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Bidirectional Relations Among Maternal Positive Emotion, Infant Positive Emotionality, and Infant Physiological Regulation Across the First 18 Months of Life

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ABSTRACT

Respiratory sinus arrhythmia (RSA), a marker of self-regulation, has been linked to developmental outcomes in young children. Although positive emotions may have the potential to facilitate physiological self-regulation, and enhanced self-regulation could underlie the development of positive emotions in early childhood, the relation between positive emotions and physiological self-regulation in infancy has been relatively overlooked. The current study examined the bidirectional associations among maternal positive emotion, infant positive emotionality, and infant resting RSA across the first 18 months of life. We used data from the Longitudinal Attention and Temperament Study (LanTs; $N = 309$ in the current analysis) to test the within- and between-person relations of study variables over time using a random-intercepts cross-lagged panel model. We found that infants with higher overall levels of positive emotionality also displayed greater resting RSA, and their mothers exhibited higher levels of positive emotion. However, there were negative cross-lagged associations within-person; higher than average infant positive emotionality predicted lower levels of infant resting RSA at the subsequent timepoint during early infancy, whereas higher than average infant RSA subsequently predicted decreased levels of infant positive emotionality later in infancy. Results highlight the importance of considering transactional relations between positive emotion and physiological self-regulation in infancy.

1 | Introduction

Infancy is characterized by developmental milestones related to the first emergence of adaptive regulation and reactivity in response to the environment (Cole, Michel, and Teti 1994). Extensive evidence suggests that positive emotions play a significant role in building personal resources, including self-regulation, social competence, and problem solving (Basso et al. 1996; Fredrickson 2001; Isen 2000; Tugade, Fredrickson, and Feldman Barrett 2004). However, the specific associations among an individual's positive emotionality, specifically the temperamental (trait-level) tendency to express positive emotions, the environmental factors that enhance an individual's positive emotionality, and the development of physiological regulation during infancy, have yet to be thoroughly explored.

Theoretical frameworks (e.g., Bell 1968; Sameroff 2010) highlight the bidirectional nature of the parent–child relationship and emphasize the need for further research to capture the dynamic interactions between parents and children over time. Prior research has demonstrated a reciprocal relationship between individual infant and maternal characteristics in achieving milestones related to the development of positive emotion and self-regulation. For example, infant positive emotionality during a mother–child interaction is associated with better self-regulation (Kochanska et al. 2007). Conversely, maternal positive emotion and self-regulation predict higher infant positive emotionality, whereas maternal parenting stress is related to lower infant positive emotionality (Bridgett et al. 2013).

Understanding how infant positive emotionality, maternal positive emotions, and infant physiological regulation mutually influence and shape each other over time will provide valuable insights into the dynamic nature of developmental processes that span across the individual and the dyad. To elucidate underlying mechanisms linking positive emotionality and physiological regulation, we examined bidirectional relations among infant positive emotionality, maternal positive emotions, and infant respiratory sinus arrhythmia (RSA) across the first 18 months of life in a socioeconomically and racially/ethnically diverse longitudinal sample of infants (Pérez-Edgar et al. 2021). Extending previous research focusing on between-person associations, we also explored within-person associations to gain a more comprehensive understanding of potential relations between positive emotionality and respiratory sinus arrhythmia. This approach allowed us to not only capture stable individual differences but also delve into dynamic within-person changes over time.

1.1 | RSA as an Index of Physiological Regulation

RSA refers to the natural variability in heart rate that occurs in synchrony with respiration. RSA is considered an index of parasympathetic function, as it reflects the interaction between the parasympathetic nervous system (PNS) and the cardiovascular system mediated by the vagus nerve (Porges 1995). The vagus nerve serves as a regulatory mechanism, like a "brake," which supports physiological homeostasis and facilitates calm behavioral states during resting conditions (Porges 2001, 2007). Reflecting the activity level of the vagus nerve, vagal tone indexes the functioning of the PNS (El-Sheikh, Hinnant, and Erath 2011). Resting RSA, a widely used measure of vagal tone and PNS activity in young children (El-Sheikh, Hinnant, and Erath 2011), is believed to capture children's ability to maintain physiological balance and flexibility, which in turn predispose children to actively engage with the environment and respond to environmental challenges (Beauchaine 2001; West et al. 2021). Higher levels of resting RSA in young children have been linked to various adaptive outcomes, including better attention, emotion, and behavior control (Marcovitch et al. 2010; Staton, El-Sheikh, and Buckhalt 2009), better socialization skills (Henderson et al. 2004), and positive emotionality (Kagan and Fox 2006; Oveis et al. 2009). Conversely, lower levels of resting RSA have been linked to internalizing and externalizing symptoms in young children (Graziano and Derefinko 2013; Zhou and Buss 2021).

