 2003). Less often addressed, but of central importance to the present investigation, is the role of infant biological characteristics in accounting for between-dyad differences in bidirectional emotion regulation and coregulation processes.

Vagal Tone and Moment-to-moment Emotion Dynamics

Although no studies to my knowledge have directly tested whether infant biological characteristics account for differences in dynamic emotion regulatory processes during interdependent mother-infant interactions, vagal tone may account for differences in infants' emotion regulation and coregulation. Thus, the **first aim** of this project is to evaluate whether infant resting RSA at 24 weeks child age accounts for between-dyad differences in infants' second-by-second changes in positive and negative affect engagement during mother-infant interactions at 24 weeks child age. Given evidence that vagal tone is an index of regulatory capacity (e.g., Appelhans & Luecken, 2006; Beauchaine, 2001, 2015; Propper, 2012), I expect relative to infants with lower resting RSA, infants with higher resting RSA will (a) exhibit more positive affect and less negative affect engagement during neutral tasks but will exhibit both more positive and negative affect engagement during challenging tasks. In other words, I expect differences in the within-person means or equilibria of infants' emotional experiences, which can be viewed as the set points to which infants' emotion will return, following a fluctuation (Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018).

Further, infants' emotion regulation, indexed by volatility, carryover, and transactions in infants' affect states, may be influenced by biological characteristics. Porges et al. (1994) suggest that higher vagal tone should be related to greater flexibility, or the ability to adaptively respond to environmental demands, which includes the ability to modulate emotional displays. Infants with higher vagal tone may be more responsive to external, unpredictable influences in the environment, which may result in greater intra-individual residual variability (e.g., more volatility, larger peaks and valleys) in their affect engagement. I expect infants with higher resting RSA (b) will exhibit more intra-individual residual variability in their positive and negative affect engagement relative to infants with lower vagal tone (see Figure 1 for example).

In addition, emotion regulation is reflected in predictable patterns of infant affect, such as the carryover and transactions between infants' affect states. Carryover reflects how quickly an individual returns to his or her set point, following a disturbance to the equilibrium, and transactions reflect the predictive relationships between affect states (Hamaker et al., 2018) and have also been interpreted as evidence of feedback loops between affect states (Butler, 2015; Hollenstein, 2015; Krone, Albers, Kuppens, & Timmerman, 2018). Values further away from zero reflect a stronger prediction of one's affect engagement at a given time point based on one's affect engagement at the prior time point; in other words, values further away from zero reflect a longer return to one's set point (Hamaker et al., 2018). I expect infant RSA to moderate the carryover and transactional (feedback) paths within infant affect engagement. Specifically, I expect, relative to lower RSA infants, higher RSA infants will (c) have less carryover in negative affect engagement, meaning that the association between their negative affect engagement at adjacent time points is weaker, such that they restore equilibrium more quickly, and more carryover in positive affect engagement, meaning that the association between their positive affect engagement at adjacent time points is stronger, such that they restore equilibrium more slowly. Figures 2 and 3 illustrate high and null carryover in positive affect engagement, respectively. I also expect that, among infants with relatively higher RSA, (d) when they experience positive affect engagement, they will take longer to return to their mean level of negative affect engagement, whereas when they experience negative affect, they will return more quickly to their mean level of positive affect engagement.

Higher vagal tone may also facilitate mother-driven emotion coregulation, or infants' responsiveness (i.e., change in affect) to mothers' prior affect state. Infants with higher RSA exhibit good attentional abilities and greater alertness and responsiveness to environmental stimuli than their lower RSA counterparts, suggesting higher RSA infants are better equipped to sustain visual attention, participate in social interactions, and may disproportionately reap the benefits of maternal regulatory support (Feldman & Eidelman, 2007; Porter, 2003). Among a small sample of predominantly Caucasian first-time mothers and their infants, Porter (2003) demonstrated that infant vagal tone was positively associated with a global measure of observed coregulation. In addition, among a sample of middle-class Israeli families, Feldman & Eidelman (2007) demonstrated that neonatal vagal tone was positively related to gaze synchrony (in terms of the conditional probability that a mother gazed at her infant given her infant gazed at her) when children were three months old, such that among infants with higher vagal tone, infants and mothers were more likely to match each other’s gaze during face-to-face play. These findings support the possibility of biologically-based differences in the capacity for coregulation, although the extant literature has not assessed moment-to-moment affect synchrony, leaving unanswered questions about differences in the temporal process of emotion coregulation.

Gaze synchrony may be a mechanism of “neuroception,” a tenet of polyvagal theory that suggests the nervous system detects safety and threat in the environment, even without conscious awareness (Porges, 2006, 2007). When raised in more chaotic and unpredictable environments, such as those characterized by poverty, higher RSA infants’ enhanced “neuroception” may be associated with more attunement to predictable maternal cues (e.g., maternal affect) and greater capacity for moment-to-moment emotion coregulation by their mothers. Whereas the limited extant research on the dynamics of emotion regulation and coregulation has focused on middle-class, ethnic majority families, it is important to evaluate the relations between vagal tone and emotion regulation and coregulation among low-income, Mexican-American mothers and their infants, who are at high-risk for future regulatory and interpersonal skills deficits (e.g., Galindo & Fuller, 2010).

Therefore, the **second aim** of this project is to evaluate whether infant resting RSA at 24 weeks child age accounts for between-dyad differences in infants’ responsiveness to their mothers’ affect engagement. Consistent with the speculation that higher vagal tone facilitates not only infant emotion regulation, but also supports emotion coregulation, I expect higher RSA infants will exhibit more contingent responses to maternal positive affect engagement. Although this pattern could be interpreted as emotion dysregulation (consistent with biological sensitivity to context, which posits higher biological reactivity is associated with responsiveness to the environment, for better and for worse; Boyce & Ellis, 2005), adaptive regulatory responses do not necessarily reduce distress and may be adaptive if they function as signals to caregivers during challenging tasks or situations (e.g., infant distress in response to relatively lower maternal positive affect engagement reflects concern about an impending threat of maternal emotional unavailability and may be an effective regulatory strategy that signals to the mother she should change her behavior; Buss & Goldsmith, 1998; Tronick, 1989). Further, in contrast to emotion dysregulation processes (e.g., emotion contagion), in which covariation occurs around a changing level of affect (e.g., escalating negative affect), emotion regulation processes function within a homeostatic system, such that covariation is driven by positive and negative feedback loops that maintain optimal set points (Butler, 2011; Butler & Randall, 2013). Table 1 presents a review of expected carryover and transactional relations in maternal and infant affect engagement among dyads where infants exhibit higher resting RSA.

Whereas prior work has focused on evaluating infants’ emotion reactivity and regulation to challenging tasks, I propose to evaluate infants’ and mothers’ emotion dynamics during a challenging task and during free play. As noted previously, interpretation of infants’ emotions is inextricably linked to the context in which they are expressed (Cole, 2016). Infant negative affect expression (e.g., crying to gain mother’s attention and soothing) is an appropriate regulatory behavior during frustrating situations. Further, patterns of mother-infant synchrony may vary based on the goals of the interactive task (Gordon & Feldman, 2015). In contrast to tasks that place external regulatory demands on the dyad, free play may yield different patterns of emotion reactivity and regulation. Among premobile infants, playful interactions are distinguished by social engagement goals, and longer periods of mutual gaze, vocalizations, imitations, and affective sharing (Feldman, Greenbaum, Mayes, & Erlich, 1997). The structure of free play may therefore offer a unique context for evaluating "dyadic adaptation to endogenous cycles of affective involvement" (Feldman, 2007, p. 337), and biological differences in these patterns of adaptation. By evaluating patterns across free play and a challenging task that is designed to elicit negative affect, we may better understand the role of infant vagal tone in infants' emotion self-regulation and coregulation.

An Exploratory, Bottom-Up Approach: Infants' Influence on Maternal Affect Expression

Whereas research typically adopts a global approach to evaluating the specific qualities of sensitive parenting, evaluating mothers' response to second-by-second fluctuations in their infants' affect offers a finer-grained lens to understand infant-driven emotion coregulation, or maternal contingent responsiveness. In the Ainsworth tradition, sensitivity is thought to be a universal construct, defined as mothers' contingent (e.g., prompt and appropriate) responsiveness to their infants' social signals and distress cues (Ainsworth, 1967). Although research typically focuses on top-down approaches that seek to identify maternal characteristics that influence mothers' emotion regulation and parenting, the extant evidence suggests child temperament is also an important "determinant" of parenting (Belsky, 1984; Kiff, Lengua, & Zalewski, 2011).

Infants' biologically-based capacity for emotion regulation may also account for differences in mothers' responsiveness to their infants' affect (Feldman et al., 2004). Children with higher vagal regulation are thought to elicit more sensitive parenting through enhanced self-regulation, which leads to less parenting stress and smoother parent-child interactions (Perry, Mackler, Calkins, & Keane, 2014). Evidence from cross-sectional studies offers preliminary support for a link between infant vagal tone and the caregiving environment. Studies with predominantly Latino/a as well as studies with predominantly White, non-Latino/a samples have demonstrated that infants who exhibited higher HF-HRV received more sensitive maternal care (e.g., maternal sensitivity, skin-to-skin contact; Kaplan, Evans, & Monk, 2008; Marvin et al., 2018). Among a small sample of well-educated, predominantly White, first-time mothers and their six-month old infants, Porter (2003) demonstrated that infant vagal tone was positively associated with more dyadic regulation (assessed in terms of symmetrical communication) and negatively correlated with nonreciprocal communication sequences.

Longitudinal studies also demonstrate the prospective influence of infant vagal tone on maternal wellbeing and synchronous, reciprocal parenting. Recent work with this sample demonstrated that, among women with higher postpartum depressive symptoms, those whose infants had lower vagal tone at six weeks exhibited greater depressive symptoms at 36 months (Somers et al., 2019). Among a middle-class sample of preterm and full-term infants, Feldman and Eidelman (2007) demonstrated that preterm infants with low vagal tone in the early postpartum period received less concurrent maternal affiliative behavior (e.g., maternal positive affect, gaze, "motherese" vocalizations, affectionate touch) compared to preterm infants with higher vagal tone and the least amount of maternal touch at three months compared to the full sample of preterm and full-term infants. Further, across the full sample, higher neonatal vagal tone in the early postpartum period prospectively predicted more infant-mother gaze synchrony at three months, defined as the co-occurrence of social gaze between parent and child (Feldman & Eidelman, 2007). Similarly, Feldman (2006) found that higher neonatal vagal tone was prospectively related to more mother-infant synchrony (degree of coordination in affect engagement in the interaction) at three months. Notably, these studies did not disentangle the driver of synchronous interactions, rendering it unclear whether infant vagal tone was related to mothers' contingent responses to their infants', infants' contingent responses to their mothers, or both.

Given the possibility that infant vagal tone shapes maternal emotion coregulation during parent-child interactions, my **third aim** is to explore whether infant resting RSA at 24 weeks child age accounts for between-dyad differences in mothers' responsiveness to their infants' affect state. Early in life, infants expect their social partners to respond in kind during face-to-face interactions (Tronick & Beeghly, 2011), and when mothers exhibit divergent affect expressions, infants may have difficulty sensing shared states and in turn sensing their own emotional state (Beebe et al., 2010). Consistent with this interpretation, relative to mothers of future securely attached infants, mothers of future disorganized infants were more likely to show smile/surprised faces during infant facial/vocal distress (Beebe et al., 2010, 2012). Mothers of future disorganized infants were also less likely to show less coordination with infant affect engagement (Beebe et al., 2010). Failures of mothers' affective correspondence, especially with infant distress cues, may lead infants to feel they are not "sensed and known" by their mothers, which may compromise the development of emotion awareness and contribute to future disorganized states (Beebe et al., 2010, 2012). Thus, I will explore whether mothers of infants with relatively higher RSA show more contingent, matched responses to fluctuations in infant affect engagement. This slower return to equilibrium following periods of increased infant positive affect engagement may help maintain infants' positive emotional state as well as offer an affective "boost" for mothers (Somers et al., 2019). Mothers of higher RSA infants may also take longer to return to their own affect set points following increased infant negative affect engagement; this contingent responsiveness may support infants' emotion regulation, without indicating mothers are overwhelmed by their infants' negative affect.

Specific Aims

In sum, the specific aims of my dissertation study were three-fold.

Aim One.

I evaluated whether infant vagal tone accounts for differences in infants' emotion regulation processes during parent-child interactions. Specifically, I predicted that relative to infants with lower vagal tone, infants with higher vagal tone would exhibit:

a) more positive affect engagement and less negative affect engagement during neutral tasks, and both more positive and negative affect engagement during challenging tasks
b) more intra-individual residual variability in their positive and negative affect engagement
c) less carryover in negative affect engagement and more carryover in positive affect engagement

d) stronger negative association between positive affect engagement and subsequent negative affect engagement, but weaker negative association between negative affect engagement and subsequent positive affect engagement

Aim Two.

I evaluated whether infant vagal tone accounts for differences in infants' emotion coregulation processes during parent-child interactions. Specifically, I predicted that relative to infants with lower vagal tone, infants with higher vagal tone would exhibit more contingent, matched responses to maternal positive affect engagement.

Aim Three.

I evaluated whether infant vagal tone accounts for differences in mothers' emotion coregulation processes during parent-child interactions. Specifically, I predicted that relative to mothers of infants with lower vagal tone, mothers of infants with higher vagal tone would exhibit more contingent, matched responses to infant positive and negative affect engagement.

METHOD

Participants

The sample consists of 210 women and their children who participated in a 24-week home visit as part of a broader examination of very low-income, Mexican-American children's development, *Las Madres Nuevas*. Eligibility criteria for *Las Madres Nuevas* included: 1) self-identification as Mexican or Mexican American, 2) fluency in English or Spanish, 3) 18 years of age or older, 4) low-income status (defined as family income below $25,000 or eligibility for Medicaid or Federal Emergency Services coverage for childbirth), and 5) anticipated delivery of a singleton birth based on an ultrasound. The Arizona State University IRB and the Maricopa Integrated Health System IRB approved all study procedures prior to study inception. Sample characteristics are presented in Table 2.

Recruitment

During pregnancy, women were recruited from hospital-based prenatal clinics that serve low-income women by a bilingual interviewer from the research team. A bilingual, female interviewer from the research team obtained informed consent in the women's homes between 26-39 weeks gestation. Data for the present study comes from the prenatal and 24-week postpartum home visits.

Planned Missingness

To reduce participant burden, a "planned missing" design was employed as part of the broader *Las Madres Nuevas* study. Each participant was randomly assigned to miss one of the 12-, 18- or 24-week postpartum visits. The expected number of participants at each time point (two-thirds of the sample) was kept approximately equal. Of the 322 women who met inclusion criteria and consented to participate in the *Las Madres Nuevas* study during the initial home visit, 210 (93% of the randomly assigned 226 women) completed the 24-week assessment.

Procedures

The 24-week visit was conducted in participants' homes. For infants born at less than 37 weeks gestation (*n* = 10), the home visit date was age-corrected to represent the age of the child from the expected date of delivery rather than the child's chronological age. Home visits lasted between two and three hours, and included collection of physiological measurements, structured interviews, questionnaire presentations, and interaction tasks with mothers and their infants. Female bilingual interviewers read survey questions aloud and recorded participant responses through Blaise Survey Software, which is designed specifically for computer-assisted questionnaire data entry. Prior to the interaction tasks, experimenters obtained resting physiological measurements from mothers and their infants. Mothers were instructed to try to make sure their infant had eaten and slept prior to the home visit in order to minimize the possibility of infant hunger or sleepiness during the tasks. Women were compensated $75 for the prenatal interview and $50 and small gifts for the child (e.g., bibs, rattles) were provided for the 24-week interview.

Interaction Tasks.

Five interaction tasks were administered to mothers and their infants in the following order: five-minute free play, two-minute arm restraint, three-minute soothing task, five-minute teaching task, and five-minute peek-a-boo game. For my analyses, I focused on the free play and the teaching tasks. During free play, mothers were instructed to play with their infants as they normally would. In the soothing task, mothers were instructed to soothe their children as they normally would, which could include taking the baby out of the baby study seat. In the teaching task, mothers were asked to have their infant place a peg in a pegboard with six holes, which according to the Bayley Scales of Infant Development (Bayley, 1969) is too developmentally advanced for their child. Thus this task offered an opportunity to view variability in mother and infant affect during a task that can be challenging or frustrating for both infants and their caregivers.

Measures

Resting RSA

Respiratory sinus arrhythmia (RSA), the degree of change in heart rate during the respiratory cycle, is a widely-used index of parasympathetically-mediated influences on cardiac output (Beauchaine, 2001). Estimates of the stability and heredity of vagal tone vary, and vagal tone is sensitive to environmental influences, including interparental conflict, parenting behavior, and parent-child relationship quality (El-Sheikh & Hinnant, 2011; Hinnant, Erath & El-Sheikh, 2015; Feldman, 2015; Propper et al., 2008). Therefore, I assessed concurrent relations between vagal tone and emotion regulation and coregulation.

At 24 weeks of age, infants were seated upright in a car seat at rest and a research assistant placed electrodes on the infants' left shoulder and right and left waist in a standard lead configuration. Child heart rate data were recorded at 256 Hz with electrocardiography (ECG) equipment from Forest Medical, LLC (Trillium 5000; East Syracuse, NY, USA) during the 7-minute resting period.

QRSTool software 1.2.2 (Allen, Chambers, & Towers, 2007) was used to process the data and automatically obtain R-spikes from the ECG data. Trained undergraduate and graduate coders then used the QRSTool software to manually correct misidentified or unidentified R-spikes, and obtain R-R interval data. Using CardioBatch software (Brain-Body Center, 2007), a moving polynomial filter was then applied to the R-R interval data to extract heart rate variability in the frequency band of RSA (for infants, 0.3-1.3 Hz). The resting RSA estimates from this analysis were log-transformed, and a mean resting RSA value averaged from 30-second epochs during the first 5 minutes of the resting period was obtained.

Micro-coded Affect and Engagement

Mother and infant affect and engagement were coded using an adapted version of the Infant and Maternal Regulatory Scoring Systems (IRSS and MRSS; Tronick & Weinberg, 1990). The IRSS and MRSS are micro-coding systems used to capture mothers' and infants' behavior and facial expressions during dyadic interactions. Separate coding teams coded mother and infant expression of internal feeling states (maternal positive, negative, neutral affect, and unscorable affect, and infant positive, negative-fussy, negative-crying, neutral, and unscorable affect) and mother and infant attention and responsiveness to or initiation of social interaction (mother active engagement, comforting engagement, passive engagement, and disengagement and infant active engagement, infant passive engagement, or infant disengagement). Trained undergraduate research assistants were instructed to begin rating behaviors as soon as each task began, which was indicated by a beep on the experimenter's stopwatch. Using Noldus 9.0 software, coders rated specific affect behaviors in real time by turning "on" the appropriate affect or engagement state at the moment it was observed and by turning "off" the state as appropriate. Coders achieved acceptable agreement (kappa > .60) with master coders during training; 20 percent of each coder's videos were checked against master coders to continually assess reliability and minimize drift over time. Prior work with a subset of data coded using this scheme reported acceptable kappas for all coders (Coburn, Crnic, & Ross, 2015), according to interpretation of kappa values in Altman (1991). Kappa was moderate for mothers' behavior during the teaching task (kappa = 0.58) and good for mothers' behavior during free play (kappa = 0.62). Kappa was good for infants' behavior during the free play and teaching tasks combined (kappa = 0.62).

For the analyses, I exported each dyad's event log from Noldus and used the time-stamp (recorded to the millisecond) to create a dataset with second-by-second affect and engagement codes. Each code in the series reflects whether the specified state was present or absent during that second. If the infant switched from one state to another and then back to the original state within that second (i.e., if the change in the state lasted less than one second), the code reflected the different/new state during that second; this decision was designed to preserve variability in infant affect and engagement.

Affect engagement. Consistent with the perspective that affect is expressed in multiple modalities (e.g., Beebe et al., 2010; Cohn et al., 1990; Feldman, 2003, 2006; Moore et al., 2004, 2009; Weinberg et al., 1999, 2008), affect engagement was assessed by combining affect and engagement behaviors into affect engagement categories, which were then scaled. Four affect engagement scales (positive and negative affect engagement, for infants and mothers) of approximately 300 observations (for a 5-minute episode) were created for each task. Positive affect engagement represents gradations in positive affective behavior, ranging from a low score of positive, disengaged to neutral, passive engaged to a high score of positive, active engaged. Negative affect engagement represents gradations in negative affective behavior, ranging from a low score of neutral, disengaged to a high score of negative, active engaged. The descriptors that match each level of infant and maternal positive and negative affect engagement are shown in Table 3.

No mothers showed negative or neutral affect while being disengaged. Overall, maternal negative affect engagement was extremely infrequent during free play and the teaching task, occurring less than one percent of the time during these tasks. Therefore, maternal negative affect engagement was not included in the analyses. In contrast to their mothers, infants showed the full range of both positive and negative affect engagement during free play and the teaching task. The percent of time mothers and infants spent in each affect engagement state during free play and the teaching task, pooled across the sample, are shown in Table 4.

When examining within-person variability in infants' and mothers' momentary affect engagement, almost all mothers and infants showed intra-individual variability in positive affect engagement during free play. Out of 196 dyads with free play data, three mothers and four infants did not show intra-individual variability in positive affect engagement. In addition, 16 infants did not show intra-individual variability in negative affect engagement during free play. Similarly, during the teaching task, almost all mothers and infants showed intra-individual variability in positive affect engagement. Out of 197 dyads with teaching task data, eight mothers and nine infants did not show intra-individual variability in positive affect engagement during the teaching task. In addition, 26 infants did not show variability in negative affect engagement during the teaching task.