Infancy is a period of dynamic physiological development, particularly in systems supporting co- and self-regulation, as indexed by PNS activity. Although individual differences in rank order for resting RSA appear relatively stable throughout infancy and toddlerhood (Alkon et al. 2011; Bornstein and Suess 2000; Wagner et al. 2021), considerable variation exists in initial levels and developmental trajectories (Dollar et al. 2020; Wagner et al. 2021). This suggests that resting RSA changes during this period are likely influenced by a complex interplay of factors, including physical and neural maturation, as well as exposure to experiences shaping emotion regulation development.

1.2 | Positive Emotions and RSA

Positive emotions have been associated with enhanced PNS activity, which further contributes to better health and adaptive socioemotional functioning. As individuals experience positive emotions, vagal tone tends to increase, fostering a state of physiological calmness and stability. PNS activation associated with positive emotions is thought to contribute to reduced heart rate, enhanced heart rate variability, and improved overall cardiac functioning (Kok et al. 2013). This physiological state has been linked to a lower risk of cardiovascular disease (Boehm and Kubzansky 2012). But the interplay between positive emotions and PNS activity extends beyond cardiovascular health. Research with adult samples has demonstrated that positive emotions are related to improved autonomic and immune systems (Chida and Steptoe 2008; Dockray and Steptoe 2010), enhanced problem-solving abilities (Nelson and Sim 2014), and increased prosocial behavior (Kok et al. 2013).

The broaden-and-build theory (Fredrickson 2001) provides a theoretical framework to explain the beneficial role of positive emotions in both health and socioemotional functioning. According to this theory, positive emotions broaden attentional focus and encourage individuals to engage with their environment, thereby promoting the development of personal resources (Fredrickson 2001). This upward spiral of positive emotions contributes to positive functional profiles among individuals, one of which may be enhanced parasympathetic functioning. Indeed, studies conducted with adult samples have found a positive association between trait-positive affect and resting RSA (Oveis et al. 2009; Wang, Lü, and Qin 2013). Furthermore, Kok and Fredrickson (2010) demonstrated that individuals with higher vagal tone exhibit increasing levels of positive emotions over time. Their findings also revealed a reciprocal relation, suggesting that individuals experiencing greater increases in positive emotions also demonstrate increases in vagal tone over time. These reciprocal relations indicate an upward spiral dynamic between positive emotions and vagal tone, suggesting that positive emotions may serve as a psychological resource for promoting autonomic and socioemotional health.

Although the link between positive emotions and RSA has been extensively examined in adults, there is a limited understanding of how positive emotions are uniquely associated with RSA in early childhood. A few studies that have examined this link found that positive affect was associated with dynamic changes in RSA during a fear-eliciting episode in toddlers with high levels of fear (Brooker and Buss 2010). In this study, higher levels of positive affect were related to greater changes in RSA, indicating initial increases in RSA followed by later decreases. Similarly, preschoolers with high levels of positive affect showed greater changes in RSA during a challenging task, indicating adaptive self-regulation during stressful situations

(West et al. 2021). Because previous studies with young children have focused on contexts that elicit negative emotions, it remains unclear whether the observed changes in RSA directly reflect stable positive emotions or a response to the negative aspects of the contexts. More research is needed to disentangle the relations with children's capacity for regulation (i.e., resting RSA) as opposed to RSA reactivity during affective contexts.

Despite some evidence of a link between positive emotions and RSA in early childhood, longitudinal bidirectional relations between these variables across infancy have not been explored. As a result, the potential causal mechanisms and reciprocal processes between infant emotionality and physiological regulation are unclear, limiting our understanding of how they contribute to a positive feedback loop. Given that infant positive emotion is linked to RSA, understanding the complex dynamics shaping emotion in infancy will allow us to identify the underlying mechanisms between developing emotion and self-regulation.