Potential covariates

Potential covariates include factors that may influence infant vagal tone and mothers' and infants' emotion expression and regulation. Child birth outcomes (birth weight, gestational age, APGAR score) and child date of birth (which will be used to calculate child chronological age) were obtained through medical record review. Maternal country of origin and parity (number of biological children) were obtained by self-report at the prenatal visit. Of these demographic variables, those with non-null relations to primary study variables (i.e., variables with non-null relations with the random effects in the model) were retained as covariates. Maternal resting RSA (obtained with the same procedures as infant resting RSA) at 24 weeks child age was also considered as a potential covariate.

***A priori* covariates**

Given prior research suggests that there may be sex-based differences in infant affect expression (e.g., Weinberg et al., 1999), in infants' responsiveness to disruptions in mother-infant affect coordination (Tronick & Reck, 2009), and in parental emotion socialization (Cole, Michel, & Teti, 1994), child biological sex was included *a priori* as a time-invariant covariate. Child biological sex was obtained through mothers' report at the 6-week home visit.

Prenatal risk factors were included *a priori* as time-invariant covariates. By four months of age, infants' interactions during parent-child interactions reflect their expectations of contingent interactions (Beebe & Steele, 2013). In order to parse apart variation in infants' emotion regulation and coregulation due to differences in infant vagal tone from variation due to differences in mothers' tendency to be responsive, irrespective of the child, it is important to account for prenatal factors that may contribute to differences in mothers' responsiveness. Risk factors include maternal report of stressful life events (from the Pregnancy Risk Assessment Monitoring System; CDC: Centers for Disease Control and Prevention, 2009-2011), family economic hardship (the 20-item Economic Hardship Scale; Barrera et al., 2001; α = .72), maternal depressive symptoms (the 10-item Edinburgh Postnatal Depression Scale; Cox et al., 1987; α = .86), and single-parent status. These variables were chosen because prior meta-analytic work as well as work with the present sample demonstrates maternal and dyadic behavior is influenced by intrapersonal characteristics (e.g., depressive symptoms, stress) as well as characteristics of the family and household environment, such as economic opportunity/disadvantage (e.g., Booth, Macdonald, & Youssef, 2018; Coburn, Crnic, & Ross, 2015; Lin, Crnic, Luecken, & Gonzales, 2017). In order to understand how inclusion of the prenatal risk changes the primary model results, models were evaluated with and without the risk variables.

Data Analysis Plan

Researchers can choose from a plethora of statistical models to capture dynamic interpersonal emotion systems, each of which requires its own assumptions and interpretations of dyadic processes (Butler, 2011). Common parameters of interest include the largest coefficient on a cross-correlation function plot (e.g., Feldman, 2003, 2007), conditional probabilities from lag-sequential analyses (Feldman & Eidelman, 2007), and autoregressive and cross-lagged paths in multilevel time-series approaches (e.g., Beebe et al., 2010, 2018). In recent years, researchers have argued that statistical models of emotion coregulation in interpersonal relationships should account for the bidirectional statistical linkage between dyad members over time and allow dyad member's affect to oscillate around an optimal or stable level (Butler & Randall, 2013). Time series approaches consistent with this recommendation have gained prominence in the study of mother-infant emotion regulation (Beebe & Steele, 2013). These approaches can capture dynamic changes in affect states over time and offer a window into examining causal self- and coregulatory mechanisms. Further, there may be differences between dyads in within-person covariation (i.e., self-regulation) and within-dyad covariation (i.e., coregulation), which can be accounted for in a multilevel framework (Butler, 2011).

I used dynamic structural equation models (DSEMs; Asparouhov, Hamaker, & Muthén, 2018) to account for within-person variability and between-person differences therein. In a multivariate framework, DSEMs allow random effects on intercepts, slopes, and residual variance at the within-level.[1] These random effects become latent variables at the between-level, meaning that predictors can be included to account for between-person differences. In sum, DSEM enables estimation of the effect of one person's affect engagement at one moment in time on his own and his/her partner's affect engagement at

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[1] Multivariately modeling dyads collapses what would be a third level in a mixed-effects model (time nested in persons nested in dyads). In other words, the three-level structure simplifies to two levels in DSEM.

the subsequent second, which may vary for each dyad,[2] and this variation can be accounted for by inclusion of time-invariant covariates in the model.

DSEM offers several advantages for evaluating the primary study aims. First, whereas almost all existing analytic methods for understanding interpersonal emotion dynamics, including multilevel modeling, are bivariate, allowing for examination of one behavior for each of two dyad members (Butler, 2011; Ram & Gerstorf, 2009), DSEM offers a usable multivariate model. Further, unlike multilevel models that require specification of a predictor and outcome variable, the multivariate DSEM is aligned with the theoretical view that infants' affect predicts mothers' affect *and* is predicted by mothers' affect. Second, DSEM mathematically removes information about partners' absolute levels of emotion and changes in emotional state before assessing variation and covariation, which is consistent with the view of regulation as a process that maintains homeostasis. Third, DSEM disambiguates the driver of coregulatory processes, by separately estimating mothers' contingent responses to their infants' prior affect and infants' contingent responses to their mothers' prior affect. Fourth, DSEM can estimate time-lagged processes even when the timing of observations varies across individuals, as in the case of start-stop coding of affect (Asparouhov, Hamaker, & Muthén, 2018). Fifth, DSEM facilitates inclusion of auxiliary variables to account for missing data.

Finally, whereas multilevel models have generally assumed homogeneity of the Level-1 variance across people (e.g., assuming that how predictable each person is homogenous), DSEM allows the residual variance to be different for every person to

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[2] A cross-classified DSEM would allow these paths to vary over time and across the sample. In the proposed model, these paths are assumed to be constant over time.

reflect differential predictability across people in the sample, which means that each person's time series can be differentially volatile. For example, whereas dynamic multilevel models typically assume that autoregressive processes hold equally well across the sample (Rovine & Molenaar, 2015), or that differences in the variance can be perfectly explained using a mixed-effects location scale model, adding a random residual variance allows each individual to have a different error variance, which in turn can change the actual course of the time series (Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018). Accounting for within-person residual variability in affect engagement is important for understanding emotion regulation, and is necessary for obtaining unbiased estimates of other model parameters, such as the individual intercepts and within-person carryover and transactional emotion regulatory processes (Hamaker et al., 2018).

Preliminary Analyses

Stationarity

Stationarity is a requirement of DSEM; however, there are several potential reasons why there may not be stationarity in the series. If there is little variability in the series (e.g., if infants show no negative affect for the first-half of the task, and then show negative affect for the remaining half of the task), then the autocovariance may not be constant across time, in which case stationarity may not be met. Stationarity would also be violated if infants and their mothers have trends or cycles in their affect. It is convention in the time series literature to de-trend the data prior to analysis (Hamaker et al., 2018). For example, if during the teaching tasks, infants show an increased likelihood of exhibiting negative affect over time, data would be de-trended to account for this trajectory. Another possible violation of stationarity is that infants and mothers could show cycles (e.g., “seasonality”) in their affect. Although prior research suggests that, at six months, infants and mothers do not show periodic cycles in their affect/engagement (e.g., Cohn & Tronick, 1988), the data would have to be de-trended to account for whatever the cycle may be.

Prior to analysis, I evaluated whether the six series (three affect engagement series for each of the two episodes) of the outcome variables (mothers’ positive affect engagement; infants’ positive and negative affect engagement) each meet the conditions for stationarity, a requirement for applying DSEM to the data. This involves checking if there are any trends in the data (e.g., if infants’ likelihood of exhibiting positive affect changes over time). In addition, for a series to meet the conditions of stationarity, the variance of the outcome must be constant across time, and the autocorrelation between outcomes must depend only on the length of the time lag and may not differ at different points in the time series.

Primary Analyses

Analyses were conducted using M*plus* (M*plus* v.8.3; Muthén & Muthén; 1998-2017). In a DSEM with a continuous variable, the intercept can be interpreted as the person’s mean (McNeish & Hamaker, 2018). Lagged variables of mothers’ and infants’ affect engagement were created in M*plus*. The lag-1 variables were latent centered to yield pure within effects, as desired (Hamaker & Grasman, 2015). Between-level (or between-dyad) predictors (infant vagal tone and covariates) were grand mean centered. All carryover (autoregressive) and transactional (cross-lagged) paths were estimated. This means that, in the within-level (or within-dyad) model, all possible paths (slopes) between maternal and infant affect engagement series were estimated. In addition to these slopes, the intercepts and residual variances of maternal positive affect engagement and infant positive and negative affect engagement were estimated.

In DSEM, random effects can be placed on intercepts, slopes, and residual variances at the within-level, which allow these effects to differ at the between-level. In other words, inclusion of a random effect allows for between-dyad differences in within-dyad processes. The base model used to address the study aims is shown in Figure 5. Following Curran and Bauer's (2007) recommended notation for multilevel path diagrams, in the figures, measured variables are indicated by boxes, intercepts are indicated by a triangle with a label of "1," regression parameters (slopes) are indicted by a straight single-headed arrow, and random coefficients are indicated by circles and a subscript i, which denotes the path is allowed to vary across dyads in the sample.

In this model, random effects were added to the intercepts for mothers' and infants' affect engagement, residual variances of mothers' and infants' affect engagement, and all of the possible cross-lagged paths between mothers' and infants' affect engagement (see Figure 5). Key parameters, their interpretations, and specific hypotheses are delineated in Table 5. Average maternal positive affect engagement is represented by α_{1i} and residual intra-individual variability in mothers' positive affect engagement is represented by σ^2_{1i}. Average infant positive affect engagement is represented by α_{2i} and average infant negative affect engagement is represented by α_{3i}. Residual intra-individual variability in infants' positive affect engagement is represented by σ^2_{2i} and residual intra-individual variability in infants' negative affect engagement is represented by σ^2_{3i}. Carryover in mothers' positive affect (i.e., prediction of maternal positive affect engagement from maternal positive affect engagement one second prior) is represented by φ_{1i}, carryover in infants' positive affect engagement is represented by φ_{5i} and carryover in their negative affect engagement (i.e., prediction of infant negative affect engagement from infant negative affect engagement one second prior) is represented by φ_{9i}. Transactions between infants' positive affect engagement and subsequent negative affect engagement (i.e., prediction of infant positive affect engagement from infant negative affect engagement one second prior) is represented by φ_{6i} and transactions between infants' negative affect engagement and subsequent positive affect engagement is represented by φ_{8i}. Transactions between maternal positive affect engagement and subsequent infant positive engagement is represented by φ_{2i} and transactions between maternal positive affect engagement and subsequent infant negative affect engagement is represented by φ_{3i}.Transactions between infant positive affect engagement and subsequent maternal positive affect engagement is represented by φ_{4i} and transactions between infant negative affect engagement and subsequent maternal positive affect engagement is represented by φ_{7i}.

The proposed model yields estimates of average within-dyad relations between mothers' and infants' affect engagement (i.e., fixed effects). Including random effects means that the intercepts, residual variances, and aforementioned paths (slopes) become latent variables at the between-level, and between-dyad differences in these latent variables can be accounted for by exogenous variables, such as infant vagal tone. As noted above, in Figure 5, random effects are indicated by a subscript i; effects without a subscript i are constrained to be equal across the sample (i.e., there is no modeled between-dyad variability in these paths). Random intercepts were allowed to covary, but no other possible covariances between random effects were included given the large sample size requirements for reliably estimating random effects covariances (McNeish, 2019; Rast & Hofer, 2014). Infant vagal tone and covariates were included as predictors of all relevant random effects, allowing for examination of whether vagal tone accounts for non-null between-dyad differences in the within-dyad means, residual variability, and carryover and transactional relations in infants' and mothers' affect engagement.

To address the primary study aims, three sets of analyses were conducted per task (free play and teaching task). In Model 1, only infant vagal tone was included as a predictor in the model. In Model 2, covariates (excluding prenatal risk) were accounted for in the model. In Model 3, which represents the most stringent test of the hypotheses, prenatal risk was also included as a covariate in the model. The pattern of results was consistent across each model; therefore, only results from the final model (i.e., Model 3), which adjusts for covariates and prenatal risk factors, are presented in the text. Results from Model 1 can be found in Appendix Tables 2 and 4 and results from Model 2 can be found in Appendix Tables 5 and 6. Equations for the final free play model are shown in Table 6a and equations for the final teaching task model are shown in Table 6b.

Unstandardized estimates and, for comparison across tasks, standardized estimates are presented for all models. Within-person standardization was used to derive standardized estimates of within-dyad paths; this method, proposed by Schuurman et al. (2016), standardizes regression coefficients separately for each person and then takes the average of the standardized values across people for each parameter (Asparouhov et al., 2018). Between-dyad covariate effects were standardized with the grand variance.

Similar to a frequentist framework, if the 95% credible intervals (CIs) did not contain zero, the effects were determined to be non-null.

RESULTS

Preliminary Analyses

Missing Data

The free play task did not exceed 300 seconds for any of the infants. During free play, none of the infants were sleeping for more than 50 percent of the time. There was minimal missing data on infant engagement (1.1%) during free play. There was no missing data on maternal engagement during free play.

Twenty infants had teaching task longer than 300 seconds in duration (range from 301-319 seconds). During the teaching task, four infants were sleeping for more than 50 percent of time. Observed affect after 300 seconds was not included in the analytic dataset. Similarly, there was minimal missing data on infant engagement (0.1% missing) during the teaching task. There was no missing data on maternal engagement during the teaching task.

Stationarity

There is a paucity of methodological work on multilevel stationarity. Rather than naively evaluating stationarity of the whole affect engagement series, I tested stationarity of each individual person's affect engagement series. Augmented Dickey-Fuller Unit Root (ADF) tests were conducted to test each of the six series (maternal positive affect engagement and infant positive and negative affect engagement, during free play and the teaching task) for stationarity, for each dyad. Two tests of stationarity were conducted per series, per dyad: one to determine whether the series is nonzero-mean stationary (single mean) and one to determine whether the series is linear time trend stationary (trend). In both the single mean and trend models, a lag of 1 was specified. If the tau statistic has a nonsignificant *p*-value ($p > .05$) the series may have a unit root and may be nonstationary. If the tau statistic is significant ($p < .05$), the series is stationary.

During free play, there were 13 (7.69%) infants whose positive affect engagement series may be nonstationary, 18 (9.18%) infants whose negative affect engagement series may be nonstationary, and six (3.06%) mothers whose positive affect engagement series may be nonstationary, based on nonzero-mean stationarity and/or linear time trend stationarity. A sensitivity analysis was conducted to examine how inclusion of possibly nonstationary series affected the pattern of results obtained for Model 1 (i.e., the model with only infant RSA as a between-level predictor of within-dyad effects). Results with all available data are shown in Appendix Table 1. Results with only the stationary series are shown in Appendix Table 2. As shown in Appendix Tables 1 and 2, the pattern of results remained the same when potentially nonstationary series were excluded.

During the teaching task, there were 19 (9.64%) infants whose positive affect engagement series may be nonstationary, 18 (9.14%) infants whose negative affect engagement series may be nonstationary, and six (3.05%) mothers whose positive affect engagement series may be nonstationary, based on nonzero-mean stationarity and/or linear time trend stationarity. A sensitivity analysis was conducted to examine how inclusion of possibly nonstationary series affected the pattern of results obtained for Model 1 (i.e., the model with only infant RSA as a between-level predictor of within-dyad effects). Results with all available data are shown in Appendix Table 3. Results excluding the possibly nonstationary series are shown in Appendix Table 4. As shown in Appendix Tables 3 and 4, some estimates in the teaching task model became non-null when excluding the possibly nonstationary series. Given these results suggest DSEM may be sensitive to violations of stationarity, I present results for both the free play and teaching tasks models with the possibly nonstationary series excluded from the data (i.e., for people for whom an affect engagement series was possibly nonstationary, the relevant series was set to missing).

I also examined whether infants and mothers with possibly nonstationary series differed from infants and mothers with stationary series on infant and maternal RSA and potential confounds (i.e., maternal country of origin, number of biological children, maternal age, APGAR score, birth weight, gestational age, infant gender). During free play, stationarity on infant positive affect engagement and maternal affect engagement did not differ depending on these variables. However, stationarity on infant negative affect engagement during free play differed depending on maternal country of origin, $\chi^2(2) = 6.444$, $p = .040$. Infants whose mothers were born in the United States were more likely to have possibly nonstationary negative affect engagement series than were infants whose mothers were born in Mexico. Because maternal country of origin accounts in part for nonstationarity, and in turn, missingness on the infant negative affect engagement series, maternal country of origin was included as a covariate of infant negative affect engagement in Models 2 and 3 for free play. During the teaching task, stationarity on all the series did not differ depending on these variables; therefore, maternal country of origin was not included as a covariate in the teaching task models.

Primary Analyses

Free Play

Primary results from the final free play model are shown in Table 7 and in Figure 6.

Aim 1. To address whether infant vagal tone accounts for differences in within-infant emotion regulation processes, I evaluated whether infant vagal tone accounted for between-dyad differences in (a) infants' average levels of positive and negative affect engagement, (b) intra-individual residual variability in positive and negative affect engagement, (c) carryover in positive and negative affect engagement, and (d) transactional relations between infant positive and negative affect engagement. After adjusting for covariates, infants' average level of positive affect engagement, γ_{10} , was 1.403, 95% CI: [1.256, 1.550], and infants' average level of negative affect engagement, γ_{20} , was 0.244, 95% CI: [0.171, 0.327]. Contrary to expectations, infant vagal tone did not predict infants' average level of positive affect engagement, γ_{11} = 0.054, 95% CI: [-0.057, 0.165],, or negative affect engagement, γ_{21} = -0.002, 95% CI: [-0.057, 0.050].

Infants' raw intra-individual residual variability in positive affect engagement, exp(ω_{10}), was 0.183 (ω_{10} = -1.834, 95% CI: -1.998, -1.667) and infants' raw intra-individual residual variability in negative affect engagement, exp(ω_{20}), was 0.048 (ω_{10} = -3.029, 95% CI: -3.315, -2.747). Infant vagal tone also did not predict the intra-individual residual variability in infants' positive affect engagement, $\gamma_{13,1}$ = 0.101, 95% CI: [-0.089, 0.290], or negative affect engagement, $\gamma_{14,1}$ = 0.001, 95% CI: [-0.314, 0.321].

Infants showed non-null positive carryover in positive affect engagement, γ_{70} = 0.812, 95% CI: [0.796, 0.827], and in negative affect engagement, $\gamma_{11,0}$ = 0.798, 95% CI: [0.759, 0.836]. Infant vagal tone also did not predict carryover in infant positive affect engagement, γ_{71} = -0.014, 95% CI: [-0.033, 0.005], or in infant negative affect engagement, $\gamma_{11,1}$ = -0.027, 95% CI: [-0.058, 0.005].

Infants' positive affect at one time point did not predict their subsequent negative affect engagement, γ_{80} = -0.006, 95% CI: [-0.012, 0.000], and infants' negative affect at one time point did not predict their subsequent positive affect engagement, $\gamma_{10,0}$ = .003, 95% CI: [-0.018, 0.024]. Finally, infant vagal tone did not predict the association between infants' positive affect and their subsequent negative affect engagement, γ_{81} = -0.005, 95% CI: [-0.012, 0.001], or the association between infants' negative affect and their subsequent positive affect engagement, $\gamma_{10,1}$ = 0.001, 95% CI: [-0.046, 0.044].

Aim 2. To address whether infant vagal tone accounted for differences in infants' emotion coregulation processes, I evaluated whether infant vagal tone accounted for between-dyad differences in the prediction of infants' positive and negative affect engagement from their own mothers' positive affect engagement. Mothers' positive affect engagement at one time point was a non-null positive predictor of their infants' subsequent positive affect engagement, γ_{40} = 0.021, 95% CI: [0.014, 0.029], and a non-null negative predictor of their infants' subsequent negative affect engagement, γ_{50} = -0.007, 95% CI: [-0.012, -0.001]. Contrary to expectations, infant vagal tone did not predict the association between mothers' positive affect engagement and their infants' subsequent positive affect engagement, γ_{41} = 0.005, 95% CI: [-0.004, 0.014]. Infant vagal tone also did not predict the association between mothers' positive affect engagement and their infants' subsequent negative affect engagement, $\gamma_{51} =$ -0.007, 95% CI: [-0.013, 0.000].

Aim 3. To address whether infant vagal tone accounted for differences in mothers' emotion coregulation processes, I evaluated whether infant vagal tone accounted for between-dyad differences in the prediction of mothers' positive affect engagement from their infants' positive and negative affect engagement. Infants' positive affect engagement at one time point was a non-null positive predictor of their mothers' subsequent positive affect engagement, $\gamma_{60} =$ 0.022, 95% CI: [0.015, 0.30]. However, infants' negative affect engagement at one time point did not predict their mothers' subsequent positive affect engagement, $\gamma_{90} =$ -0.004, 95% CI: [-0.014, 0.006]. Contrary to expectations, infant vagal tone did not predict the association between infants' positive affect engagement and their mothers' subsequent positive affect engagement, $\gamma_{61} =$ -0.003, 95% CI: [-0.011, 0.005]. Infant vagal tone also did not predict the association between infants' negative affect engagement and their mothers' subsequent positive affect engagement, $\gamma_{91} =$ 0.004, 95% CI: [-0.008, 0.016].

Covariate Effects. Of the potential covariates (child birth outcomes, child gestational age, child chronological age, maternal country of origin, number of children, child sex, and maternal resting RSA), several covariate effects were non-null in the final model, with all potential covariates included. Infant gestational age predicted the intercept of infant positive affect engagement, such that infants with older gestational age displayed more positive affect engagement, $\gamma_{17} =$ 0.051, 95% CI: [0.011, 0.090]. Infant APGAR predicted carryover in infant positive affect engagement, such that higher APGAR scores predicted greater carryover in infant positive affect engagement, $\gamma_{72} =$

0.014, 95% CI: [0.002, 0.026]. Child sex (coded 0 = boys, 1 = girls) predicted carryover in infant negative affect engagement, such that girls had less carryover in infant negative affect, $\gamma_{11,3} = -0.059$, 95% CI: [-0.111, -0.007]. Maternal prenatal depressive symptoms predicted the residual variability in infant positive affect engagement, $\gamma_{13,2} = 0.069$, 95% CI: [0.026, 0.109], and in infant negative affect engagement, $\gamma_{14,2} = 0.108$, 95% CI: [0.032, 0.173]. Infants whose mothers exhibited more depressive symptoms demonstrated greater intra-individual variability in their positive and negative affect engagement: For a one-unit increase in maternal depressive symptoms, the raw residual variance in infants' positive affect engagement was expected to change multiplicatively by 1.07 and the raw residual variance in infants' negative affect engagement was expected to change multiplicatively by 1.11.

More biological children predicted higher intercepts of maternal positive affect engagement, $\gamma_{07} = 0.107$, 95% CI: [0.060, 0.154]. Prenatal economic hardship predicted greater residual variability in mothers' positive affect engagement: $\gamma_{12,3} = 0.060$, 95% CI: [0.011, 0.108]. For a one-unit increase in economic hardship, the raw residual variance in mothers' positive affect engagement was expected to change multiplicatively by 1.06.

In addition, child sex was included as an *a priori* predictor of the intercepts in infant positive affect engagement, infant negative affect engagement, and maternal positive affect engagement; these effects were all null. Prenatal risk factors (economic hardship, maternal depressive symptoms, negative life events, and single-parent status) were included as *a priori* predictors of the intercepts in infant positive affect engagement, infant negative affect engagement, and maternal positive affect engagement; these effects were all null. Maternal country of origin was included as a predictor of random effects involving infant negative affect engagement; these effects were all null.

Teaching Task

Primary results from the final teaching task model are shown in Table 8 and Figure 7.

Aim 1. To address whether infant vagal tone accounted for differences in within-infant emotion regulation processes, I evaluated whether infant vagal tone accounted for (a) between-dyad differences in infants' average levels of positive and negative affect engagement, (b) intra-individual residual variability in positive and negative affect engagement, (c) carryover in positive and negative affect engagement, and (d) transactional relations between infant positive and negative affect engagement. After adjusting for covariates, infants' average level of positive affect engagement, γ_{10}, was 1.261, 95% CI: [1.123, 1.391], and infants' average level of negative affect engagement, γ_{20}, was 1.041, 95% CI: [0.803, 1.301]. Contrary to expectations, infant vagal tone did not predict infants' average level of positive affect engagement, γ_{11} = -0.053, 95% CI: [-0.154, 0.055], or negative affect engagement, γ_{21} = 0.119, 95% CI: [-0.074, 0.298].

Infants' raw intra-individual residual variability in positive affect engagement, exp(ω_{10}), was 0.095 (ω_{10} = -2.350, 95% CI: -2.534, -2.174) and infants' raw intra-individual residual variability in negative affect engagement, exp(ω_{20}), was 0.235 (ω_{20} = -1.448, 95% CI: -1.880, -1.007). Infant vagal tone also did not predict the intra-individual residual variability in infants' positive affect engagement, $\gamma_{13,1}$ = 0.034, 95% CI: [-0.176, 0.259], or negative affect engagement, $\gamma_{14,1}$ = 0.022, 95% CI: [-0.331, 0.382].

Infants exhibited non-null positive carryover in their positive affect engagement, γ_{70} = 0.820, 95% CI: [0.802, 0.839], and in their negative affect engagement, $\gamma_{11,0}$ = 0.820, 95% CI: [0.798, 0.841]. Infant vagal tone also did not predict carryover in infant positive affect engagement, γ_{71} = -0.013, 95% CI: [-0.033, 0.008], or in infant negative affect engagement, $\gamma_{11,1}$ = 0.016, 95% CI: [-0.010, 0.044].

Infants' positive affect engagement at one time point did not predict their negative engagement at the subsequent time point, γ_{80} = 0.008, 95% CI: [-0.001, 0.017]. In addition, infant vagal tone did not predict the association between infants' positive affect and their subsequent negative affect engagement, γ_{81} = 0.003, 95% CI: [-0.009, 0.014]. However, infants' negative affect engagement at one time point did predict their positive affect engagement at the subsequent time point, $\gamma_{10,0}$ = 0.012, 95% CI: [0.002, 0.022]. Further, infant vagal tone predicted the association between infants' negative affect and their subsequent positive affect engagement, $\gamma_{10,1}$ = -0.012, 95% CI: [-0.023, 0.000].

Results of post-hoc probing using Kris Preacher's multilevel moderation web utility (http://quantpsy.org/interact/hlm2.htm; Preacher, Curran, & Bauer, 2006) supported the hypothesis that infants with higher RSA would show a weaker association between negative affect and subsequent positive affect engagement. Results indicated that the regression of infant positive affect engagement on prior infant negative affect engagement was only significant at values less than average (< 3.27; 63.4% of the sample) or values well above average (> 53.6; 0% of the sample) values of infant RSA (see Figure 8).

Similarly, the regression of infant positive affect engagement on prior infant negative affect engagement was positive and statistically significant at average levels of infant RSA, est = 0.01, $p = .016$, as well as at below average (-1 SD) levels of infant RSA, est = 0.02, $p = .002$, but was not statistically significant at above average (+1 SD) levels of infant RSA, est = 0.00, $p = .80$. Thus, results were consistent with the expectation that infants with higher RSA would show a weaker association between negative affect engagement and subsequent positive affect engagement. However, contrary to expectations, infants with relatively lower RSA exhibited a *positive* association between negative affect engagement and subsequent positive affect engagement, after adjusting for prior infant and maternal positive affect engagement.

Aim 2. To address whether infant vagal tone accounted for differences in infants' emotion coregulation processes, I evaluated whether infant vagal tone accounted for between-dyad differences in the prediction of infants' positive and negative affect engagement from their own mothers' positive affect engagement. Mothers' positive affect engagement at one time point did not predict infants' positive affect engagement at the subsequent time point, $\gamma_{40} = 0.003$, 95% CI: [-0.003, 0.009], nor did it predict infants' negative affect engagement at the subsequent time point, $\gamma_{50} = -0.003$, 95% CI: [-0.012, 0.005]. Contrary to expectations, infant vagal tone did not predict the association between mothers' positive affect engagement and their infants' subsequent positive affect engagement, $\gamma_{41} = 0.005$, 95% CI: [-0.001, 0.012]. Infant vagal tone also did not predict the association between mothers' positive affect engagement and their infants' subsequent negative affect engagement, $\gamma_{51} = -0.007$, 95% CI: [-0.019, 0.004].

Aim 3. To address whether infant vagal tone accounts for differences in mothers' emotion coregulation processes, I evaluated whether infant vagal tone accounted for between-dyad differences in the prediction of mothers' positive affect engagement from their infants' positive and negative affect engagement. Infants' positive affect engagement at one time point did not predict their mothers' positive affect engagement at the subsequent time point, $\gamma_{60} = 0.010$, 95% CI: [.000, 0.019], nor did infants' negative affect engagement, $\gamma_{90} = 0.004$, 95% CI: [-0.002, 0.010]. Contrary to expectations, infant vagal tone did not predict the association between infants' positive affect engagement and their mothers' subsequent positive affect engagement, $\gamma_{61} = 0.005$, 95% CI: [-0.007, 0.016]. Infant vagal tone also did not predict the association between infants' negative affect engagement and their mothers' subsequent positive affect engagement, $\gamma_{91} = 0.002$, 95% CI: [-0.007, 0.009].

Covariate Effects. Of the potential covariates (child birth outcomes, child gestational age, child chronological age, maternal country of origin, number of children, child sex, and maternal resting RSA), child sex was a non-null predictor of the volatility in infant negative affect engagement, $\gamma_{14,2} = -0.837$, 95% CI: [-1.450, -0.210]. Girls' residual variability in negative affect engagement was expected to be approximately half that of boys' residual variability: Whereas boys' residual variability in negative affect engagement was expected to be 0.235, girls' residual variability in negative affect was expected to be 0.102. In addition, mothers' number of other children was a non-null predictor of the intercept of maternal positive affect engagement, $\gamma_{07} = 0.096$, 95% CI: [0.053, 0.136]. Prenatal maternal negative life events predicted greater carryover in infant positive affect engagement, $\gamma_{73} = 0.009$, 95% CI: [0.001, 0.016]. Prenatal household economic hardship predicted a stronger (i.e., more positive) association between infant negative affect engagement and subsequent infant positive affect engagement, $\gamma_{10,1} = 0.004$, 95% CI: [0.001, 0.008]. Prenatal maternal depressive symptoms predicted a weaker (i.e., more negative) association between maternal positive affect engagement and subsequent infant positive affect engagement, $\gamma_{42} = -0.002$, 95% CI: [-0.004, -0.001], and a stronger association between maternal positive affect engagement and subsequent infant negative affect engagement, $\gamma_{52} = 0.003$, 95% CI: [0.001, 0.006].

In addition, child sex was included as an *a priori* predictor of the intercepts in infant positive affect engagement, infant negative affect engagement, and maternal positive affect engagement; these effects were all null. Prenatal risk factors (economic hardship, maternal depressive symptoms, negative life events, and single-parent status) were also included as *a priori* predictors of the intercepts in infant positive affect engagement, infant negative affect engagement, and maternal positive affect engagement; these effects were all null.

DISCUSSION

Understanding emotion regulation and coregulation processes among infants at elevated risk for future socioemotional problems may shed light on pathways that start early in life and either promote resilience or confer risk (Cicchetti & Toth, 2009; Sroufe, 2007). Capitalizing on recent methodological innovations, the current study evaluated biologically-based differences in dynamic, temporally-based emotion regulation and coregulation processes that unfold during mother-infant interactions, among low-income, Mexican-origin families. Evaluating moment-to-moment fluctuations in infants' and mothers' emotional responding during social interactions offers strong inferences about potentially causal processes of emotion regulation and coregulation (Ekas, Braungart-Rieker, & Messinger, 2018; Kuppens & Verduyn, 2015). Dynamic changes in infants' affect over time offer a window into how infants modulate their own emotional experience and its expression (Buss & Goldsmith, 1998; Haviland & Lelwica, 1987; Kuppens & Verduyn, 2015). Infants' emotion expression not only guides infants' behavior, but also captures mothers' attention and can facilitate coregulatory efforts (Cole, 2016; Fox, Kirwan, & Reeb-Sutherland, 2013). Further, children's parasympathetic nervous system functioning, and vagal functioning in particular, is thought to provide a "biobehavioral platform" for emotion regulation and smooth, synchronous interactions (Porges, 2001, 2003; Porges & Furman, 2011; Porges et al., 2019).

Consistent with polyvagal theory's claim that vagal tone supports one's capacity to quickly, flexibly, and adaptively respond to the social environment (e.g., Porges, 2003, 2007), I expected infants with greater vagal tone would show (a) more task-appropriate positive and negative affect engagement and (b) more intra-individual residual variability in their positive and negative affect engagement. I also expected infants with greater vagal tone would be better able to maintain positive affect and switch out of negative affect states, such that they would (c) return to negative affect engagement equilibrium more quickly (i.e., exhibit weaker carryover in negative affect engagement) but sustain fluctuations in positive affect engagement (i.e., exhibit stronger carryover in positive affect engagement), and (d) show a weaker dampening effect of negative affect on subsequent positive affect engagement (i.e., weaker negative association between negative affect and subsequent positive affect engagement) but a stronger dampening effect of positive affect on subsequent negative affect engagement (i.e., stronger negative association between positive affect and subsequent negative affect engagement). In addition, drawing from polyvagal theory's central tenet that vagal tone promotes social engagement and the development of self-regulation (Porges, 2003, 2007), as well as Feldman's hierarchical-integrative model of the ontogeny of emotion regulation (e.g., Feldman, 2009, 2015), my second aim was to evaluate whether infant vagal tone was positively related to mother-driven emotion coregulation (i.e, stronger effect of mothers' on infants' affect engagement). My final aim was to evaluate whether infant vagal tone was related to greater infant-driven emotion coregulation, as infants with greater vagal tone may have clearer signals (e.g., facial expressions and vocalization, gaze) during face-to-face interactions to which mothers may more easily respond (Porges, 2001, 2003; Porges & Furman, 2011; Porges et al., 2019).

Results suggested distinct average patterns of infants' and mothers' second-by-second emotional responding during free play and the teaching task, which generally did not differ based on infant vagal tone. During free play and the teaching task, infants typically fluctuated around neutral, passively engaged affect engagement and around little negative affect engagement during free play and around neutral, disengaged affect in the teaching task. Infants showed intra-individual residual variability in their positive and negative affect engagement across each task. Fluctuations in infant affect engagement were generally sustained from one second to the next, such that relatively higher positive (or negative) affect engagement at one time point was associated with relatively higher positive (or negative) affect engagement at the subsequent time point. Results also suggested that infants' affect engagement is regulated through feedback loops. Although there was no evidence of transactional relations between positive and negative infant affect engagement during free play, during the teaching task, an increase in infant negative affect predicted a subsequent increase (i.e., augmentation) in infant positive affect engagement, but only among infants with average or lower vagal tone.

Results also offered evidence of both mother-driven and infant-driven emotion coregulation during free play, but not during the teaching task. On average, during free play, fluctuations in infants' positive and negative affect engagement matched changes in their mothers' positive affect engagement, and mothers' positive affect engagement was similarly responsive to changes in their infants' positive affect engagement. Yet, mothers' positive affect engagement was not synchronized with fluctuations in their infants' negative affect engagement during free play.

Infant Vagal Tone and Infant Emotion Regulation

Aims 1a & 1b: Equilibria and Intra-individual Residual Variability of Infants' Emotions

Infant vagal tone was not related to infants' emotional equilibrium of positive or negative affect engagement during either task. In a homeostatic or mean-reverting system, the equilibria of infants' emotional experiences can be viewed as the set points to which infants' emotion will return, following a fluctuation (Hamaker, Asparouhov, Brose, Schmiedek, & Muthén, 2018). Consistent with the conceptualization of emotion regulation as "an ongoing process of the individual's emotion patterns in relation to moment-by-moment contextual demands," static measures such as mean levels of affect engagement may be less sensitive indicators of regulatory processes (Cole, Michel, & Teti, 1994, p. 74). In contrast, the extent to which infants deviate from their emotional equilibrium, as well as carryover and transactions in infants' affect engagement, shed light onto the processes that govern how infants' emotions fluctuate over time.

Infant vagal tone was also not associated with intra-individual residual variability (i.e., volatility) in infants' positive or negative affect engagement in either task. According to polyvagal theory, higher vagal tone supports the ability to respond flexibly to environmental opportunities and challenges, including the ability to modulate emotional displays (Porges et al., 1994). The null associations between infant vagal tone and intra-individual residual variability in positive and negative affect engagement are unexpected given theoretical expectations as well as prior evidence that higher vagal tone is related to greater behavioral reactivity to a range of stressors (e.g., Propper, 2012), including in response to everyday tasks designed to elicit frustration, such as pacifier withdrawal or arm restraint (Fox, 1989; Stifter & Fox, 1990; Stifter, Fox & Porges, 1986; Calkins et al., 2002). Prior work that has relied on global measures of affect frequency and intensity suggests that infants with greater vagal tone may be more likely to activate negative affect when frustrated (Fox, 1989; Stifter & Fox, 1990; Stifter, Fox & Porges, 1986; Calkins et al., 2002). However, these global measures capture between-infant differences in qualitative aspects of behavior, whereas the present study focused on *intra-individual* variation in infants' affect engagement, after accounting for the time course of infants' affect engagement as well as prior levels of maternal affect engagement, in order to capture each infant's volatility throughout the task. Yet, consistent with prior evidence that infants respond to stressors with decreases in intra-individual reactivity (e.g., Montirosso et al., 2010), infants showed relatively less intra-individual variability in positive affect engagement during the teaching task than they did during free play, which may have rendered it more difficult to detect biologically-based differences in infants' emotional volatility during the teaching task. Combining micro-analytic coding of infant affect expressions with statistical methods that can account for moment-to-moment variability in infant affect engagement may be necessary to detect differences in intra-individual variability during frustrating or stressful tasks.

Aim 1c. Carryover in Infants' Emotions

Although on average there was non-null carryover in infants' emotions, contrary to expectations, infant vagal tone was not related to carryover in infants' positive or negative affect engagement. One possible explanation for these null findings is that carryover in infants' affect engagement may not directly reflect self-regulatory processes.

Whereas results from prior research (e.g., Beebe et al., 2018) lend support to the interpretation of positive carryover in vocal affect as a meaningful index of infants' self-regulatory processes, research with adolescent and adult populations suggests carryover may represent a form of "emotional inertia" that confers risk for psychopathology (Kuppens, Allen, & Sheeber, 2010). Given the limited research on infants' emotional carryover, more work is needed to evaluate optimal levels of carryover; if a moderate level of carryover is most adaptive, then there may be curvilinear rather than linear relations between vagal tone and carryover. It is also possible that the meaning of emotional carryover may vary across development and may be specific to the domain in which emotion is expressed (e.g., carryover in vocal affect may have different correlates and sequelae than carryover in affect engagement) and to the valence of affect.

It is also important to bear in mind that emotional carryover was assessed in terms of the prediction of affect engagement from one second to the next. Infant vagal tone, indexed by resting levels of infant RSA, may influence these rapid, subtle fluctuations in infant affect indirectly, through regulation of the vagal brake. The extent to which infants activate or suppress the vagal brake supports subtle changes in infants' cardiometabolic output to meet changing contextual demands (e.g., Porges, 1995). In contrast to infant vagal tone, infant vagal responsivity may be more directly related to infants' ability to be reactive and modulate their affect and behavior in response to second-by-second changes in contextual demands. Recent meta-analytic work demonstrated small effect sizes between greater vagal withdrawal during challenging states and fewer subsequent externalizing, internalizing, and academic problems (Graziano & Derefinko, 2013), suggesting appropriate vagal responsivity may support self-regulatory processes, although consensus on the optimal measurement of vagal responsivity is needed.

Aim 1d. Transactions Between Infants' Emotions

For over a decade, emotion theorists have argued that because "emotions are managed as emotions are generated... emotion regulation must be studied as a component of emotion itself" (Thompson, Lewis, & Calkins, 2008, p. 129), although empirical work has often not reflected this conceptualization of emotion regulation. Examining ongoing transactions within dynamic emotion systems offers a methodological lens through which to examine how emotions unfold in a self-regulating system (Butler, 2015; Hollenstein, 2015). In a well-functioning, self-regulated system, these transactional relations reflect feedback loops that either dampen (negative feedback) or augment (positive feedback) emotions as part of their continuous regulation and maintenance of a stable equilibrium (Butler, 2015; Hollenstein, 2015). Feedback between emotional states (indexed by the predictive relations between affect states; e.g., Krone, Albers, Kuppens, & Timmerman, 2018) reflects flexibility in one's responses to internal or external demands, as feedback requires both inhibition of the current state (negative feedback) and activation of a subsequent, different state (positive feedback) whereas weaker feedback processes can result in getting "stuck" at one's equilibrium (Hollenstein, 2015).

There was some evidence of biologically-based differences in these transactional or feedback processes. On average, there was a null effect of infant positive affect on subsequent infant negative affect engagement during the teaching task, and this effect did not differ depending on infant vagal tone. Infants, regardless of their biological regulatory capacities, may not be able to draw on small, brief fluctuations in infant positive affect to protect against fluctuations in infant negative affect during a stressful task designed to elicit frustration. However, as expected, during the teaching task, infants with above average vagal tone returned more quickly to their mean level of positive affect engagement after experiencing a perturbation in negative affect engagement. In contrast, during the teaching task, infants with average or below average vagal tone took longer to return to their mean level of positive affect engagement following a change in negative affect engagement. Surprisingly, for infants with relatively lower vagal tone, infants' negative affect engagement did not dampen subsequent positive affect engagement; rather, for these infants, prior negative affect *amplified* subsequent positive affect engagement. Although all infants moved toward their equilibrium in positive affect engagement, only infants with lower RSA showed a regulatory feedback process, such that their negative affect engagement augmented the subsequent experience of positive affect engagement.

Given this pattern was contrary to expectations, evidence of augmentation of infant positive affect engagement by prior negative affect engagement raises questions about the underlying behaviors that give rise to positive emotional feedback during the teaching task. Although feedback loops reflect the *process* and not the content of infant behavior, prior research on infants' behaviors during challenging tasks may shed light on the patterns observed in the present study. Adaptive regulatory strategies available to infants include social support-seeking, self-soothing, and gaze aversion (Cole, 2016). After becoming wary of or even frustrated with a difficult task, infants with lower vagal tone may direct their attention to the broader social context, wherein they may positively respond to their mothers' attempt to scaffold learning with sustained engagement in the task. Alternatively, mothers of infants with low vagal tone may offer more soothing or regulatory support when their infants become frustrated (Huffman et al., 1998). In contrast, increased negative affect may guide infants with greater vagal tone to engage in self-soothing behavior or gaze aversion (e.g., Bornstein & Suess, 2000; Gardner et al., 2018; Porges, 2007; Calkins, Blandon, Williford, & Keane, 2007; Degangi, DiPietro, Greenspan, & Porges, 1991; Porges, Doussard-Roosevelt, Portales, & Suess, 1994). Whereas autonomous regulatory strategies, such as gaze aversion or non-nutritive sucking, may inhibit negative affect engagement and help infants return to their emotional equilibrium, infants who use their strategies may miss opportunities to reap the benefits of social support.