1.3 | The Role of Maternal Positive Emotions in Infant Positive Emotionality and RSA

Drawing on Rothbart and Bates's (2006) conceptualization of temperament traits as individual differences in emotional reactivity, we view positive emotionality as a temperamental tendency to express positive emotions. As the first and primary context for infant development, maternal traits and behaviors play a crucial role in shaping infants' regulatory functioning. Research has consistently demonstrated the association between maternal behaviors and infants' PNS activity. For example, mothers who show sensitivity to their children and engage in supportive and warm parenting practices tend to have children with better physiological regulation (Calkins et al. 2008; Haley and Stansbury 2003; Gueron-Sela et al. 2017; Moore and Calkins 2004). Conversely, maternal intrusiveness or maladaptive and hostile parenting undermine physiological regulation in young children (Skowron et al. 2011; Smith et al. 2016). Furthermore, higher levels of maternal internalizing symptoms are associated with lower levels of resting RSA in infants, indicating a link between maternal psychopathology and reduced parasympathetic activity (Field et al. 1995; Lin et al. 2021; Zhou et al. 2023). These findings suggest that maternal characteristics can either disrupt or promote the development of infants' parasympathetic regulation, which, in turn, underlies their physiological flexibility and adaptive responses to environmental demands.

Maternal positive emotions also contribute to the development of an infant's positive emotionality and regulatory functioning. Although infant positive emotionality is rooted in biological underpinnings, emotional experiences with mothers contribute to its development through a process of person–environment transactions (Campos et al. 1994); thus, early temperament is probabilistic with respect to outcomes, not deterministic. Infants rely on social cues and attempt to adjust to their environment (Prochazkova and Kret 2017). These early emotional experiences with caregivers provide the foundation for emotional processing (Feldman and Eidelman 2007). Notably, during this early sensitive period for building attachment, social signals from mothers and automatic mimicry of their emotional expressions can elicit emotional contagion (Hatfield et al. 2014). The emergence of contagious emotion appears as early as 10 weeks of age (Haviland and Lelwica 1987), suggesting an early-emerging link between maternal and child emotional states. As infants develop mirroring mechanisms and a sense of intersubjectivity, they become capable of engaging in reciprocal interactions with their mothers (Marshall and Meltzoff 2014; Rochat 2001). Through the process of contingency detection during social interactions, infants are increasingly able to recognize and respond to maternal emotions, eliciting and sharing these emotions (Soussignan et al. 2006). Furthermore, biobehavioral synchrony between parent and child may underlie infants' sensitivity to mothers' social cues and emotion expressions at neural, physiological, and behavioral levels (Feldman 2012). Indeed, mothers with higher positive emotion tend to have infants who show greater socioemotional competence and adaptive behavior (Hanley, Brain, and Oberlander 2013). Considering the effect of maternal mood disorder and depression in early life on infant emotional development (Bjertrup et al. 2022; Rigato et al. 2020), maternal emotional climate plays an important role in shaping positive emotionality in infants.

Emerging evidence indicates a link between maternal positive emotions and higher RSA in children during recovery from frustrating tasks (Delgadillo et al. 2021; Liew et al. 2011). As described, considering the evidence of emotional contagion between mothers and infants (Feldman and Eidelman 2007), the positive emotional climate created by mothers may foster a secure base for infants to explore their environment and regulate their emotions effectively, in part by mirroring and reciprocating these positive emotions (Feldman 2012; Liew et al. 2011). In contrast, children who are exposed to negative emotions may become easily over-aroused, leading to difficulties in responding to their environment in an adaptive manner (Eisenberg, Smith, and Spinrad 2011). This heightened emotional arousal can narrow their attentional focus, compromising their ability to manage emotions effectively (Fredrickson 2001; Eisenberg et al. 2005). These findings suggest that a positive emotional context may enhance children's capacity for positivity in general, allowing them to broaden their attention and develop effective regulatory strategies.

Positive emotions also enhance an individual's psychological resources, fostering persistence and optimism while also counteracting the physiological effects of negative emotions (Fredrickson 2001; Salovey et al. 2000). Expanding upon these findings, mothers who experience higher levels of positive emotions tend to recover quickly from negative emotions (Tice et al. 2007), which, in turn, could enhance their ability to effectively deal with the demands of parenting. Robust psychological resources, facilitated by positive emotionality, may enable mothers to engage with their infants in warm and responsive ways, building a positive parent–child relationship. As such, maternal positive emotion serves as a model for infants, teaching them how to recognize, express, and regulate their emotions (Kopp 1982). Indeed, preschool children whose parents expressed positive emotions during a discussion of an upsetting event showed adaptive regulatory skills when they worked on a frustrating task (Shin et al. 2023). Taken together, maternal positive emotion is associated with greater emotional availability and responsiveness, leading to increased positive emotions and regulatory functioning in infants.