Implicit in this explanation is the notion that infants with lower vagal tone rely more on their mothers' affective cues and/or have mothers who are more responsive to their frustration during the task, such that maternal redirection and encouragement of perseverance facilitate up-regulation of infant positive affect engagement. Extant evidence suggests that, among low-income, Mexican-origin families, lower infant vagal tone may confer susceptibility to the socioemotional benefits of positive social environments (Somers, Jewell, Ibrahim, & Luecken, 2018; Somers, Luecken, Spinrad, & Crnic, 2018). In addition, research examining dynamic processes suggests that infants' emotional feedback loops are affected by maternal caregiving, such that infants were more likely to transition from more negative to more positive vocal affect if their mothers participated in an intervention that promoted sensitive maternal behavior (Beebe et al., 2018). However, to my knowledge, no existing studies using time series methods have directly tested the assumption that mother-infant emotion coregulation facilitates temporal processes of infant emotional self-regulation. Future research that is sufficiently powered to detect non-null covariances between random effects (e.g., with sample sizes of at least 1,000; Rast & Hofer, 1994) is needed to test the assumption that infants' self-regulation, such as infants' ability to switch from negative into more positive states, is related to moment-to-moment synchrony with mothers' positive affect engagement (Beebe et al., 2018; Feldman, 2003).

Although I interpret augmentation of infants' positive affect by prior increases in infants' negative affect as evidence of a regulatory process that occurs through positive emotional feedback loops, the pattern of results obtained in this study should be interpreted with caution, given that few studies have been conducted on emotional cross-lag (for exceptions, see Krone, Albers, Kuppens, & Timmerman, 2018; Simons, Simons, Grimm, Keith, & Stoltenberg, 2020). Nevertheless, this interpretation of emotional feedback is consistent with the relatively larger literature on emotional inertia, which suggests that emotional flexibility, or the ability to adaptively shift in and out of affective states, is a hallmark of emotional well-being (e.g., Hollenstein, 2015). Recent work among adult veterans also supports the claim that the tendency to respond to increased negative affect engagement with subsequent increases in positive affect engagement reflects more adaptive emotion regulation, specifically higher levels of distress tolerance (Simons et al., 2020).

The patterns obtained here should also be interpreted within these families' unique cultural context. Cultural variations may influence how mothers and infants appraise interpersonal situations and express their emotions and engage in emotion-related behaviors, and may determine the social appropriateness of emotional displays (e.g., Cole, Bruschi, & Tamang, 2002; Eisenberg, Spinrad, & Cumberland, 1998). Mexican-American children may be encouraged to openly express their emotions, as long as doing so does not interrupt activities or social cohesion (Howes & Obregon, 2009; Soto, Levenson, & Ebling, 2005). Among families with less traditional values or from less interdependent communities, children's emotional expression and regulation may favor autonomous goals rather than social cohesion, which may result in different temporal patterns of emotion expression and regulation. Similarly, the content of infant emotion regulation processes may differ depending on the cultural context, such that more interdependent cultures may show more proximal interactive styles, with an emphasis on maintaining physical proximity, whereas more individualistic cultures may show a more distal style, characterized by active engagement through vocalizations and facial affect (Cole, 2016; Feldman, 2007; Silk, 2019).

In contrast to the teaching task, there was no empirical support for biologically-based, between-infant differences in emotional feedback loops during free play. Whereas the interaction goals of a teaching task are clear and consistent across dyads, appropriate infant behavior during free play spans a wider range of exploration and emotional expression. Small fluctuations in infant negative affect engagement may even be adaptive during this task, if they capture caregiver attention and guide caregiver behavior (Buss & Goldsmith, 1998; Cole, 2016). Given the wide range of acceptable infant behavior during free play, as well as the fact that infants infrequently showed negative affect during free play, self-regulatory feedback loops between infants' positive and negative affect engagement may be harder to detect during free play. In addition, given the presence of mother- and infant-driven emotion coregulation processes during free play, it may be harder to detect infant self-regulatory processes and between-dyad differences therein during this task.

Infant vagal tone and mother-infant emotion coregulation

Aims 2 and 3. Biologically-based Differences in Mother-infant Affect Synchrony

In recent years, the synchronous, bidirectional linkage of mothers' and infants' emotional experiences and behaviors within a stable emotional system (i.e., fluctuations in partners' emotional responses that are matched in the direction of change) has been put forth as strong evidentiary criteria for emotion coregulation (Butler & Randall, 2013). In order to capture these potentially causal coregulatory processes, the present study defined synchrony as contingent fluctuations in affect engagement in response to fluctuations in one's partner's affect engagement during the prior second. Although on average there was evidence of mother-driven and infant-driven synchrony during free play, average levels of synchrony during the teaching task indicated null effects. Among premobile infants, playful interactions may offer a unique context for capturing synchrony due to longer periods of mutual gaze, vocalizations, imitations, and affective sharing (Feldman, Greenbaum, Mayes, & Erlich, 1997). In contrast, during challenging tasks, synchrony may require greater regulatory resources, such that more vulnerable dyads may not demonstrate synchrony (e.g., dyads where mothers endorsed greater prenatal depressive symptoms, as described below).

Further, contrary to expectations, infants with greater vagal tone did not exhibit more contingent responses to maternal positive affect engagement, and their mothers did not show more contingent responses to infant affect engagement, during free play or teaching task. The present null findings are inconsistent with neurobiological models of the ontogeny of emotion regulation (e.g., Feldman, 2015), but may be better understood in light of mixed findings from prior work using time series methods to evaluate vagal tone-based differences in mother-infant emotion coregulation. Among samples of middle-class, Israeli families, Feldman and colleagues have demonstrated that greater neonatal vagal tone was positively related to mother-infant synchrony in gaze and affect engagement during free play at three months child age (Feldman, 2006; Feldman & Eidelman, 2007). In contrast, Busuito et al. (2019) recently demonstrated that lower infant vagal tone was associated with higher levels of mother-infant synchrony in affect engagement following a stressor, among a low-risk, predominantly White sample of six-month-old infants and their mothers.

Methodological differences may have contributed to discrepancies between the present findings and prior work. First, researchers differ in how they operationalize synchrony. Synchrony has sometimes been evaluated as the concurrent matching of mothers' and infants' affective states (e.g., conditional probability of sharing gaze, Feldman & Eidelman, 2007; Pearson correlation coefficient between mothers' and infants' affect engagement over the time series, Busuito et al., 20019) or as peak synchrony across a range of possible lags (e.g., Feldman, 2006). In contrast, in order to evaluate potentially causal coregulatory processes, I assessed synchrony in terms of lead-lag relations between mothers and their infants, at a lag of 1 second for each dyad. In addition, unlike prior work that has evaluated synchrony as the linkage between mothers' and their infants' behavior, the present study used a modeling approach (DSEM) that disambiguated the driver of synchrony. Modeling mother- and infant-driven coregulation separately is consistent with theoretical accounts of emotional coregulation, which highlight the bidirectional coordination between mothers and their infants, although this approach may have resulted in reduced variability to detect between-dyad differences in synchrony. Finally, prior work that has demonstrated relations between infant vagal tone and synchrony has evaluated these relations among low-risk, ethnic majority samples (e.g., Busuito et al., 2019; Feldman, 2006; Feldman & Eidelman, 2007) and the effects of infant biological characteristics on interactional processes may be harder to detect among samples at elevated risk for socioemotional problems, such as economically disadvantaged, ethnic minority families, who face greater contextual challenges to regulatory processes. In addition, although synchrony is thought to be a universal predictor of positive socioemotional outcomes, the specific behaviors in which synchrony is expressed may be influenced by cultural factors, such as an emphasis on face-to-face visual contact versus motor or vocal stimulation (e.g., Gordon & Feldman, 2015; Silk, 2019). Finally, Feldman's work has focused on preterm infants, who are biologically at-risk for regulatory deficits; biological factors that promote resilience or confer risk may be more salient among this sample.

Whereas vagal tone is a putative marker of an individual's capacity to quickly, flexibly, and adaptively respond to the social environment (Beauchaine, 2001; Obradović, 2012; Porges, 2003, 2007), responsivity of the vagal brake during social interactions is thought to be the direct mechanism through which vagal functioning supports social engagement and disengagement (Porges et al., 2019). Effective regulation of the vagal brake is thought to help maintain homeostasis in the face of changing demands, which can include preserving resting, calm states during neutral tasks as well as mobilization of cardiometabolic resources to face challenges (Porges, 1995). Recent meta-analytic work suggests that vagal reactivity following a stressor is related to attachment security, whereas vagal tone was nonsignificantly associated with attachment security (Groh & Narayan, 2019). Further, prior work has demonstrated that vagal reactivity is related to synchrony, such that dyads where infants showed vagal suppression during a stressor were more synchronous in normal play than dyads where infants did not show vagal suppression (Moore & Calkins, 2004). Similarly, among school-aged children, children with greater RSA reactivity showed greater synchronization with parents' positive emotional cues, suggesting RSA reactivity may account for differences in interactive contingencies (Rousseau et al., 2019). Overall, synchrony, defined in terms of moment-to-moment fluctuations in affect engagement, may be more sensitive to variations in dynamic vagal functioning, such as RSA reactivity.

Role of Maternal Prenatal Depressive Symptoms

Maternal prenatal depressive symptoms were included as a covariate in primary analyses in order to adjust for maternal characteristics that exist independent of the child and could shape patterns of parent-child interactions. Results yielded compelling depression-based differences in dynamic processes of infant emotion regulation and coregulation during free play and the teaching task. Maternal prenatal depressive symptoms predicted greater volatility in infant positive and negative affect engagement. These results are consistent with prior work that maternal prenatal depressive symptoms are related to infants' negative emotionality (Davis et al., 2018), and extend prior work by demonstrating that these infants' enhanced reactivity can be indexed by variability in second-by-second changes in infant affect that remains after accounting for their emotional equilibrium, continuity in their affective experience, and responsiveness to their caregiver. For infants born to more depressed mothers, who may be withdrawn and less responsive to infants' bids, enhanced variability in one's affect state may be an effective strategy for eliciting responses from caregivers (Goodman et al., 2018). Whether this strategy of increased emotional variability has long-term costs in terms of subsequent socioemotional problems warrants exploration in future longitudinal research.

Prenatal maternal depressive symptoms also predicted mother-driven emotion coregulation during the teaching task. During the teaching task, increases in mothers' positive affect engagement predicted subsequent increases in infants' positive affect engagement, only among dyads where mothers reported low (below average) prenatal depressive symptoms. Similarly, among dyads where mothers reported low prenatal depressive symptoms, increases in mothers' positive affect engagement predicted subsequent decreases in infants' negative affect engagement. In contrast, among dyads where mothers reported high (above average) prenatal depressive symptoms, increases in mothers' positive affect engagement predicted subsequent increases in infants' negative affect engagement. These results build on extant work that suggests depressed mothers do not have the typical "external regulatory" effect on their infants (e.g., Feldman, 2003; Goodman et al., 2017; Moore & Calkins, 2004; Reck et al., 2011; Tronick & Beeghly, 2011). Infants of depressed mothers may resort to self-directed self-soothing strategies to modulate arousal, as mothers may be less available or less consistently responsive to meet infants' emotional needs; with their attention focused inward, infants of depressed mothers may be less attuned to the potentially beneficial effects of maternal positive affect engagement (Manian & Bornstein, 2009). Further, depressed mothers' positive affect engagement may be dysregulating for their infants, either because it represents a novel departure from withdrawn mothers' typical affect state or because positive engagement is interpreted as intrusive. Overall, by disambiguating the driver of synchrony, these results highlight depression-based differences in how infants respond to changes in their mothers' affective engagement, and not necessarily in how mothers respond to their infants.

Exploratory post-hoc analyses (not reported here) demonstrated that the effects of prenatal depressive symptoms on infant emotional volatility and mother-infant synchrony held after adjusting for concurrent postpartum depressive symptoms. These results demonstrate the unique impact of *prenatal* depressive symptoms on postpartum dyadic interactions. Prenatal programming of infants' emotional responsiveness and regulation by maternal prenatal depressive symptoms may operate through a variety of neurobiological mechanisms, beginning *in utero*. Preliminary evidence suggests depressive symptoms during pregnancy shape infant neural development, such that infants of depressed mothers are less neurobiologically attuned to gaze, smiling, and maternal speech (e.g., Davis et al., 2018; Piazza et al., 2020), which may make infants of depressed moms less likely to reap the benefits of mother-driven emotion regulation, which in turn may render infants more volatile. Nevertheless, causal inferences regarding the impact of prenatal depressive symptoms are precluded by the observational design, as unmeasured factors (e.g., genetic predispositions) may influence risk for both elevated prenatal depressive symptoms and less regulated dyadic interactions. Experimental designs (e.g., randomized controlled trials for maternal depression) may offer an opportunity to address the causal effects of maternal depression (e.g., Davis et al., 2018; Goodman et al., 2018).

Strengths

The present investigation benefited from several strengths. First, by focusing on second-by-second fluctuations in mothers' and infants' affect engagement, the present study was able to test novel hypotheses about biologically-based, between-dyad differences in the dynamic processes of emotion regulation and coregulation that unfold during mother-infant interactions. Although the time course of emotion regulation has traditionally been overlooked (Cole, Martin, & Dennis, 2004; Krone et al., 2018; Silk, 2019), in recent years, researchers have argued for statistical models of emotion coregulation in close personal relationships that account for the bidirectional linkage between dyad members over time (Butler & Randall, 2013). The present investigation offers insight into how mothers' and infants' affect engagement unfolds during parent-child interactions, highlighting the unique roles both infants and their mothers play in regulating their own and each other's emotions. Whereas time series models statistically remove self-contingency, the present investigation evaluates both self- and interactive contingencies in mothers' and infants' emotion dynamics in order to separate infants' emotion regulation from coregulation. Further, my results challenge preexisting conceptions regarding mother-driven coregulation by demonstrating both infants and mothers can contribute to bidirectional coordination of emotional exchanges. A final advantage of DSEM is that, unlike other multilevel time series models, each person's time series was allowed to be differentially volatile, which not only offers more accurate estimates of all parameters in the model (e.g., Jongerling, Laurenceau, & Hamaker, 2015) but also elucidates between-dyad differences in infants' intra-individual emotional variability. Primary analyses also offered rigorous examination of the effects of infant vagal tone by statistically adjusting for prenatal risk factors that may account for differences in infant emotion regulation and coregulation.

Second, rather than focusing on specific domains of affect expression, I assessed infants' affect engagement, consistent with Tronick's (1989) multimodal perspective that affect is expressed not only facially, but also vocally and bodily, and that these configurations of emotion and behavior form the basic units of infants' experience (Weinberg & Tronick, 1994). The multidomain assessment of affect engagement is also well-aligned with polyvagal theory's description of the social engagement system, which involves an interconnected network of neural circuits that control looking, listening, vocalizing, and facial gesturing (Porges, 2003). At the same time, multimodal measures of affect engagement are limited in their ability to examine contingencies within specific domains, and there may be meaningful differences in regulatory processes within communication modalities as well as between modalities (e.g., synchrony of infant vocal affect with maternal facial affect; Beebe et al., 2011).

Finally, I evaluated mother-infant interactions during naturalistic tasks that took place in mothers' homes. Whereas the majority of studies that evaluate relations between infant vagal tone and mother-infant interactions are conducted in laboratory settings (Thayer, Hansen, & Johnsen, 2008), evaluating these processes in the home may offer a more ecologically valid assessment of these relations. Nevertheless, consistent with prior work, mothers exhibited very little negative affect and disengagement, which may be attributed in part to the presence of experimenters who were videotaping the interactions.

In addition, evaluating mothers' and infants' affect engagement during both the free play and teaching task shed light on task-based differences in dynamic patterns of infant emotion regulation and coregulation, as well as differential prediction of these dynamic processes.

Limitations

Several limitations are noteworthy in considering my findings. Although affect engagement is a well-established and widely-used construct in the literature, the coding system employed in the present study defined infant engagement broadly as "the infants' visual attention and responsiveness to or initiation of social exchanges with mother or objects of interaction." Fluctuations in the direction of infant gaze may shed light onto the specific regulatory strategies infants use (e.g., self- versus other-directed) and how effective they are in producing changes in infants' emotion expression. One possible interpretation of vagal tone-based differences in infants' transition from negative affect engagement into more positive affect engagement is that infants with greater vagal tone were more likely to rely on more self-directed regulatory behaviors (e.g., gaze aversion) and therefore less likely to show an increase in positive affect engagement due to their temporary disengagement from task demands, whereas infants with lower vagal tone may have been more likely to rely on or experience mother-driven regulation. However, without distinguishing whether changes in affect engagement refer to changes in object engagement or engagement with the mother, it is difficult to draw strong conclusions about the behaviors that contribute to temporally-based regulatory processes.

The operationalization of affect engagement also had several noteworthy limitations from a methodological standpoint. Positive and negative affect engagement were treated as two continuous variables, in order to evaluate potential differences in emotion regulation and coregulation processes depending on the valence of infant affect, as well as to account for potential nonlinear relations in affect engagement. Nevertheless, it is possible affect engagement would be best represented on a single continuum. Further, ideally, affect engagement would have ideally been treated categorically, but due to computational issues, was treated continuously. If affect engagement were scaled differently, it is possible a different pattern of results would have been obtained.

The present investigation sought to build on prior work that has demonstrated associations between vagal tone and infant regulation and coregulation during free play and frustrating tasks. Although mothers exhibited very little negative affect and disengagement during both the free play and teaching tasks, infants generally showed more negative affect engagement during the teaching task than they did during free play. Fluctuations in negative and positive affect engagement likely capture infants' and mothers' regulation of frustration. However, according to polyvagal theory, vagal tone is related to the perception of and response to cues of threat and safety (Porges, 2006, 2007), which may suggest the salience of vagal tone in the regulation of fear. Examining mothers' and infants' affective responding to tasks that are designed to elicit fear, such as simulations of interparental conflict, may also offer an opportunity to examine infants' response to maternal negative affect engagement. In addition, although the home visit was structured so that infants could recover between tasks, information was not available about events that may have occurred between tasks (e.g., feeding) and influenced the dyadic behaviors observed during the teaching task. Although all infants were presumed to be in a neutral state at the start of the teaching task, infants' and mothers' affect engagement prior to the teaching task was not available, so analyses could not adjust for any potential differences in infants' or mothers' affect engagement at the start of the task, which may have influenced the subsequent unfolding of their affect engagement during the task.

Results from the present investigation may not generalize to different developmental stages. By five months, children are capable of maintaining alertness and engagement required to sustain social interactions, and also have enhanced abilities to dampen negative facial affect (Malatesta & Haviland, 1982); however, synchrony in mother-infant face-to-face interactions has been observed as early as three months child age (Beebe et al., 2010; Cohn & Tronick, 1988; Feldman, 2007; Gordon & Feldman, 2015; Malatesta, Culver, Tesman, & Shepard, 1989; Messinger, 2002; Tronick, 1989). Earlier assessments of emotion regulation and coregulation processes may be less sensitive to the history of parent-child interactions, and therefore more open to concurrent biological influences, whereas the pattern of mother-child interactions observed at 24 weeks may be more strongly shaped by children's expectations of mothers' availability and responsiveness. The present investigation attempted to isolate the unique effect of infant biological characteristics by statistically adjusting for prenatal factors shown to impact parent-child interactions; however, such adjustment may not fully address the complex interconnections between maternal, child, and dyadic adjustment.

My results also may not generalize to children from different ethnic or socioeconomic backgrounds or to different child-caregiver relationships. Cultural norms regarding interactive behavior and emotion socialization may lead to differences in the specific behavioral patterns in which regulatory processes are expressed (e.g., Cole, 2016; Silk, 2019). Culture-specific parenting practices and child social engagement behaviors may influence the expression and regulation of affect engagement, especially considering "active" engagement in the domains of touch, gaze, affect, and vocalizations may be more prevalent in more individualistic cultures, whereas social exchanges may be coordinated through physical proximity in more collectivistic cultures (Feldman & Masalha, 2010). Further, whether higher vagal tone is adaptive may depend on children's socioeconomic advantage, such that lower levels of vagal tone and less vagal reactivity may be more adaptive in contexts where children are faced with chronic stressors (Johnson et al., 2017). Taken together, these considerations suggest there may be context-specific relations between vagal tone and emotion regulation processes. Finally, although the majority of empirical work, including the present investigation, has evaluated mother-infant emotion coregulation, other caregiver-child relationships play an important role in shaping children's socioemotional development. Prior work has demonstrated vagal tone supports both infant-mother and infant-father gaze synchrony at three months (Feldman & Eidelman, 2007), although it is not clear whether the pattern of findings obtained in the present study would generalize to father-child relationships.

Future Directions

Although infants' vagal tone is thought to support flexible and adaptive responding within their environmental context, the effects of vagal tone on regulatory processes during infant-mother interactions may take time to accumulate. Longitudinal work has demonstrated prospective relations between neonatal vagal tone and subsequent dyadic functioning and child emotion regulation (e.g., Feldman, 2006, 2009, 2015; Feldman & Eidelman, 2007), suggesting that vagal tone early in life may set the stage for adaptive dyadic functioning later in infancy, when the parent-child context becomes more tailored to child dispositions and when children are more physically capable of participating in dynamic face-to-face interactions (Feldman, 2006, 2015). Autonomic maturity very early in life may be internalized by infants and have cascading effects on developing parent-child interactions and infant emotion regulation, continuing to predict later behavioral and physiological responses (Propper, 2012; Propper & Holochwost, 2013), warranting examination of not only concurrent relations, but also prospective relations between vagal tone and emotion regulation during parent-child interactions.

Future research is needed to address the gap in our understanding of how, within a dyad, vagal tone shapes and is shaped by within-dyad interaction patterns. According to bioecological models of development, development is a fundamentally dynamic process (Calkins, 2015), and the influences of children's developing physiological functioning on their environment and environmental influences on children's physiological development work together in a transactional, reciprocal manner to influence biopsychosocial functioning (e.g., Calkins et al., 2013; Kennedy et al., 2004; Perry et al., 2018). Supporting these models, there is a burgeoning body of longitudinal work that demonstrates transactional processes between maternal parenting (e.g., supportive parenting practices, restrictive/overcontrolling parenting, intrusive parenting) and children's vagal tone, usually among ethnic majority, middle-class samples (e.g., Kennedy, Rubin, Hastings, & Maisel, 2004; Perry, Dollar, Calkins, & Bell, 2018). In addition, a ten-year longitudinal study demonstrated that higher vagal tone at birth was related to higher vagal tone at ten years via improved child emotion regulation and parent-child reciprocity across the first five years of life (Feldman, 2015). However, extant literature has focused on mothers' report of parenting attitudes and beliefs and global observations of parenting, and little is known about whether and how emotion regulation and coregulation processes change throughout the course of development. Further, no studies to my knowledge have evaluated transactional processes between emotion coregulation and vagal tone during the first nine months postpartum, a period of exceptional plasticity in vagal functioning given the rapid increase in myelinated vagal fibers (Pereyra et al., 1992; Sachis et al., 1982). Future work from a developmental, transactional perspective is needed to evaluate how vagal tone shapes and is shaped by emotion regulation and coregulation processes (Bornstein, 2013; Malatesta & Haviland, 1982).

Infants' vagal responsivity and synchrony of infants' vagal responsivity with their caregivers' vagal responsivity may also be important proximal mechanisms through which emotion coregulation unfolds. Given that the central vagal complex can react within milliseconds (Thayer et al., 2008), intra-individual variation in vagal functioning, including vagal responsivity to external contextual demands, may offer new insights into whether and how infants' vagal functioning shapes emotion regulation during social interactions. Future work on the links between vagal functioning and emotion regulation and mother-infant coregulation processes may capitalize on recent methodological work that has applied a dynamic systems perspective to derive novel measures of vagal functioning and synchrony (e.g., Gates et al., 2015; Berry et al., 2019).

Incorporating mothers' and infants' vagal reactivity during tasks, and mother-infant vagal synchrony, may help elucidate mechanisms that link children's vagal tone and emotion regulation and coregulation processes. Feldman's biobehavioral synchrony model (e.g., Feldman, 2003; Feldman, 2012) posits that interpersonal coherence of behavior and physiology promotes children's socioemotional development. Affect synchrony may influence child development directly, as well as indirectly, through physiological attunement. Similar to the concept of hidden regulators (Hofer, 1995), infants may detect changes in their mothers' physiological state, which in turn may influence the infants' physiological and emotional state (e.g., Feldman et al., 2011). However, to my knowledge, only one study thus far has demonstrated mother-infant affective synchrony is related to physiological synchrony (Feldman et al., 2011). Recent work also suggests that behavioral synchrony following a stressor is related to mothers' vagal reactivity to a challenge (Busuito et al., 2019). Infants with lower vagal tone may require more of mothers' physiological regulatory capacity to support behavioral synchrony (Busuito et al., 2019), which may be adaptive in the short-term but may have deleterious consequences for dyadic functioning in the long-term.

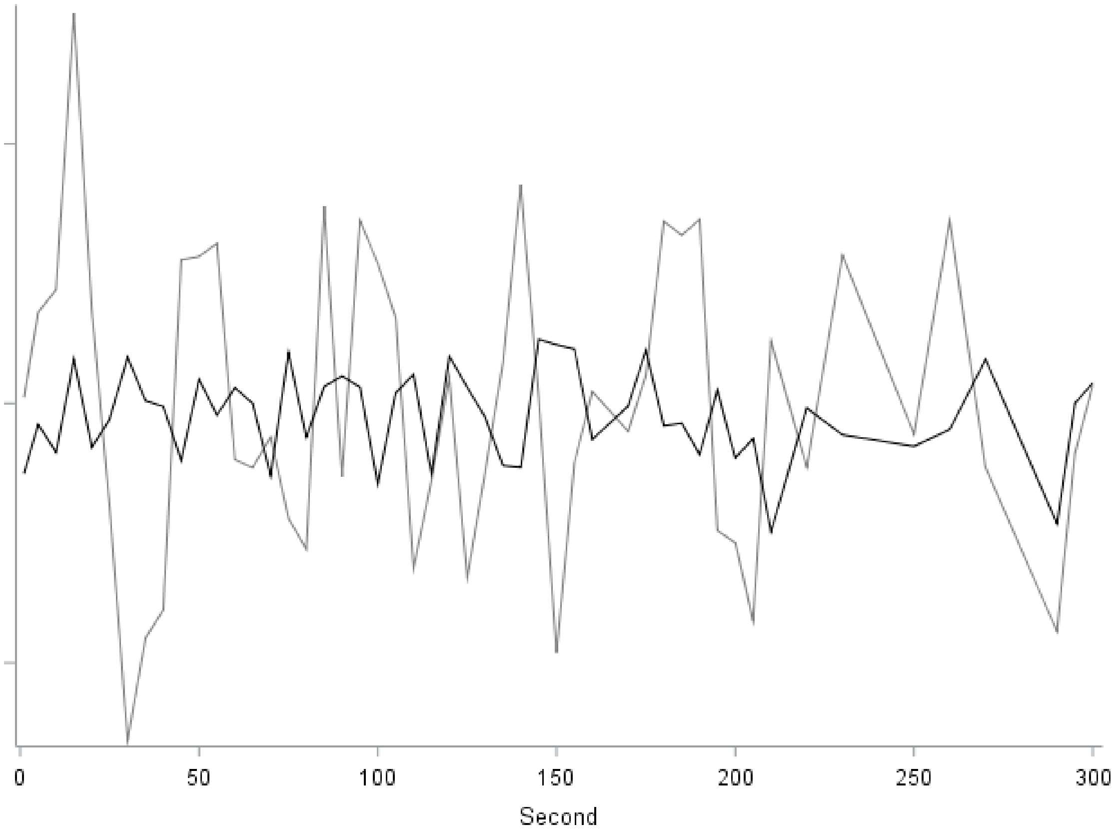
Drawing from dynamic systems theories, moment-by-moment processes within mother-infant interactions may be similar to emotion regulation and coregulation patterns that are repeated over time and eventually have long-term effects on the development of children's emotion regulation strategies and socioemotional outcomes (Morris, Cui, Criss, & Simons, 2018; Thelen & Smith, 1998). For example, a recent meta-analysis found that heightened variability, instability, and inertia in emotions (assessed in terms of changes in self-reported or observed emotions over a course of seconds, hours, or days) were related to lower psychological well-being (Houben, van den Noortgate, & Kuppens, 2015). Longitudinal research is needed to evaluate the sequelae of infant emotion regulation and mother-infant coregulation processes. Incorporating objective measures of children's behavior competence and problems can shed light on unanswered questions about the levels at which and circumstances under which volatility, carryover, feedback, and synchrony in mothers' and infants' affect engagement promote resilience or portend maladjustment. In keeping with a dynamic systems perspective that emphasizes the importance of balancing chaos and rigidity (e.g., Thayer & Lane, 2000), and the optimal midrange model (e.g., Beebe et al., 2011), fluctuations in infants' emotional responding, including spontaneous reactivity to stimuli and reactivity to one's own and other's prior behavior, may be most adaptive at moderate levels (Calkins, 1994; Cole, 2016). However, the meaning of these parameters likely depends on the interactive context in which they were observed, such that they may have different correlates and consequences in response to different kinds of tasks (e.g., Goodman et al., 2018), and may also differ depending on dyads' broader cultural context (Mancini & Luebbe, 2016). Further, the longer-term consequences of emotion regulation and coregulation processes may also vary depending on the broader environmental context, such that highly supportive environments may buffer against the potentially adverse effects of less efficient regulatory processes.

Heeding the call for examination of regulatory processes that operate in stable emotional systems (Butler & Randall, 2013), the present study assessed volatility, carryover, feedback loops, and coregulation that occur around stable equilibria in mothers' and infants' affect engagement. However, the dynamic processes that undergird effective emotion regulation may differ from processes that give rise to emotional dysregulation in mother-infant dyads. Morphogenic processes (i.e., processes that contribute to changes in mean levels of affect; Butler, 2011) that disrupt emotional equilibrium (e.g., positive spirals that serve to increase positive affect, or negative coercive cycles that lead to increased negative affect) may be more potent indicators of emotion dysregulation. Although the present study was focused on regulatory processes, future work that employs nonlinear, dynamic models that do not assume stationarity could offer a complementary approach to evaluating infant emotion regulatory and dysregulatory processes that may contribute to long-term socioemotional outcomes.

Conclusions

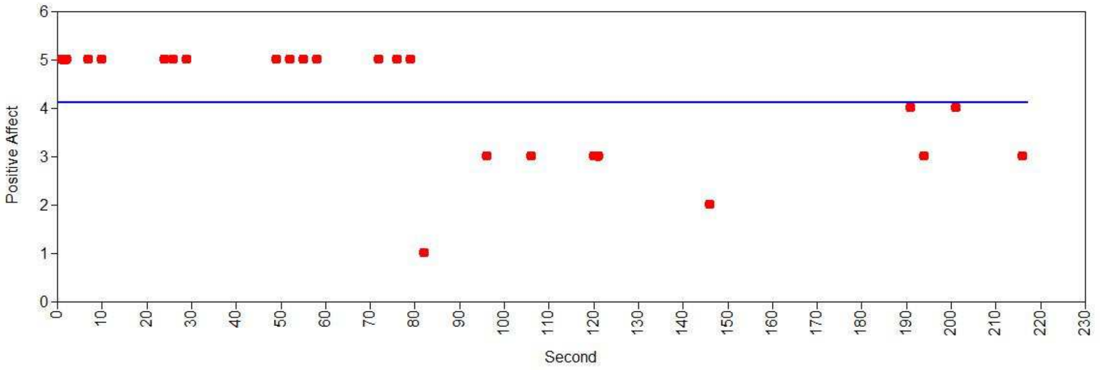
Relative to their Caucasian peers, low-income Mexican-origin children are at elevated risk for future regulatory and interpersonal skills deficits and emotional and behavioral problems (e.g., Avila & Bramlett, 2013; Bird et al., 2001; Galindo & Fuller, 2010; Joiner et al., 2001). In addition, poverty and poverty-related stressors may not only hinder children's developing emotion self-regulation, but may also compromise mothers' ability to be emotionally aware and skillful in responding to children's emotional cues (Cole, 2016). By examining dynamic fluctuations in infants' and mothers' affect during social interactions, this project illuminated temporally-based emotion regulation and coregulation processes, as well as how infant biological and maternal prenatal characteristics predict the processes of emotion regulation and coregulation, among a high-risk sample. During free play, fluctuations in infants' affect engagement were matched in the direction of change with their mothers' affect engagement, and mothers similarly exhibited contingent responsiveness to changes in their infants' positive affect engagement, providing novel evidence for bidirectional emotion coregulation. In contrast, during a potentially frustrating teaching task, there was evidence of feedback loops between infants' positive and negative affect engagement. Although results from the dissertation project generally failed to support the hypotheses that greater infant vagal tone promotes flexible, contingent, and adaptive responding to the social context, they suggested prenatal depressive symptoms account for differences in infants' emotional volatility and ability to reap the benefits of maternal coregulatory efforts. Results also point to several avenues for future research, including integration of micro-level dynamic processes within longitudinal research in order to assess the complex interplay between biological, emotional, and interpersonal regulatory processes at multiple timescales. Studying processes of emotion regulation and coregulation in vulnerable populations may lead to new insights for early interventions that aims to transform maladaptive interaction patterns into adaptive ones (Provenzi et al., 2018).

Figure 1. Differences in intra-individual variability in positive affect engagement



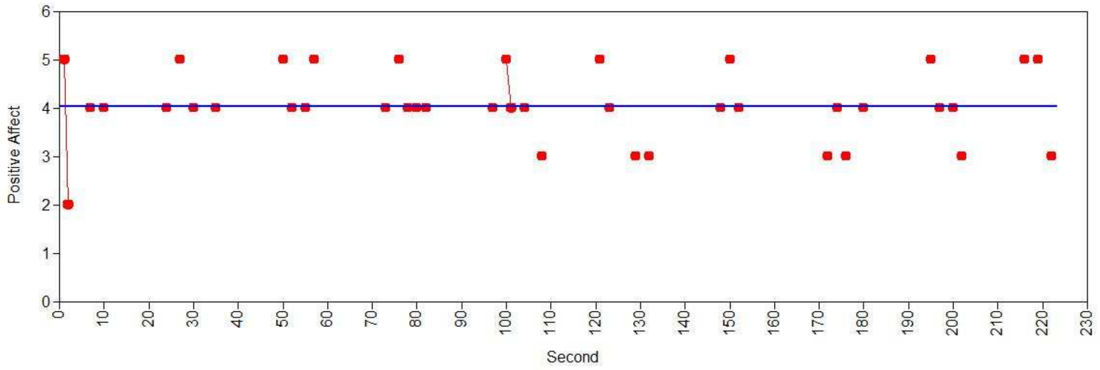
Note. The gray line represents a time series for positive affect engagement for a person with more variability. The black line represents a time series for positive affect engagement for a person with less variability.

Figure 2. Time series for positive affect for an individual with a high positive carryover



Note. The horizontal line represents the average value of positive affect for this person. The dots reflect the amount of positive affect, at each second that it was observed. This person exhibits a high level of positive carryover (estimate = .904).

Figure 3. Time series for positive affect for an individual with null carryover



Note. The horizontal line represents the average value of positive affect for this person. The dots reflect the amount of positive affect, at each second that it was observed. This person exhibits a null amount positive carryover (estimate = -.003).

Figure 4. *Example of Anticipated Between-Dyad Differences in Within-Dyad Emotion Coregulation During Free Play*

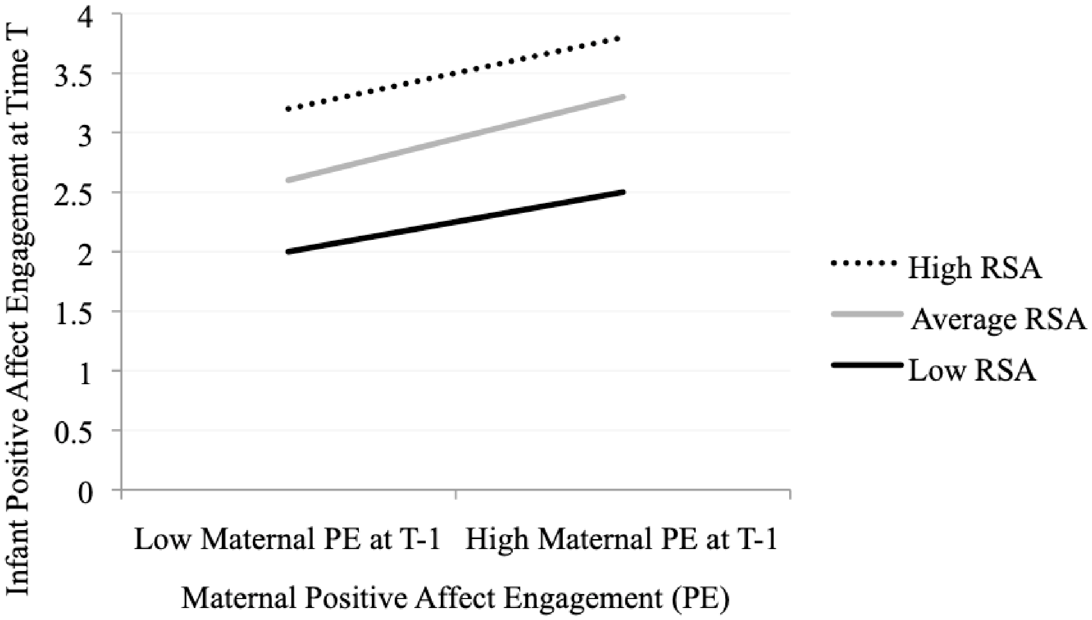


Table 1. Summary of predictions for carryover and transactional relations in affect, for high RSA infants

	Affect Engagement at Time T		
Affect Engagement at Time T-1	Infant Positive Affect Engagement	Infant Negative Affect Engagement	Maternal Positive Affect Engagement
Infant Positive Affect Engagement	+	-	+
Infant Negative Affect Engagement	**0**	**0**	-
Maternal Positive Affect Engagement	+	-	

Note. RSA = respiratory sinus arrhythmia. Values of zero reflect mean-reverting behavior whereas values further away from zero reflect longer time to return to one's personal set point (Hamaker et al., 2018). A positive sign reflects stronger positive associations between adjacent time points, whereas a negative sign reflects stronger negative associations between adjacent time points. I expect the same pattern of associations to exist across the full sample, but I expect the magnitude of the associations between affect at adjacent time points to be stronger among infants with higher RSA.

Table 2

Sample demographics

Age - Range; M (SD)	18-42; 27.8 (6.5)
First-time mothers – %	20.4%
Number of other children[a] **-** Range; M (SD)	1-9; 2.0 (1.7)
Country of birth – %	
Mexico	86.6%
United States	13.4%
Years in the United States[b] – Range; M (SD)	0-32; 11.8 (5.9)
Maternal Education – %	
0 through 8 years of school	26.9%
Some high school completed	33.3%
High school graduate	25.9%
Some college or vocational school	9.0%
College degree (BS/BA) or above	5.0%
Work Status – %	
Not employed	85.6%
Working part-time	9.5%
Working full-time	5.0%
Family Income - %	
≤ $10,000	32.1%
$10,001 - $15,000	26.4%
$15,001 - $25,000	11.9%
≥ $25,001	14.9%
Household size - Range; M (SD)	1-14; 4.4 (2.0)
Relationship status at prenatal visit – %	
Living with a partner/spouse	79.6%
Not living with a partner/spouse	20.4%
Child sex – %	
Male	47.8%
Female	52.2%
Preterm birth (< 37 weeks) - %	3.0%
Gestational age (weeks) - Range; M (SD)	26-42; 39.3 (1.5)
Low birth weight (< 2500 g) – %	1.0%
Child birth weight (ounces)-	42-174; 119.9 (18.4)

Range; M (SD)

---

[a] Of the multiparous children

[b] Of women not born in the United States

Table 3. Descriptions of infant and maternal positive and negative affect engagement

	Infant Positive Affect Engagement	Maternal Positive Affect Engagement
Value		
0	Showed any sign of negative affect engagement	Showed any sign of negative affect engagement
1	Positive, disengaged; Neutral or uncodable affect, passive engaged; Uncodable affect, active engaged	Positive, disengaged
2	Neutral affect, active engaged	Neutral or uncodable affect, passive engaged; Neutral or uncodable affect, comforting or active engaged; Positive affect, comforting engaged
3	Positive affect, passive engaged	Positive affect, passive engaged
4	Positive affect, active engaged	Positive affect, active engaged
	Infant Negative Affect Engagement	Maternal Negative Affect Engagement
Value		
0	Showed any sign of positive affect engagement	Showed any sign of positive affect engagement
1	Neutral affect, disengaged	Neutral affect, disengaged
2	Negative or uncodable affect, disengaged	Negative or uncodable affect, disengaged
3	Negative affect, passive engaged	Negative affect, passive engaged
4	Negative affect, active engaged	Negative affect, active engaged

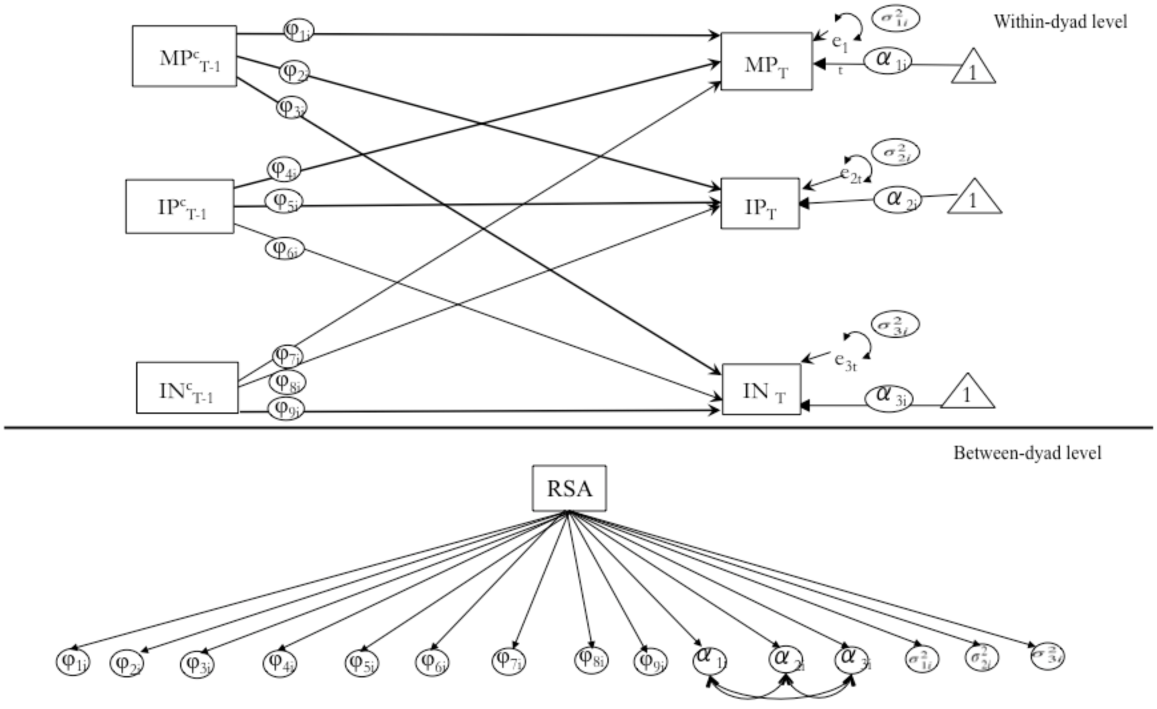
Note. Affect engagement was treated as missing when engagement was not scored. Per the coding manual, if mothers expressed negative affect during comforting engaged behavior, this affect was coded as neutral affect.