1.4 | Bidirectional Relations Among Maternal Positive Emotions, the Development of Infant Positive Emotionality, and RSA

In Bell's (1968) foundational work, the parent–child relationship is characterized by bidirectional and transactional processes where both parents and children actively influence each other. Researchers have increasingly focused on understanding the mutual impact of mothers and children, acknowledging the complex interplay between their behaviors and traits in shaping child development. For instance, infants with higher resting RSA, which is associated with better regulation and engagement with the environment (Beauchaine 2001; Conradt et al. 2016) and greater positive emotionality (Somers et al. 2022), are more likely to respond actively to their mother in adaptive ways. This active responsiveness, in turn, may enhance the mother's positive emotions and foster the development of warm and sensitive parenting behaviors toward the infant over time. Indeed, infants who exhibit greater positive emotions tend to receive more positive and responsive caregiving from their parents (Kochanska et al. 2004). Additionally, Somers et al. (2022) found a positive correlation between a mother's positive affect and her infant's subsequent positive affect and a negative correlation between a mother's positive affect and her infant's subsequent negative affect in 6-month-old infants with higher resting RSA during a second-by-second observation.

Despite evidence for dynamic changes in infants' positive emotionality and autonomic nervous system functioning (Gartstein and Rothbart 2003; Porges and Furman 2011), we have a limited understanding of how changes in the reciprocal influences between the emotional experiences of infants and their mothers and the mutual shaping of physiological regulation unfold. Considering the existing research that has established a link between young children's positive emotionality and RSA (Brooker and Buss 2010; Calkins et al. 2008), as well as between maternal positive emotions and their infant's RSA (Delgadillo et al. 2021; Liew et al. 2011), there is a potential for mutual associations among infant positive emotionality, maternal positive emotions, and the development of physiological regulation. Understanding how infant RSA influences and is influenced by positive emotions in both the mother and infant can advance our knowledge of the mechanisms involved in self-regulation during early childhood.

1.5 | Current Study

Considering previous research indicating that positive emotions contribute to the development of personal resources (Isen 2000; Kok et al. 2013; West et al. 2021), we examined the potential role of individual and parental positive emotions in the development of physiological regulation during infancy. By exploring these bidirectional associations, we can unravel the complex interdependencies between maternal and infant emotional processes and their mutual influence on infant physiological regulation. Therefore, we examined longitudinal and bidirectional associations among maternal positive emotion, infant positive emotionality, and infant resting RSA across the first 18 months of life, using a random-intercepts cross-lagged panel model (RI-CLPM; Hamaker, Kuiper, and Grasman 2015).

RI-CLPM has been widely used to examine transactional relations among variables over time while accounting for individual differences (Level et al. 2021; Vallorani et al. 2023; Zhou et al. 2023). This model allows for the estimation of reciprocal influences between variables by incorporating lagged effects and individual-specific intercepts. With this feature, RI-CLPM captures both between- and within-person effects. Between-person effects represent the stable, trait-like differences that distinguish individuals on these variables. These effects are often captured by the random-intercepts component of the model, which estimates an average level for each variable specific to each individual (Mulder and Hanmaker 2021). In contrast, within-person effects focus on how fluctuations in one variable within a single person at a specific timepoint are associated with fluctuations in another variable for the same person over time. This allows us to examine how temporary changes from an individual's baseline score in one variable are associated with temporary changes in another variable (Usami 2021). Utilizing this model enabled us to understand how variables mutually influence and shape each other over time, providing insights into the dynamic nature of our developmental processes of interest.