Table 4. Percent of time spent in each affect engagement state, pooled across the sample

	Infant Positive	Infant Negative	Maternal Positive
Free Play			
Value			
0	22.1	75.2	0.1
1	31.4	12.6	7.2
2	35.3	0.9	51.6
3	1.4	3.4	38.4
4	7.2	5.3	2.8
Teaching Task			
Value			
0	29.8	69.9	0.5
1	14.2	4.2	7.1
2	55.2	1.4	69.5
3	0.1	6.1	21.8
4	0.5	18.1	1.2

Note. Percentages may not add to 100 due to missing data.

Figure 5. Proposed Dynamic Structural Equation Model (DSEM)



Note. MP = mom positive affect engagement; IP = infant positive affect engagement; IN = infant negative affect engagement; superscript c = centered; subscript t-1 = time point 1 second prior; subscript t = time point. Following suggestions for multilevel path diagrams (Curran & Bauer, 2007), circles over paths indicate random effects and triangles labeled with the number “1” indicate intercepts.

Table 5
Hypotheses for Between-Level Differences in Within-Level Intercepts (Model 1)

				Model 1	
Effect	Interpretation			Random Effect	Between-level Hypothesis
Intercepts					
Int. (MP)	Average Maternal Positive Affect Engagement			α_{1i}	
Int. (IP)	Average Infant Positive Affect Engagement			α_{2i}	a: Higher among higher RSA infants during both tasks
Int. (IN)	Average Infant Negative Affect Engagement			α_{3i}	a: Lower among higher RSA infants during free play; Higher among higher RSA infants during teaching task
Var(MP)	Intra-individual residual variability of maternal positive affect engagement			σ^2_{1i}	
Var(IP)	Intra-individual residual variability of infant positive affect engagement			σ^2_{2i}	b: Higher among higher RSA infants
Var(IN)	Intra-individual residual variability of infant negative affect engagement			σ^2_{3i}	b: Higher among higher RSA infants
Regression Path Intercepts					
Predictor at Time *t*-1	Outcome at Time *t*	Interpretation		Random Effect	Between-level hypothesis
MP	MP	Carryover in Maternal Positive Affect Engagement		φ_1	
MP	IP	Mother-driven		φ_{2i}	Aim 2:

		Coregulation of Infant Positive Affect Engagement			Stronger positive association between mothers' positive affect and their infants' subsequent positive affect among higher RSA infants
MP	IN	Mother-driven Coregulation of Infant Negative Affect Engagement		φ_{3i}	Aim 2: Stronger negative association between mothers' positive affect and their infants' subsequent negative affect among higher RSA infants
IP	MP	Infant-driven Coregulation of Maternal Positive Affect Engagement (by Infant Positive Affect Engagement)		φ_{4i}	Aim 3: Stronger positive association between infant positive affect and subsequent maternal positive affect among higher RSA infants
IP	IP	Carryover in Infant Positive Affect Engagement		φ_{5i}	c: Stronger positive association between positive

					affect at adjacent time points among higher RSA infants
IP	IN	Transaction (feedback loop) from Infant Positive Affect Engagement to Infant Negative Affect Engagement		φ_{6i}	d: Stronger negative association between positive affect and subsequent negative affect among higher RSA infants
IN	MP	Infant-driven Coregulation of Maternal Positive Affect Engagement (by Infant Negative Affect Engagement)		φ_{7i}	Aim 3: Stronger negative association between infant negative affect and subsequent maternal positive affect among higher RSA infants
IN	IP	Transaction (feedback loop) from Infant Negative Affect Engagement to Infant Positive Affect Engagement		φ_{8i}	d: Weaker negative association between negative affect and subsequent positive affect among higher RSA infants
IN	IN	Carryover in Infant Negative Affect Engagement		φ_{9i}	c: Weaker positive association between negative

					affect at adjacent time points among higher RSA infants
Note. Model 1 corresponds to Figure 5. MP = Maternal Positive Affect Engagement. IP = Infant Positive Affect Engagement. IN = Infant Negative Affect Engagement. Random effects are indicated by a subscript i; effects without a subscript i are constrained to be equal across the sample.					

Table 6a. Model equations for free play

Within-dyad equations

$$MP_{ti} = \alpha_{1i} + \varphi_{1i}MP^{c}_{(t-1)i} + \varphi_{4i}IP^{c}_{(t-1)i} + \varphi_{7i}IN^{c}_{(t-1)i} + e_{1ti}$$

$$IP_{ti} = \alpha_{2i} + \varphi_{2}MP^{c}_{(t-1)} + \varphi_{5i}IP^{c}_{(t-1)i} + \varphi_{8i}IN^{c}_{(t-1)i} + e_{2ti}$$

$$IN_{ti} = \alpha_{3i} + \varphi_{3}MP^{c}_{(t-1)} + \varphi_{6i}IP^{c}_{(t-1)i} + \varphi_{9i}IN^{c}_{(t-1)i} + e_{3ti}$$

Between-dyad equations

$$\alpha_{1i} = \gamma_{00} + \gamma_{01}RSA^{c}_{i} + \gamma_{02}ECO^{c}_{i} + \gamma_{03}NLE^{c}_{i} + \gamma_{04}DEP^{c}_{i} + \gamma_{05}REL^{c}_{i} + \gamma_{06}SEX^{c}_{i} + \gamma_{07}CH^{c}_{i} + u_{0i}$$

$$\alpha_{2i} = \gamma_{10} + \gamma_{11}RSA^{c}_{i} + \gamma_{12}ECO^{c}_{i} + \gamma_{13}NLE^{c}_{i} + \gamma_{14}DEP^{c}_{i} + \gamma_{15}REL^{c}_{i} + \gamma_{16}SEX^{c}_{i} + \gamma_{17}GAGE^{c}_{i} + u_{1i}$$

$$\alpha_{3i} = \gamma_{20} + \gamma_{21}RSA^{c}_{i} + \gamma_{22}ECO^{c}_{i} + \gamma_{23}NLE^{c}_{i} + \gamma_{24}DEP^{c}_{i} + \gamma_{25}REL^{c}_{i} + \gamma_{26}SEX^{c}_{i} + \gamma_{27}COG^{c}_{i} + u_{2i}$$

$$\varphi_{1i} = \gamma_{30} + \gamma_{31}RSA^{c}_{i} + u_{3i}$$

$$\varphi_{2i} = \gamma_{40} + \gamma_{41}RSA^{c}_{i} + u_{4i}$$

$$\varphi_{3i} = \gamma_{50} + \gamma_{51}RSA^{c}_{i} + \gamma_{52}COG^{c}_{i} + u_{5i}$$

$$\varphi_{4i} = \gamma_{60} + \gamma_{61}RSA^{c}_{i} + u_{6i}$$

$$\varphi_{5i} = \gamma_{70} + \gamma_{71}RSA^{c}_{i} + \gamma_{72}APGAR^{c}_{i} + u_{7i}$$

$$\varphi_{6i} = \gamma_{80} + \gamma_{81}RSA^{c}_{i} + \gamma_{82}COG^{c}_{i} + u_{8i}$$

$$\varphi_{7i} = \gamma_{90} + \gamma_{91}RSA^{c}_{i} + \gamma_{92}COG^{c}_{i} + u_{9i}$$

$$\varphi_{8i} = \gamma_{10,0} + \gamma_{10,1}RSA^{c}_{i} + \gamma_{10,2}COG^{c}_{i} + u_{10i}$$

$$\varphi_{9i} = \gamma_{11,0} + \gamma_{11,1}RSA^{c}_{i} + \gamma_{11,2}COG^{c}_{i} + \gamma_{11,3}SEX^{c}_{i} + u_{11i}$$

$$\sigma^{2}_{1i} = \exp(\omega_{00} + \gamma_{12,1}RSA^{c}_{i} + \gamma_{12,2}CH^{c}_{i} + \gamma_{12,3}ECO^{c}_{i} + u_{12i})$$

$$\sigma^{2}_{2i} = \exp(\omega_{10} + \gamma_{13,1}RSA^{c}_{i} + \gamma_{13,2}DEP^{c}_{i} + u_{13i})$$

$$\sigma^{2}_{3i} = \exp(\omega_{20} + \gamma_{14,1}RSA^{c}_{i} + \gamma_{14,2}DEP^{c}_{i} + \gamma_{14,3}COG^{c}_{i} + u_{14i})$$

Covariances

$$\mathbf{u}_i \sim \mathrm{MVN}\left(\mathbf{0}_{15}, \begin{bmatrix}
\tau_{00} \\
\tau_{10} & \tau_{11} \\
\tau_{20} & \tau_{21} & \tau_{22} \\
 & & & \tau_{33} \\
 & & & & \tau_{44} \\
 & & & & & \tau_{55} \\
 & & & & & & \tau_{66} \\
 & & & & & & & \tau_{77} \\
 & & & & & & & & \tau_{88} \\
 & & & & & & & & & \tau_{99} \\
 & & & & & & & & & & \tau_{10.10} \\
 & & & & & & & & & & & \tau_{11,11} \\
 & & & & & & & & & & & & \tau_{12,12} \\
 & & & & & & & & & & & & & \tau_{13,13} \\
 & & & & & & & & & & & & & & \tau_{14,14}
\end{bmatrix}\right)$$

Note. MP = Maternal positive affect engagement. IP = Infant positive affect engagement. IN = Infant negative affect engagement. RSA = Infant respiratory sinus arrhythmia. ECO = Prenatal economic hardship. NLE = Prenatal negative life events. DEP = Prenatal depressive symptoms. REL = Single-parent status (0 = Partnered, 1 = Not partnered). SEX = Infant sex (0 = boy, 1 = girl). CH = Maternal number of children. COG = Maternal country of origin (0 = Mexico, 1 = United States). GAGE = Gestational age. APGAR = APGAR at 1-minute.

Table 6b. Model equations for teaching task

Within-dyad equations

$\mathrm{MP}_{ti} = \alpha_{1i} + \varphi_{1i}\mathrm{MP}^{c}_{(t-1)i} + \varphi_{4i}\mathrm{IP}^{c}_{(t-1)i} + \varphi_{7i}\mathrm{IN}^{c}_{(t-1)i} + e_{1ti}$

$\mathrm{IP}_{ti} = \alpha_{2i} + \varphi_{2}\mathrm{MP}^{c}_{(t-1)} + \varphi_{5i}\mathrm{IP}^{c}_{(t-1)i} + \varphi_{8i}\mathrm{IN}^{c}_{(t-1)i} + e_{2ti}$

$\mathrm{IN}_{ti} = \alpha_{3i} + \varphi_{3}\mathrm{MP}^{c}_{(t-1)} + \varphi_{6i}\mathrm{IP}^{c}_{(t-1)i} + \varphi_{9i}\mathrm{IN}^{c}_{(t-1)i} + e_{3ti}$

Between-dyad equations

$\alpha_{1i} = \gamma_{00} + \gamma_{01}\mathrm{RSA}^{c}_{i} + \gamma_{02}\mathrm{ECO}^{c}_{i} + \gamma_{03}\mathrm{NLE}^{c}_{i} + \gamma_{04}\mathrm{DEP}^{c}_{i} + \gamma_{05}\mathrm{REL}^{c}_{i} + \gamma_{06}\mathrm{SEX}^{c}_{i} + \gamma_{07}\mathrm{CH}^{c}_{i} + u_{0i}$

$\alpha_{2i} = \gamma_{10} + \gamma_{11}\mathrm{RSA}^{c}_{i} + \gamma_{12}\mathrm{ECO}^{c}_{i} + \gamma_{13}\mathrm{NLE}^{c}_{i} + \gamma_{14}\mathrm{DEP}^{c}_{i} + \gamma_{15}\mathrm{REL}^{c}_{i} + \gamma_{16}\mathrm{SEX}^{c}_{i} + u_{1i}$

$\alpha_{3i} = \gamma_{20} + \gamma_{21}\mathrm{RSA}^{c}_{i} + \gamma_{22}\mathrm{ECO}^{c}_{i} + \gamma_{23}\mathrm{NLE}^{c}_{i} + \gamma_{24}\mathrm{DEP}^{c}_{i} + \gamma_{25}\mathrm{REL}^{c}_{i} + \gamma_{26}\mathrm{SEX}^{c}_{i} + u_{2i}$

$\varphi_{1i} = \gamma_{30} + \gamma_{31}\mathrm{RSA}^{c}_{i} + u_{3i}$

$\varphi_{2i} = \gamma_{40} + \gamma_{41}\mathrm{RSA}^{c}_{i} + \gamma_{42}\mathrm{DEP}^{c}_{i} + u_{4i}$

$\varphi_{3i} = \gamma_{50} + \gamma_{51}\mathrm{RSA}^{c}_{i} + \gamma_{52}\mathrm{DEP}^{c}_{i} + u_{5i}$

$\varphi_{4i} = \gamma_{60} + \gamma_{61}\mathrm{RSA}^{c}_{i} + u_{6i}$

$\varphi_{5i} = \gamma_{70} + \gamma_{71}\mathrm{RSA}^{c}_{i} + \gamma_{73}\mathrm{NLE}^{c}_{i} + u_{7i}$

$\varphi_{6i} = \gamma_{80} + \gamma_{81}\mathrm{RSA}^{c}_{i} + u_{8i}$

$\varphi_{7i} = \gamma_{90} + \gamma_{91}\mathrm{RSA}^{c}_{i} + u_{9i}$

$\varphi_{8i} = \gamma_{10,0} + \gamma_{10,1}\mathrm{RSA}^{c}_{i} + \gamma_{10,1}\mathrm{ECO}^{c}_{i} + u_{10i}$

$\varphi_{9i} = \gamma_{11,0} + \gamma_{11,1}\mathrm{RSA}^{c}_{i} + u_{11i}$

$\sigma^{2}_{1i} = \exp(\omega_{00} + \gamma_{12,1}\mathrm{RSA}^{c}_{i} + u_{12i})$

$\sigma^{2}_{2i} = \exp(\omega_{10} + \gamma_{13,1}\mathrm{RSA}^{c}_{i} + u_{13i})$

$\sigma^{2}_{3i} = \exp(\omega_{20} + \gamma_{14,1}\mathrm{RSA}^{c}_{i} + \gamma_{14,2}\mathrm{SEX}^{c}_{i} + u_{14i})$

Covariances

$$\mathbf{u}_i \sim \text{MVN}\,\left(\mathbf{0}_{15},\ \begin{bmatrix}
\tau_{00} \\
\tau_{10} & \tau_{11} \\
\tau_{20} & \tau_{21} & \tau_{22} \\
 & & & \tau_{33} \\
 & & & & \tau_{44} \\
 & & & & & \tau_{55} \\
 & & & & & & \tau_{66} \\
 & & & & & & & \tau_{77} \\
 & & & & & & & & \tau_{88} \\
 & & & & & & & & & \tau_{99} \\
 & & & & & & & & & & \tau_{10,10} \\
 & & & & & & & & & & & \tau_{11,11} \\
 & & & & & & & & & & & & \tau_{12,12} \\
 & & & & & & & & & & & & & \tau_{13,13} \\
 & & & & & & & & & & & & & & \tau_{14,14}
\end{bmatrix}\right)$$

Note. MP = Maternal positive affect engagement. IP = Infant positive affect engagement. IN = Infant negative affect engagement. RSA = Infant respiratory sinus arrhythmia. ECO = Prenatal economic hardship. NLE = Prenatal negative life events. DEP = Prenatal depressive symptoms. REL = Single-parent status (0 = Partnered, 1 = Not partnered). SEX = Infant sex (0 = boy, 1 = girl). CH = Maternal number of children.

Table 7a
Model results for free play, adjusting for covariates and prenatal risk

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.797**	**[2.667, 2.931]**	**2.797**	**[2.667, 2.931]**
Int. (IP)	γ_{10}	**1.403**	**[1.256, 1.550]**	**1.403**	**[1.256, 1.550]**
Int. (IN)	γ_{20}	**0.244**	**[0.171, 0.327]**	**0.244**	**[0.171, 0.327]**
Ln(Var(MP))	ω_{00}	**-1.701**	**[-1.841, 1.556]**	**0.709**	**[0.578, 1.097]**
Ln(Var(IP))	ω_{10}	**-1.834**	**[-1.998, -1.667]**	**0.250**	**[0.232, 0.267]**
Ln(Var(IN))	ω_{20}	**-3.029**	**[-3.315, -2.747]**	**0.207**	**[0.184, 0.364]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.816**	**[0.805, 0.827]**	**0.816**	**[0.810, 0.822]**
Mom PE	Infant PE	γ_{40}	**0.021**	**[0.014, 0.029]**	**0.022**	**[0.017, 0.028]**
Mom PE	Infant NE	γ_{50}	**-0.007**	**[-0.012, -0.001]**	**-0.006**	**[-0.010, -0.003]**
Infant PE	Mom PE	γ_{60}	**0.022**	**[0.015, 0.030]**	**0.023**	**[0.018, 0.029]**
Infant PE	Infant PE	γ_{70}	**0.812**	**[0.796, 0.827]**	**0.812**	**[0.804, 0.820]**
Infant PE	Infant NE	γ_{80}	-0.006	[-0.012, 0.000]	**-0.006**	**[-0.010, -0.002]**
Infant NE	Mom PE	γ_{90}	-0.004	[-0.014, 0.006]	-0.003	[-0.011, 0.006]
Infant NE	Infant PE	$\gamma_{10,0}$	0.003	[-0.018, 0.024]	0.002	[-0.010, 0.015]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.798**	**[0.759, 0.836]**	**0.766**	**[0.756, 0.777]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.284**
Var. (u_{1i})	τ_{11}	**0.346**
Var. (u_{2i})	τ_{22}	**0.072**
Cov. (u_{0i}, u_{1i})	τ_{01}	**0.083**
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.007
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.128**
Var. (u_{3i})	τ_{33}	**0.005**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.009**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.010**
Var. (u_{11i})	$\tau_{11,11}$	**0.028**
Var. (u_{12i})	$\tau_{12,12}$	**0.977**
Var. (u_{13i})	$\tau_{13, 13}$	**1.190**
Var. (u_{14i})	$\tau_{14. 14}$	**3.333**

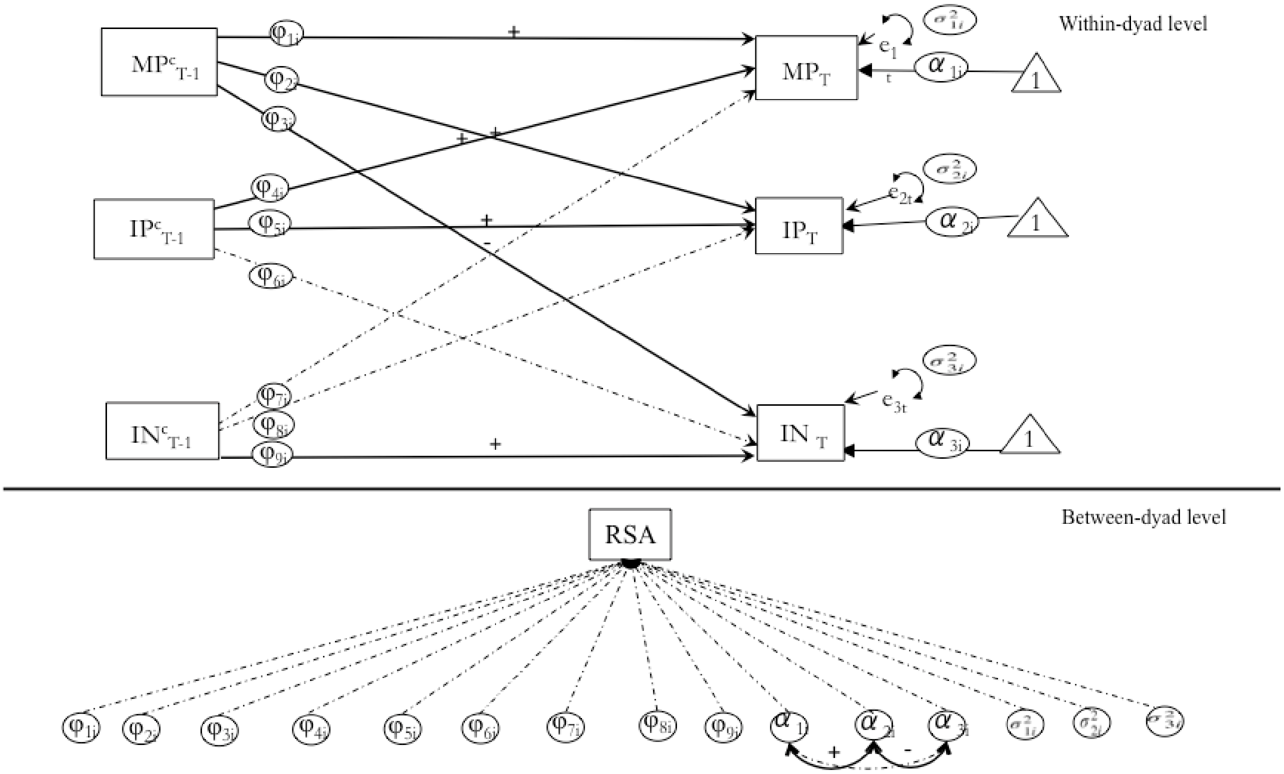
Note. Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Table 7b
Between-Dyad covariate effects, adjusting for covariates and prenatal risk

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.017	[-0.081, 0.116]	0.017	[-0.081, 0.116]
α_{2i} on RSA	γ_{11}	0.054	[-0.057, 0.165]	0.054	[-0.057, 0.165]
α_{3i} on RSA	γ_{21}	-0.002	[-0.057, 0.050]	-0.002	[-0.057, 0.050]
φ_{1i} on RSA	γ_{31}	-0.010	[-0.024, 0.004]	-0.142	[-0.320, 0.051]
φ_{2i} on RSA	γ_{41}	0.005	[-0.004, 0.014]	0.143	[-0.102, 0.372]
φ_{3i} on RSA	γ_{51}	-0.007	[-0.013, 0.000]	-0.244	[-0.465, 0.005]
φ_{4i} on RSA	γ_{61}	-0.003	[-0.011, 0.005]	-0.093	[-0.347, 0.178]
φ_{5i} on RSA	γ_{71}	-0.014	[-0.033, 0.005]	-0.145	[-0.327, 0.048]
φ_{6i} on RSA	γ_{81}	-0.005	[-0.012, 0.001]	-0.185	[-0.403, 0.052]
φ_{7i} on RSA	γ_{91}	0.004	[-0.008, 0.016]	0.135	[-0.239, 0.484]
φ_{8i} on RSA	$\gamma_{10,1}$	0.001	[-0.025, 0.027]	0.012	[-0.241, 0.270]
φ_{9i} on RSA	$\gamma_{11,1}$	-0.027	[-0.058, 0.005]	-0.153	[-0.325, 0.026]
$Ln(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	-0.071	[-0.272, 0.132]	-0.069	[-0.260, 0.128]
$Ln(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.101	[-0.089, 0.290]	0.088	[-0.078, 0.248]
$Ln(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	0.001	[-0.314, 0.321]	0.000	[-0.163, 0.163]

Note. RSA = Infant respiratory sinus arrhythmia. Covariate effects of infant gestational age, APGAR, sex; maternal country of origin; maternal number of children; and prenatal economic hardship, maternal negative life events, depressive symptoms, and single-parent status not shown. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Figure 6. Results for free play



Note. MP = mom positive affect engagement; IP = infant positive affect engagement; IN = infant negative affect engagement; superscript c = centered; subscript t-1 = time point 1 second prior; subscript t = time point. Following suggestions for multilevel path diagrams (Curran & Bauer, 2007), circles over paths indicate random effects and triangles labeled with the number "1" indicate intercepts. Bold lines indicate non-null effects and dashed lines indicate null effects. Covariate effects of infant gestational age, APGAR, sex; maternal country of origin; maternal number of children; and prenatal economic hardship, maternal negative life events, depressive symptoms, and single-parent status not shown.