We hypothesized that there would be positive associations between trait levels of maternal positive emotions and infant positive emotionality. Additionally, we expected that higher levels of maternal positive emotions and infant positive emotionality would both be associated with greater infant resting RSA. Consistent with transactional models of parent–child interactions (e.g., Patterson and Reid 1970), we predicted that state-level relations would be evident in cross-lagged associations among maternal positive emotions, infant positive emotionality, and infant resting RSA across time, such that higher levels of maternal positive emotions would predict an increase in infant resting RSA through increases in infant positive emotionality over time. Moreover, we took into consideration the potential influence of child effects on these cross-lagged associations at state levels, thus expecting that higher levels of infant positive emotionality would predict increases in maternal positive emotions, which in turn would lead to further increases in infant positive emotionality and resting RSA over time.

2 | Methods

2.1 | Overview

The current study was part of the Longitudinal Anxiety and Temperament Study (Pérez-Edgar et al. 2021), focusing on temperament, attention bias, and anxiety in the first 2 years of life. Data were collected longitudinally from infants and their mothers ($N = 357$) at 4, 8, 12, 18, and 24 months, using a multimethod approach that included parental questionnaires assessing infant temperament, their own psychological state and traits, and the sociodemographic features of their environment as well as experimental measures of infant physiological response. As attention skills and temperament profiles develop rapidly during the first year (Hunnis 2007), we opted for three data collection

TABLE 1 | Demographics by site.

	State college ($N = 150$)	Harrisburg ($N = 75$)	Newark ($N = 84$)
Maternal education	17.33 (2.42)	15.13 (2.81)	13.05 (3.51)
Infant sex (F/M)	75/75	34/41	49/35
Household income % reporting			
$15,000 or less	3.3	13.3	23.8
$16,000–$20,000	1.3	4.0	9.5
$21,000–$30,000	2.6	8.0	8.3
$31,000–$40,000	4.6	6.6	2.4
$41,000–$50,000	10.0	4.0	3.6
$51,000–$60,000	11.3	6.6	0.0
Above $60,000	56.0	36.0	7.1
Non-report	10.6	21.3	45.2
Infant race/Ethnicity % identifying			
African American/Black	0.0	20.0	33.3
Asian	4.6	0.0	2.4
Latinx	4.6	12.0	41.6
Native American	0.0	0.0	3.6
White	80.6	52.0	5.9
Biracial/Mixed race	8.0	12.0	4.8
Non-report	2.0	4.0	8.3

points during this time window and two timepoints during the second year, balancing developmental considerations with participant burden. Given evidence of temperamental reactivity emerging as early as 4 months (Kagan and Snidman 1991), the first data collection point was set at 4 months. The Institutional Review Boards at the Pennsylvania State University and Rutgers University approved all procedures, and parents provided written consent and were compensated for their participation. Because of the impact of the COVID-19 pandemic on in-person data collection and the substantial proportion of missing physiology data at the 24-month visit (comprising 79% of the full sample), the current study utilized data at 4, 8, 12, and 18 months.

2.2 | Participants

Mother–child dyads with a diverse demographic background were recruited through university-affiliated and community advertisements from the regions surrounding State College, PA (N = 150), Harrisburg, PA (N = 75), and Newark, NJ (N = 84). Demographic information by site is included in Table 1.

Infants and their caregivers were enrolled when the infants were 4 months of age (N = 298; 151 males, 147 females; M_{age} = 4.80 months; SD_{age} = 0.80, $Range_{age}$ = 3.27–7.60 months), with an additional 46 participants enrolled at 8 months (N = 46; 19 males, 27 females; M_{age} = 8.83 months; SD_{age} = 0.73, $Range_{age}$ = 7.53–10.20 months), and 13 participants at 12 months (N = 13; 6 males, 7 females; M_{age} = 12.73 months; SD_{age} = 1.12, $Range_{age}$ = 10.63–14.90 months), for a total enrollment of 357 infants in the full sample (176 males, 181 females). Of these, 309 infants (51% female) and their mothers participated in all core measures and the four study timepoints, forming the final sample for the current analyses.

2.3 | Measures

Most mothers completed questionnaires via Qualtrics before each laboratory visit. For parents who were unable to complete the questionnaires ahead of time, they were instead completed using a laptop during a laboratory visit. Versions of each questionnaire were available in both English and Spanish and were administered on the basis of the caregiver's first language.

2.3.1 | Infant Positive Emotionality

Mothers reported their infant's tendency to express positive emotions at 4 and 8 months using the Infant Behavior Questionnaire-Revised (IBQ-R; Putnam et al. 2014) and at 12 and 18 months using the Toddler Behavior Assessment Questionnaire (TBAQ; Goldsmith 1996). Measurement equivalence between the IBQ and the TBAQ subscales has been established in previous studies, reporting high levels of convergence with various subscales of the IBQ (Goldsmith 1996). In the current sample, mothers reported on both the IBQ and TBAQ at 12 months and indicated a strong correlation between the two instruments ($r = 0.70$, $p < 0.001$).

The IBQ-R is designed to assess general behavioral patterns associated with infant temperament, consisting of 191 items (Parade and Leerkes 2008; Putnam et al. 2014). In the current study, a dimension of smiling and laughter from the IBQ-R was used. Mothers rated how often they observed their children's smiling or laughter in general caretaking and play situations in the past week. Items described an infant's expression of positive emotions (e.g., *How often during the last week did the baby smile or laugh when given a toy?*) using a 7-point scale (1 = never and 7 = always). Additionally, parents were provided with a "not applicable" response alternative to be chosen when the specified situation had not been observed with the infant. Cronbach's alpha indicated good reliability at both 4 ($\alpha = 0.84$) and 8 months ($\alpha = 0.80$).

The TBAQ is the follow-up measure to the IBQ, with the dimension of pleasure serving as the corresponding subscale to the smiling and laughter subscales from the IBQ (Goldsmith 1996). Mothers reported their infant's general behavioral patterns through 120 items. In this study, we used the pleasure dimension at 12- and 18-month timepoints. Similar to the IBQ-R, parents rated how often their children displayed smiles, laughter, and other positive vocalizations or in a rage of familiar situations in the past month (e.g., *when playing quietly with one of her/his favorite toys, how often did your child smile?*) using a 7-point Likert scale (1 = never and 7 = always). There was good reliability at 12 ($\alpha = 0.84$) and 18 months ($\alpha = 0.69$).

2.3.2 | Maternal Positive Emotion

Mothers' positive emotion was measured using Positive and Negative Affect Scales (PANAS; Watson, Clark, and Tellegen 1988). The PANAS has been widely used as a self-reported measure of adult affect in both research and clinical contexts. The PANAS consists of 20 items and was collected at all four included timepoints. Each item is a word that depicts a feeling or emotion (e.g., excited, proud), and parents rate the extent of their general experience of these emotions on a 5-point scale (1 = very slightly/not at all; 5 = extremely). For this study, items related to positive affect are summed to yield a composite score. The PANAS had good-to-excellent scale reliability (4 months $\alpha = 0.89$; 8 months $\alpha = 0.89$; 12 months $\alpha = 0.91$; 18 months $\alpha = 0.91$).

2.3.3 | Respiratory Sinus Arrhythmia

Electrocardiograph (ECG) signal from the infant was continuously recorded during a neutral "Resting" task at 8, 12, and 18 months. Gelled sensors (stickers) were placed by the experimenter on the child's right collarbone, and lower left and right rib prior to baseline. Resting RSA was 4 min in duration, and the infant was positioned on a parent's lap and given non-stimulating toys to keep them occupied. Parents were instructed to avoid social contact and keep as neutral as possible. ECG was sampled at a rate of 500 ms using a Mindware MW1000A mobile device and BioLab software (Mindware Technologies, Ltd., Westerville, OH). The device was attached to the back of the highchair or the parent's chair. At the 18-month visit, the infant wore the device inside a small backpack to allow for locomotor activity for other study procedures. Data were analyzed offline using the Mindware editing program Mindware HRV, Versions 3.1.4 and 3.1.5, which identified interbeat intervals and detected physiologically improbable intervals using a validated algorithm. Trained personnel visually inspected ECG data for R-peak and artifact identification. RSA was calculated in 30-s epochs using the 0.240–1.040 Hz power band, consistent with prior work (Bar-Haim, Marshall, and Fox 2000). The mean RSA value from across all epochs per task was used for analyses. From among the infants that attempted ECG across the entire sample, several participants at each timepoint had no recoverable data upon visual inspection, 2.2% at 8 months, 5.3% at 12 months, and 0% at 18 months. Of the remaining data, 4.6% at 8 months, 7.5% at 12 months, and 10.4% at 18 months did not complete the entire task due to electrodes detaching, operator error, participant fussing out, or software/wireless connection malfunction. On average, participants included in the current study had usable data from 3.90 min of the 4-min resting baseline. Amount of usable ECG data was not significantly related to resting RSA scores ($p = 0.07$).