Table 8a
Model results for teaching task, adjusting for covariates and prenatal risk

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.365**	**[2.259, 2.469]**	**5.141**	**[4.479, 5.900]**
Int. (IP)	γ_{10}	**1.261**	**[1.123, 1.391]**	**2.125**	**[1.773, 2.439]**
Int. (IN)	γ_{20}	**1.041**	**[0.803, 1.301]**	**0.998**	**[0.744, 1.258]**
Ln(Var(MP))	ω_{00}	**-2.009**	**[-2.206, -1.797]**	**0.362**	**[0.340, 0.376]**
Ln(Var(IP))	ω_{10}	**-2.350**	**[-2.534, -2.174]**	**0.281**	**[0.265, 0.297]**
Ln(Var(IN))	ω_{20}	**-1.448**	**[-1.880, -1.007]**	**0.305**	**[0.288, 0.328]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.770**	**[0.749, 0.791]**	**0.770**	**[0.759, 0.789]**
Mom PE	Infant PE	γ_{40}	0.003	[-0.003, 0.009]	0.006	[-0.001, 0.014]
Mom PE	Infant NE	γ_{50}	-0.003	[-0.003, 0.009]	-0.005	[-0.014, 0.004]
Infant PE	Mom PE	γ_{60}	0.010	[0.000, 0.019]	**0.012**	**[0.002, 0.025]**
Infant PE	Infant PE	γ_{70}	**0.820**	**[0.802, 0.839]**	**0.818**	**[0.805, 0.830]**
Infant PE	Infant NE	γ_{80}	0.008	[-0.001, 0.017]	0.006	[-0.002, 0.013]
Infant NE	Mom PE	γ_{90}	0.004	[-0.002, 0.010]	0.006	[-0.002, 0.016]
Infant NE	Infant PE	$\gamma_{10,0}$	**0.012**	**[0.002, 0.022]**	0.004	[-0.006, 0.014]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.820**	**[0.798, 0.841]**	**0.811**	**[0.796, 0.824]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.171**
Var. (u_{1i})	τ_{11}	**0.317**
Var. (u_{2i})	τ_{22}	**0.979**
Cov. (u_{0i}, u_{1i})	τ_{01}	0.028
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.049
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.544**
Var. (u_{3i})	τ_{33}	**0.019**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.010**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.003**
Var. (u_{11i})	$\tau_{11,11}$	**0.018**
Var. (u_{12i})	$\tau_{12,12}$	**2.020**
Var. (u_{13i})	$\tau_{13,13}$	**1.662**
Var. (u_{14i})	$\tau_{14.14}$	**4.438**

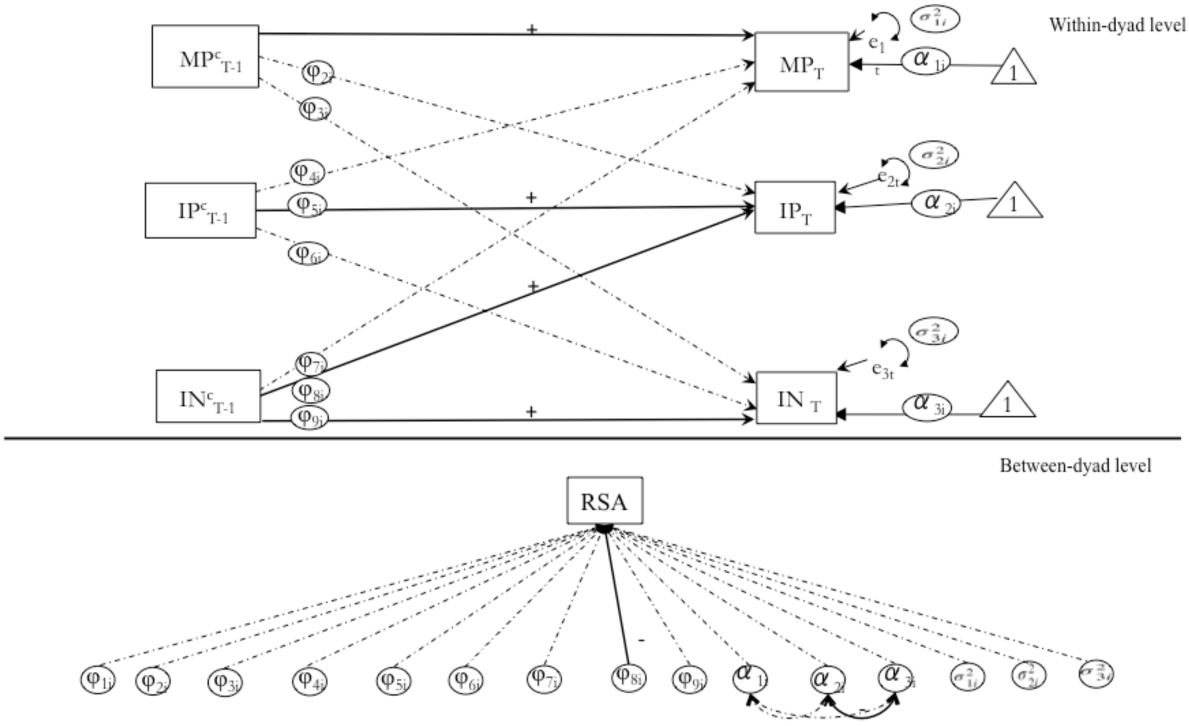
Note. Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Table 8b
Between-Dyad covariate effects, adjusting for covariates and prenatal risk

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.008	[-0.064, 0.088]	0.016	[-0.118, 0.160]
α_{2i} on RSA	γ_{11}	-0.053	[-0.154, 0.055]	-0.078	[-0.222, 0.075]
α_{3i} on RSA	γ_{21}	0.119	[-0.074, 0.298]	0.096	[-0.060, 0.247]
φ_{1i} on RSA	γ_{31}	-0.013	[-0.040, 0.013]	-0.081	[-0.240, 0.079]
φ_{2i} on RSA	γ_{41}	0.005	[-0.001, 0.012]	0.149	[-0.039, 0.344]
φ_{3i} on RSA	γ_{51}	-0.007	[-0.019, 0.004]	-0.151	[-0.358, 0.085]
φ_{4i} on RSA	γ_{61}	0.005	[-0.007, 0.016]	0.109	[-0.163, 0.353]
φ_{5i} on RSA	γ_{71}	-0.013	[-0.033, 0.008]	-0.110	[-0.274, 0.066]
φ_{6i} on RSA	γ_{81}	0.003	[-0.009, 0.014]	0.095	[-0.248, 0.386]
φ_{7i} on RSA	γ_{91}	0.002	[-0.007, 0.009]	0.047	[-0.208, 0.292]
φ_{8i} on RSA	$\gamma_{10,1}$	**-0.012**	**[-0.023, 0.000]**	**-0.188**	**[-0.353, -0.002]**
φ_{9i} on RSA	$\gamma_{11,1}$	0.016	[-0.010, 0.044]	0.103	[-0.062, 0.268]
$Ln(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	0.055	[-0.212, 0.293]	0.032	[-0.124, 0.176]
$Ln(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.034	[-0.176, 0.259]	0.022	[-0.117, 0.166]
$Ln(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	0.022	[-0.331, 0.382]	0.009	[-0.130, 0.155]

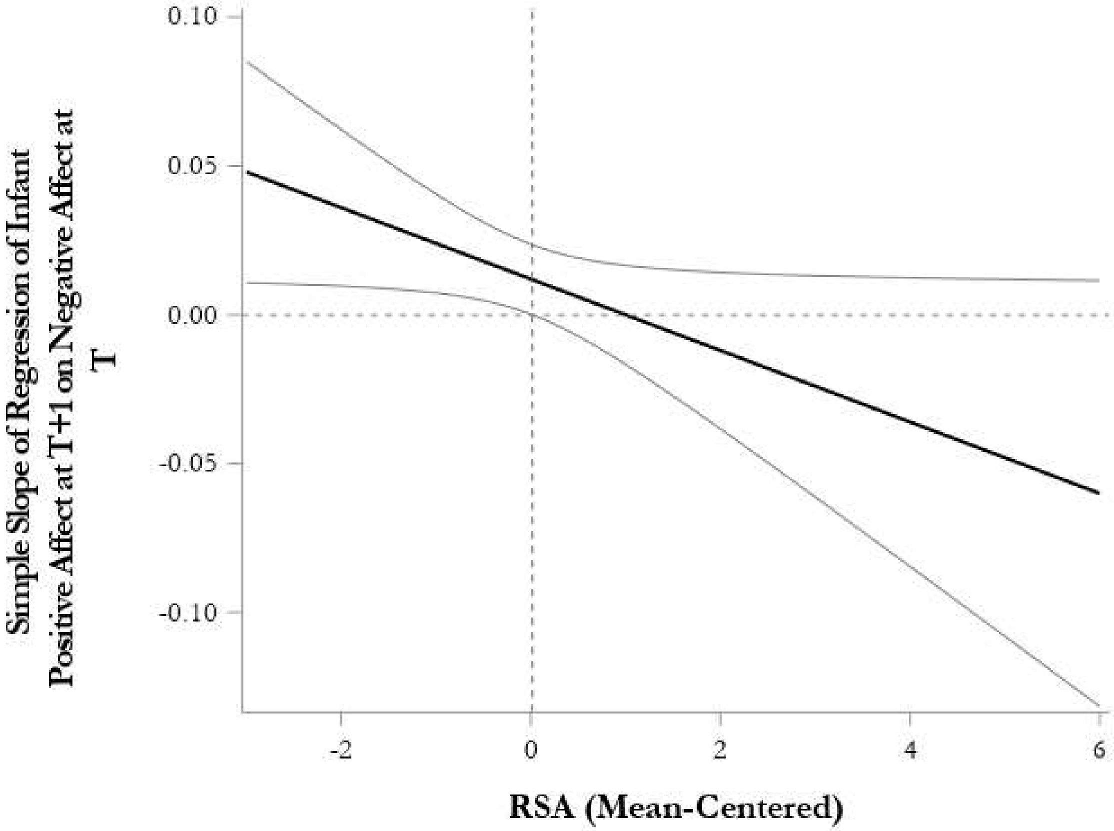
Note. RSA = Infant respiratory sinus arrhythmia. Covariate effects of infant sex; maternal maternal number of children; prenatal household economic hardship, number of negative life events, depressive symptoms, and single-parent status not shown. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Figure 7. Results for teaching task



Note. MP = mom positive affect engagement; IP = infant positive affect engagement; IN = infant negative affect engagement; superscript c = centered; subscript t-1 = time point 1 second prior; subscript t = time point. Following suggestions for multilevel path diagrams (Curran & Bauer, 2007), circles over paths indicate random effects and triangles labeled with the number "1" indicate intercepts. Bold lines indicate non-null effects and dashed lines indicate null effects. Covariate effects of infant sex; maternal maternal number of children; prenatal household economic hardship, number of negative life events, depressive symptoms, and single-parent status not shown.

Figure 8. Moderation of within-infant emotion regulation by infant RSA



Note. Infant RSA (respiratory sinus arrhythmia) was grand mean centered. Results show the regions of significance on infant RSA for the prediction of infant positive affect engagement by prior infant negative affect engagement.

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APPENDIX A

APPENDIX TABLES

APPENDIX TABLES

Appendix Table 1.
Model results for free play, with all available data

Intercepts

Effect	Notation	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.791**	**[2.708, 2.867]**
Int. (IP)	γ_{10}	**1.375**	**[1.280, 1.472]**
Int. (IN)	γ_{20}	**0.268**	**[0.215, 0.322]**
Ln(Var(MP))	ω_{00}	**-1.828**	**[-1.932, -1.725]**
Ln(Var(IP))	ω_{10}	**-1.846**	**[-2.005, -1.670]**
Ln(Var(IN))	ω_{20}	**-2.935**	**[-3.205, -2.633]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.822**	**[0.810, 0.833]**
Mom PE	Infant PE	γ_{40}	**0.020**	**[0.013, 0.027]**
Mom PE	Infant NE	γ_{50}	-0.004	[-0.008, 0.001]
Infant PE	Mom PE	γ_{60}	**0.023**	**[0.016, 0.029]**
Infant PE	Infant PE	γ_{70}	**0.815**	**[0.801, 0.832]**
Infant PE	Infant NE	γ_{80}	-0.005	[-0.010, .000]
Infant NE	Mom PE	γ_{90}	-0.004	[-0.011, .005]
Infant NE	Infant PE	$\gamma_{10,0}$	-0.013	[-0.027, .001]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.795**	**[0.771, 0.819]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.309**
Var. (u_{1i})	τ_{11}	**0.358**
Var. (u_{2i})	τ_{22}	**0.081**
Cov. (u_{0i}, u_{1i})	τ_{01}	**0.061**

Cov. (u_{0i}, u_{2i})	τ_{12}	0.001
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.138**
Var. (u_{3i})	τ_{33}	**0.005**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.009**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.005**
Var. (u_{11i})	$\tau_{11,11}$	**0.025**
Var. (u_{12i})	$\tau_{12,12}$	**0.679**
Var. (u_{13i})	$\tau_{13,13}$	**1.306**
Var. (u_{14i})	$\tau_{14,14}$	**3.679**

Note: Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Unstandardized effects are reported. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 1.
Between-Dyad Covariate Effects

Effect	Notation	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.022	[-0.066, 0.115]
α_{2i} on RSA	γ_{11}	0.020	[-0.096, 0.129]
α_{3i} on RSA	γ_{21}	0.015	[-0.036, 0.070]
φ_{1i} on RSA	γ_{31}	-0.009	[-0.022, 0.004]
φ_{2i} on RSA	γ_{41}	0.000	[-0.008, 0.009]
φ_{3i} on RSA	γ_{51}	-0.004	[-0.010, 0.002]
φ_{4i} on RSA	γ_{61}	0.000	[-0.008, 0.008]
φ_{5i} on RSA	γ_{71}	-0.014	[-0.031, 0.006]
φ_{6i} on RSA	γ_{81}	-0.005	[-0.011, 0.001]
φ_{7i} on RSA	γ_{91}	0.007	[-0.003, 0.018]
φ_{8i} on RSA	$\gamma_{10,1}$	-0.012	[-0.030, 0.005]
φ_{9i} on RSA	$\gamma_{11,1}$	-0.006	[-0.032, 0.023]
$\text{Ln}(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	-0.071	[-0.230, 0.065]
$\text{Ln}(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.085	[-0.108, 0.286]
$\text{Ln}(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	-0.037	[-0.360, 0.289]

Note: RSA = Infant respiratory sinus arrhythmia. Unstandardized effects are reported. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Appendix Table 2

Model results for free play, excluding potentially nonstationary series

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.792**	**[2.707, 2.877]**	**2.792**	**[2.707, 2.877]**
Int. (IP)	γ_{10}	**1.406**	**[1.313, 1.499]**	**1.406**	**[1.313, 1.499]**
Int. (IN)	γ_{20}	**0.249**	**[0.201, 0.303]**	**0.249**	**[0.201, 0.303]**
Ln(Var(MP))	ω_{00}	**-1.691**	**[-1.837, -1.544]**	**0.881**	**[0.591, 1.153]**
Ln(Var(IP))	ω_{10}	**-1.845**	**[-2.014, -1.678]**	**0.244**	**[0.235, 0.254]**
Ln(Var(IN))	ω_{20}	**-2.993**	**[-3.267, -2.716]**	**0.191**	**[0.170, 0.291]**

Regression Path Intercepts

Predictor at Time t -1	Outcome at Time t	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.815**	**[0.804, 0.827]**	**0.816**	**[0.810, 0.821]**
Mom PE	Infant PE	γ_{40}	**0.022**	**[0.015, 0.029]**	**0.022**	**[0.017, 0.027]**
Mom PE	Infant Negative Affect	γ_{50}	**-0.007**	**[-0.012, -0.002]**	**-0.007**	**[-0.010, -0.003]**
Infant PE	Mom PE	γ_{60}	**0.023**	**[0.016, 0.030]**	**0.023**	**[0.018, 0.028]**
Infant PE	Infant PE	γ_{70}	**0.812**	**[0.796, 0.827]**	**0.812**	**[0.804, 0.819]**
Infant PE	Infant NE	γ_{80}	-0.005	[-0.011, .001]	**-0.005**	**[-0.009, -0.001]**
Infant NE	Mom PE	γ_{90}	-0.003	[-0.012, 0.006]	-0.004	[-0.012, 0.003]
Infant NE	Infant PE	$\gamma_{10,0}$	0.001	[-0.021, 0.023]	0.000	[-0.014, 0.015]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.771**	**[0.744, 0.797]**	**0.767**	**[0.756, 0.776]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.310**
Var. (u_{1i})	τ_{11}	**0.353**
Var. (u_{2i})	τ_{22}	**0.076**
Cov. (u_{0i}, u_{1i})	τ_{01}	**0.076**
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.004
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.131**
Var. (u_{3i})	τ_{33}	**0.005**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.009**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.011**
Var. (u_{11i})	$\tau_{11,11}$	**0.029**
Var. (u_{12i})	$\tau_{12,12}$	**1.068**
Var. (u_{13i})	$\tau_{13,13}$	**1.301**
Var. (u_{14i})	$\tau_{14.14}$	**3.605**

Note: Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Unstandardized effects are reported. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 2
Between-Dyad Covariate Effects

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.033	[-0.068, 0.133]	0.033	[-0.068, 0.133]
α_{2i} on RSA	γ_{11}	0.039	[-0.073, 0.150]	0.039	[-0.073, 0.150]
α_{3i} on RSA	γ_{21}	0.008	[-0.046, 0.061]	0.008	[-0.046, 0.061]
φ_{1i} on RSA	γ_{31}	-0.010	[-0.024, 0.004]	-0.139	[-0.320, 0.052]
φ_{2i} on RSA	γ_{41}	0.002	[-0.007, 0.011]	0.059	[-0.200, 0.305]
φ_{3i} on RSA	γ_{51}	-0.006	[-0.012, .001]	-0.203	[-0.435, 0.053]
φ_{4i} on RSA	γ_{61}	-0.002	[-0.030, 0.025]	-0.068	[-0.331, 0.198]
φ_{5i} on RSA	γ_{71}	-0.014	[-0.033, 0.005]	-0.146	[-0.332, 0.049]
φ_{6i} on RSA	γ_{81}	-0.005	[-0.012, 0.001]	-0.186	[-0.408, 0.053]
φ_{7i} on RSA	γ_{91}	0.005	[-0.007, 0.017]	0.171	[-0.215, 0.517]
φ_{8i} on RSA	$\gamma_{10,1}$	-0.002	[-0.011, 0.006]	-0.019	[-0.274, 0.236]
φ_{9i} on RSA	$\gamma_{11,1}$	-0.021	[-0.054, 0.011]	-0.124	[-0.304, 0.066]
$\mathrm{Ln}(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	-0.020	[-0.030, 0.025]	-0.019	[-0.220, 0.182]
$\mathrm{Ln}(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.096	[-0.103, 0.293]	0.084	[-0.089, 0.251]
$\mathrm{Ln}(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	-0.034	[-0.370, 0.299]	-0.018	[-0.191, 0.155]

Note: RSA = Infant respiratory sinus arrhythmia. Unstandardized effects are reported. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Appendix Table 3
Model results for teaching task, with all available data

Intercepts

Effect	Notation	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.425**	**[2.363, 2.490]**
Int. (IP)	γ_{10}	**1.331**	**[1.245, 1.418]**
Int. (IN)	γ_{20}	**0.999**	**[0.852, 1.143]**
Ln(Var(MP))	ω_{00}	**-2.152**	**[-2.312, -1.998]**
Ln(Var(IP))	ω_{10}	**-2.435**	**[-2.596, -2.286]**
Ln(Var(IN))	ω_{20}	**-1.930**	**[-2.221, -1.615]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.793**	**[0.777, 0.810]**
Mom PE	Infant PE	γ_{40}	0.002	[-0.003, 0.007]
Mom PE	Infant NE	γ_{50}	-0.002	[-0.009, 0.005]
Infant PE	Mom PE	γ_{60}	**0.010**	**[0.003, 0.019]**
Infant PE	Infant PE	γ_{70}	**0.832**	**[0.817, 0.850]**
Infant PE	Infant NE	γ_{80}	0.004	[-0.006, 0.013]
Infant NE	Mom PE	γ_{90}	0.004	[-0.002, 0.010]
Infant NE	Infant PE	$\gamma_{10,0}$	0.005	[-0.004, 0.015]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.833**	**[0.812, 0.856]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.190**
Var. (u_{1i})	τ_{11}	**0.331**
Var. (u_{2i})	τ_{22}	**0.997**
Cov. (u_{0i}, u_{1i})	τ_{01}	0.012
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.031
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.569**

Var. (u_{3i})	τ_{33}	**0.011**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.001**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.003**
Var. (u_{11i})	$\tau_{11,11}$	**0.018**
Var. (u_{12i})	$\tau_{12,12}$	**1.443**
Var. (u_{13i})	$\tau_{13,13}$	**1.521**
Var. (u_{14i})	$\tau_{14,14}$	**4.574**

Note: Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Unstandardized effects are reported. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 3
Between-Dyad Covariate Effects

Effect	Notation	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.022	[-0.067, 0.103]
α_{2i} on RSA	γ_{11}	-0.063	[-0.176, 0.035]
α_{3i} on RSA	γ_{21}	0.133	[-0.021, 0.328]
φ_{1i} on RSA	γ_{31}	-0.008	[-0.026, 0.012]
φ_{2i} on RSA	γ_{41}	0.003	[-0.003, 0.009]
φ_{3i} on RSA	γ_{51}	-0.001	[-0.007, 0.007]
φ_{4i} on RSA	γ_{61}	0.001	[-0.010, 0.013]
φ_{5i} on RSA	γ_{71}	-0.005	[-0.024, 0.015]
φ_{6i} on RSA	γ_{81}	0.004	[-0.008, 0.013]
φ_{7i} on RSA	γ_{91}	0.000	[-0.008, 0.007]
φ_{8i} on RSA	$\gamma_{10,1}$	-0.008	[-0.026, 0.012]
φ_{9i} on RSA	$\gamma_{11,1}$	0.019	[-0.012, 0.042]
$\mathrm{Ln}(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	-0.013	[-0.231, 0.196]
$\mathrm{Ln}(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.001	[-0.010, 0.013]
$\mathrm{Ln}(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	0.140	[-0.228, 0.482]

Note: RSA = Infant respiratory sinus arrhythmia. Unstandardized effects are reported. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Appendix Table 4
Model results for teaching task, excluding possibly nonstationary series

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.413**	**[2.347, 2.479]**	**5.600**	**[4.961, 6.291]**
Int. (IP)	γ_{10}	**1.324**	**[1.239, 1.409]**	**2.287**	**[1.999, 2.575]**
Int. (IN)	γ_{20}	**0.980**	**[0.838, 1.128]**	**0.976**	**[0.797, 1.145]**
Ln(Var(MP))	ω_{00}	**-1.977**	**[-2.180, -1.771]**	**0.366**	**[0.354, 0.376]**
Ln(Var(IP))	ω_{10}	**-2.347**	**[-2.536, -2.161]**	**0.280**	**[0.264, 0.295]**
Ln(Var(IN))	ω_{20}	**-1.945**	**[-2.255, -1.632]**	**0.295**	**[0.281, 0.310]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.769**	**[0.747, 0.791]**	**0.767**	**[0.760, 0.776]**
Mom PE	Infant PE	γ_{40}	0.002	[-0.004, 0.008]	-0.001	[-0.008, 0.006]
Mom PE	Infant NE	γ_{50}	0.000	[-0.010, 0.010]	0.002	[-0.002, 0.011]
Infant PE	Mom PE	γ_{60}	**0.011**	**[0.001, 0.021]**	**0.013**	**[0.003, 0.022]**
Infant PE	Infant PE	γ_{70}	**0.817**	**[0.799, 0.834]**	**0.815**	**[0.805, 0.826]**
Infant PE	Infant NE	γ_{80}	0.008	[-0.001, 0.017]	0.005	[-0.002, 0.011]
Infant NE	Mom PE	γ_{90}	0.005	[-0.002, 0.011]	0.006	[-0.003, 0.015]
Infant NE	Infant PE	$\gamma_{10,0}$	**0.012**	**[0.001, 0.023]**	0.000	[-0.010, 0.010]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.822**	**[0.801, 0.842]**	**0.816**	**[0.806, 0.825]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.185**
Var. (u_{1i})	τ_{11}	**0.332**
Var. (u_{2i})	τ_{22}	**0.990**
Cov. (u_{0i}, u_{1i})	τ_{01}	0.018
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.035
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.565**
Var. (u_{3i})	τ_{33}	**0.020**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.009**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.003**
Var. (u_{11i})	$\tau_{11,11}$	**0.018**
Var. (u_{12i})	$\tau_{12,12}$	**2.234**
Var. (u_{13i})	$\tau_{13,13}$	**1.660**
Var. (u_{14i})	$\tau_{14.14}$	**4.709**

Note: Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Unstandardized effects are reported. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 4
Between-Dyad Covariate Effects

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.021	[-0.058, 0.098]	0.042	[-0.114, 0.198]
α_{2i} on RSA	γ_{11}	-0.063	[-0.165, 0.046]	-0.093	[-0.242, 0.070]
α_{3i} on RSA	γ_{21}	0.146	[-0.037, 0.319]	0.126	[-0.031, 0.276]
φ_{1i} on RSA	γ_{31}	-0.016	[-0.043, 0.009]	-0.097	[-0.258, 0.056]
φ_{2i} on RSA	γ_{41}	0.004	[-0.003, 0.011]	0.114	[-0.099, 0.327]
φ_{3i} on RSA	γ_{51}	0.000	[-0.010, 0.011]	0.011	[-0.224, 0.248]
φ_{4i} on RSA	γ_{61}	0.000	[-0.012, 0.011]	-0.002	[-0.276, 0.257]
φ_{5i} on RSA	γ_{71}	-0.014	[-0.036, 0.005]	-0.124	[-0.300, 0.046]
φ_{6i} on RSA	γ_{81}	0.005	[-0.007, 0.017]	0.144	[-0.212, 0.458]
φ_{7i} on RSA	γ_{91}	0.000	[-0.010, 0.011]	-0.010	[-0.238, 0.228]
φ_{8i} on RSA	$\gamma_{10,1}$	**-0.014**	**[-0.026, -0.001]**	**-0.213**	**[-0.390, -0.017]**
φ_{9i} on RSA	$\gamma_{11,1}$	0.017	[-0.010, 0.042]	0.106	[-0.061, 0.261]
Ln(σ_{1i}^2) on RSA	$\gamma_{12,1}$	0.080	[-0.183, 0.354]	0.046	[-0.100, 0.201]
Ln(σ_{2i}^2) on RSA	$\gamma_{13,1}$	-0.031	[-0.262, 0.182]	-0.021	[-0.172, 0.120]
Ln(σ_{3i}^2) on RSA	$\gamma_{14,1}$	0.076	[-0.300, 0.446]	0.030	[-0.119, 0.176]

Note: RSA = Infant respiratory sinus arrhythmia. Unstandardized effects are reported. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Free Play Model 2

Of the potential covariates (child birth outcomes, child gestational age, child chronological age, maternal country of origin, number of children, child sex, and maternal resting RSA), several covariate effects were non-null in the final model, with all potential covariates included. Infant APGAR predicted carryover in infant positive affect engagement, such that higher APGAR scores predicted greater carryover in infant positive affect engagement, est = 0.015, 95% credible interval (CI): [0.003, 0.027]. Infant gestational age predicted the intercept of infant positive affect engagement, such that infants with older gestational age displayed more positive affect engagement, est = 0.052, 95% CI: [0.012, 0.092]. More biological children predicted greater volatility in maternal positive affect engagement, est = 0.095, 95% CI: [0.011, 0.181]. Child sex (coded 1 = boys, 2 = girls) predicted carryover in infant negative affect engagement, such that girls had less carryover in infant negative affect, est = -0.060, 95% CI: -0.114, -0.007.

In addition, child sex was included as an *a priori* predictor of the intercepts in infant positive affect engagement; these effects were all null. Maternal country of origin was included as a predictor of random effects involving infant negative affect engagement; these effects were all null.

Appendix Table 5a

Within-dyad intercepts and between-dyad variances, adjusting for covariates

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.788**	**[2.672, 2.907]**	**2.788**	**[2.672, 2.907]**
Int. (IP)	γ_{10}	**1.376**	**[1.242, 1.512]**	**1.376**	**[1.242, 1.512]**
Int. (IN)	γ_{20}	**0.252**	**[0.183, 0.325]**	**0.252**	**[0.183, 0.325]**
Ln(Var(MP))	ω_{00}	**-1.701**	**[-1.845, -1.553]**	**0.905**	**[0.768, 1.170]**
Ln(Var(IP))	ω_{10}	**-1.838**	**[-2.003, -1.669]**	**0.255**	**[0.242, 0.289]**
Ln(Var(IN))	ω_{20}	**-3.072**	**[-3.359, -2.777]**	**0.183**	**[0.174, 0.201]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.815**	**[0.803, 0.827]**	**0.815**	**[0.809, 0.820]**
Mom PE	Infant PE	γ_{40}	**0.021**	**[.013, 0.028]**	**0.021**	**[0.015, 0.027]**
Mom PE	Infant NE	γ_{50}	-0.006	[-0.012, .000]	**-0.006**	**[-0.010, -0.002]**
Infant PE	Mom PE	γ_{60}	**0.023**	**[0.016, 0.030]**	**0.023**	**[0.017, 0.028]**
Infant PE	Infant PE	γ_{70}	**0.812**	**[0.796, 0.828]**	**0.811**	**[0.805, 0.819]**
Infant PE	Infant NE	γ_{80}	-0.006	[-0.012, 0.000]	**-0.006**	**[-0.010, -0.002]**
Infant NE	Mom PE	γ_{90}	-0.004	[-0.014, 0.006]	-0.003	[-0.011, 0.004]
Infant NE	Infant PE	$\gamma_{10,0}$	0.003	[-0.019,	0.004	[-0.011,

				0.026]		0.018]
Infant NE	Infant NE	$\gamma_{11,0}$	**0.801**	**[0.762, 0.840]**	**0.768**	**[0.758, 0.778]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.285**
Var. (u_{1i})	τ_{11}	**0.359**
Var. (u_{2i})	τ_{22}	**0.079**
Cov. (u_{0i}, u_{1i})	τ_{01}	**0.070**
Cov. (u_{0i}, u_{2i})	τ_{12}	0.004
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.136**
Var. (u_{3i})	τ_{33}	**0.005**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.009**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.011**
Var. (u_{11i})	$\tau_{11,11}$	**0.028**
Var. (u_{12i})	$\tau_{12,12}$	**1.004**
Var. (u_{13i})	$\tau_{13,13}$	**1.317**
Var. (u_{14i})	$\tau_{14,14}$	**3.597**

Note: Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 5b
Between-Dyad Covariate Effects, adjusting for covariates

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.014	[-0.085, 0.110]	0.014	[-0.085, 0.110]
α_{2i} on RSA	γ_{11}	0.058	[-0.053, 0.171]	0.058	[-0.053, 0.171]
α_{3i} on RSA	γ_{21}	-0.001	[-0.056, 0.052]	-0.001	[-0.056, 0.052]
φ_{1i} on RSA	γ_{31}	-0.009	[-0.023, 0.004]	-0.131	[-0.312, 0.060]
φ_{2i} on RSA	γ_{41}	0.002	[-0.008, 0.011]	0.043	[-0.218, 0.295]
φ_{3i} on RSA	γ_{51}	-0.005	[-0.012, 0.002]	-0.185	[-0.419, 0.085]
φ_{4i} on RSA	γ_{61}	-0.002	[-0.010, 0.006]	-0.057	[-0.322, 0.208]
φ_{5i} on RSA	γ_{71}	-0.016	[-0.034, 0.003]	-0.159	[-0.342, 0.032]
φ_{6i} on RSA	γ_{81}	-0.006	[-0.012, 0.001]	-0.197	[-0.415, 0.043]
φ_{7i} on RSA	γ_{91}	0.006	[-0.006, 0.017]	0.184	[-0.182, 0.536]
φ_{8i} on RSA	$\gamma_{10,1}$	-0.003	[-0.031, 0.025]	-0.034	[-0.287, 0.226]
φ_{9i} on RSA	$\gamma_{11,1}$	-0.019	[-0.051, 0.013]	-0.113	[-0.288, 0.078]
$\mathrm{Ln}(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	-0.079	[-0.023, 0.004]	-0.078	[-0.271, 0.118]
$\mathrm{Ln}(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.100	[-0.092, 0.305]	0.087	[-0.080, 0.259]
$\mathrm{Ln}(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	-0.024	[-0.335, 0.301]	-0.013	[-0.182, 0.155]

Note: RSA = Infant respiratory sinus arrhythmia. Covariate effects of infant gestational age, APGAR, sex; maternal country of origin; and maternal number of children not shown. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.

Teaching Task Model 2

Of the potential covariates (child birth outcomes, child gestational age, child chronological age, maternal country of origin, number of children, child sex, and maternal resting RSA), child sex was a non-null predictor of the volatility in infant negative affect engagement, est = -0.799, 95% CI: [-1.425, -0.148]. Girls' residual variability in negative affect engagement was expected to be approximately half that of boys' residual variability: Whereas boys' residual variability in negative affect engagement was expected to be 0.198, girls' residual variability in negative affect was expected to be 0.089. In addition, mothers' number of other children was a non-null predictor of the intercept of maternal positive affect engagement, est = 0.090, 95% CI: [0.053, 0.127]. Child sex was a null predictor of the random intercepts.

As shown in Table 6 below, infant RSA predicted the effect of prior infant negative affect engagement on subsequent infant positive affect engagement. Results of post-hoc probing using Kris Preacher's multilevel moderation web utility (http://quantpsy.org/interact/hlm2.htm; Preacher, Curran, & Bauer, 2006) indicated that the regression of infant positive affect engagement on prior infant negative affect engagement was only significant at values less than average (< 3.28; 63.9% of the sample) or values well above average (> 10.0; 0% of the sample) values of infant RSA. Whereas the regression of infant positive affect engagement on prior infant negative affect engagement was positive (est = 0.01, *p* = .05) at the lower bound of the region of nonsignificance, it was negative (est = -0.10, *p* = .05) at the upper bound of the region of nonsignificance.

Similarly, the regression of infant positive affect engagement on prior infant negative affect engagement was positive and statistically significant at average levels of infant RSA, est = 0.02, *p* = .012, as well as at below average (-1 SD) levels of infant RSA, est = 0.03, *p* = .0007, but was not statistically significant at above average (+1 SD) levels of infant RSA, est = 0.00, *p* = .87.

Appendix Table 6a
Model results for teaching task, adjusting for covariates

Intercepts

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Int. (MP)	γ_{00}	**2.386**	**[2.295, 2.478]**	**5.419**	**[4.761, 6.126]**
Int. (IP)	γ_{10}	**1.232**	**[1.108, 1.359]**	**2.077**	**[1.754, 2.404]**
Int. (IN)	γ_{20}	**1.118**	**[0.904, 1.334]**	**1.092**	**[0.859, 1.316]**
Ln(Var(MP))	ω_{00}	**-1.962**	**[-2.182, -1.748]**	**0.364**	**[0.354, 0.375]**
Ln(Var(IP))	ω_{10}	**-2.405**	**[-2.591, -2.216]**	**0.274**	**[0.261, 0.288]**
Ln(Var(IN))	ω_{20}	**-1.621**	**[-2.081, -1.171]**	**0.290**	**[0.275, 0.306]**

Regression Path Intercepts

Predictor at Time *t* -1	Outcome at Time *t*	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
Mom PE	Mom PE	γ_{30}	**0.770**	**[0.748, 0.791]**	**0.769**	**[0.762, 0.776]**
Mom PE	Infant PE	γ_{40}	0.003	[-0.004, 0.009]	0.001	[-0.010, 0.012]
Mom PE	Infant NE	γ_{50}	-0.001	[-0.010, 0.007]	0.000	[-0.009, 0.012]
Infant PE	Mom PE	γ_{60}	**0.001**	**[0.001, 0.021]**	**0.014**	**[0.005, 0.023]**
Infant PE	Infant PE	γ_{70}	**0.818**	**[0.801, 0.835]**	**0.817**	**[0.807, 0.825]**
Infant PE	Infant NE	γ_{80}	0.009	[0.000, 0.018]	0.006	[-0.002, 0.013]
Infant NE	Mom PE	γ_{90}	0.004	[-0.003, 0.011’	0.007	[-0.001, 0.015]
Infant NE	Infant PE	$\gamma_{10,0}$	**0.015**	**[0.004, 0.026]**	0.009	[-0.001, 0.017]
Infant NE	Infant	$\gamma_{11,0}$	**0.820**	**[0.799,**	**0.819**	**[0.808,**

	NE	**0.841]**	**0.828]**

Between-Dyad Residual Variances

Effect	Notation	Posterior Median
Var. (u_{oi})	τ_{00}	**0.166**
Var. (u_{1i})	τ_{11}	**0.338**
Var. (u_{2i})	τ_{22}	**1.010**
Cov. (u_{0i}, u_{1i})	τ_{01}	0.028
Cov. (u_{0i}, u_{2i})	τ_{12}	-0.055
Cov. (u_{1i}, u_{2i})	τ_{20}	**-0.576**
Var. (u_{3i})	τ_{33}	**0.020**
Var. (u_{4i})	τ_{44}	**0.001**
Var. (u_{5i})	τ_{55}	**0.001**
Var. (u_{6i})	τ_{66}	**0.001**
Var. (u_{7i})	τ_{77}	**0.010**
Var. (u_{8i})	τ_{88}	**0.001**
Var. (u_{9i})	τ_{99}	**0.001**
Var. (u_{10i})	$\tau_{10,10}$	**0.003**
Var. (u_{11i})	$\tau_{11,11}$	**0.019**
Var. (u_{12i})	$\tau_{12,12}$	**2.400**
Var. (u_{13i})	$\tau_{13,13}$	**1.640**
Var. (u_{14i})	$\tau_{14,14}$	**4.610**

Note. Int = Intercept. Var = Variance. Cov = Covariance. MP = Maternal Positive Affect Engagement (PE). IP = Infant Positive Affect Engagement (PE). IN = Infant Negative Affect Engagement (NE). Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval. Residual variances are not exponeniated and will not include 0 in the credible interval due to the prior used.

Appendix Table 6b
Between-Dyad Covariate Effects, adjusting for covariates

		Unstandardized Estimate		Standardized Estimate	
Effect	Notation	Posterior Median	95% Credible Interval	Posterior Median	95% Credible Interval
α_{1i} on RSA	γ_{01}	0.011	[-0.063, 0.086]	0.022	[-0.121, 0.167]
α_{2i} on RSA	γ_{11}	-0.060	[-0.173, 0.049]	-0.088	[-0.247, 0.070]
α_{3i} on RSA	γ_{21}	0.143	[-0.046, 0.334]	0.121	[-0.039, 0.277]
φ_{1i} on RSA	γ_{31}	-0.019	[-0.045, 0.008]	-0.114	[-0.268, 0.046]
φ_{2i} on RSA	γ_{41}	0.004	[-0.004, 0.012]	0.127	[-0.108, 0.347]
φ_{3i} on RSA	γ_{51}	-0.002	[-0.012, 0.008]	-0.042	[-0.304, 0.220]
φ_{4i} on RSA	γ_{61}	0.001	[-0.011, 0.013]	0.027	[-0.250, 0.289]
φ_{5i} on RSA	γ_{71}	-0.014	[-0.035, 0.007]	-0.122	[-0.298, 0.061]
φ_{6i} on RSA	γ_{81}	0.003	[-0.009, 0.015]	0.076	[-0.258, 0.404]
φ_{7i} on RSA	γ_{91}	0.000	[-0.007, 0.008]	0.009	[-0.225, 0.245]
φ_{8i} on RSA	$\gamma_{10,1}$	**-0.016**	**[-0.030, -0.003]**	**-0.245**	**[-0.426, -0.051]**
φ_{9i} on RSA	$\gamma_{11,1}$	0.014	[-0.012, 0.039]	0.088	[-0.076, 0.242]
$\mathrm{Ln}(\sigma_{1i}^2)$ on RSA	$\gamma_{12,1}$	0.101	[-0.182, 0.374]	0.056	[-0.099, 0.205]
$\mathrm{Ln}(\sigma_{2i}^2)$ on RSA	$\gamma_{13,1}$	0.012	[-0.215, 0.237]	0.008	[-0.145, 0.157]
$\mathrm{Ln}(\sigma_{3i}^2)$ on RSA	$\gamma_{14,1}$	0.034	[-0.376, 0.433]	0.013	[-0.147, 0.168]

Note. RSA = Infant respiratory sinus arrhythmia. Covariate effects of infant sex and maternal number of children not shown. Covariates of the residual variances are not exponeniated. Bolded entries designate effects that are non-null based on 0 not being within the 95% credible interval.