2.4 | Analytic Plan

We began by performing a missing data analysis to investigate patterns of missingness and attrition across the sample. Auxiliary variable analyses (Collins, Schafer, and Kam 2001) were performed across included demographic variables in the dataset, including child sex, data collection site, prenatal medication use to investigate if missingness could be well accounted for with the included model variables and full information maximum likelihood (FIML). Variables that are identified as potential auxiliary variables were incorporated into the full model by covarying the auxiliary variable with all other model variables.

To assess our question of interest in the transactional relations among maternal positive emotion, infant positive emotionality, and infant physiological regulation, we implemented an RI-CLPM. In a traditional CLPM, each variable is both regressed on itself at the prior timepoint (autoregressive paths) as well as every other variable at the prior timepoint (cross-lagged paths), and concurrent timepoint variables are allowed to covary to account for shared timepoint variance (Hamaker, Kuiper, and Grasman 2015). The RI-CLPM extends the CLPM model with the addition of random-intercept terms that account for the expected value or "latent average" of the individual across timepoints, which effectively disaggregates the within- and between-person effects (Mulder and Hamaker 2021). Therefore, covariation between the random intercepts may be interpreted as global associations among the constructs across the sampling period (4–18 months), and covariations among individual timepoint variables can be thought of as associations in fluctuations from that global average at that timepoint. Autoregressive paths can be interpreted as capturing carryover effects in the fluctuations from the person's average from timepoint to timepoint. Lastly, cross-lagged paths can be interpreted as the degree to which change from the expected or average level at a prior timepoint affects variation from the average of another variable at a subsequent timepoint.

TABLE 2 | Means, standard deviations, and correlations of study variables.

Variable	*N*	*M* (*SD*)	1	2	3	4	5	6	7	8	9	10	11
1. Infant PE 4M	254	4.80 (1.14)	1.00										
2. Infant PE 8M	206	4.88 (1.02)	0.58***	1.00									
3. Infant PE 12M	169	5.05 (0.92)	0.30***	0.49***	1.00								
4. Infant PE 18M	178	5.22 (0.79)	0.27***	0.41***	0.47***	1.00							
5. Parent PE 4M	229	3.39 (0.72)	0.14*	0.24**	0.17*	0.07	1.00						
6. Parent PE 8M	188	3.54 (0.70)	0.20*	0.28***	0.22**	0.06	0.68***	1.00					
7. Parent PE 12M	159	3.35 (0.70)	0.14	0.20*	0.02	−0.04	0.57***	0.63***	1.00				
8. Parent PE 18M	161	3.31 (0.75)	0.25**	0.20*	0.18*	0.07	0.51***	0.65***	0.63***	1.00			
9. RSA 8M	203	3.55 (0.92)	−0.06	−0.11	−0.08	0.10	−0.10	−0.07	−0.14	−0.13	1.00		
10. RSA 12M	152	3.79 (0.90)	0.02	−0.05	−0.10	−0.10	0.09	0.10	0.02	0.13	0.50***	1.00	
11. RSA 18M	117	4.01 (1.01)	0.24*	0.24*	−0.14	0.14	0.13	0.18	0.09	0.12	0.37***	0.46***	1.00

Abbreviations: M, months; PE, positive emotionality; RSA, respiratory sinus arrhythmia.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

The RI-CLPM model was estimated using the *lavaan* package for R (Rosseel 2012). Missing data were accounted for using FIML (Cham et al. 2016). Model fit was assessed using model Chi-square, root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), Tucker–Lewis index (TLI), and comparative fit index (CFI) (Hu and Bentler 1999). Acceptable fit indices are as follows: $\chi^2 = p > 0.05$, RMSEA < 0.08, SRMR < 0.08, CFI ≥ 0.9, and TLI ≥ 0.95. The model was also refitted to test for measurement invariance across timepoints in the three study measures. Measurement equivalence is indicated by no significant differences between model fit between the constrained and unconstrained models. Additionally, the RI-CLPM is a discrete time model in that it assumes that each infant is the same age at the indicated timepoint. Given this assumption, the model was retested after visit data were removed from participants who fell outside of a 3-month window of the visit (e.g., aged less than 3.0 months or greater than 6.0 months for the 4-month visit) and compared to the original model.

3 | Results

3.1 | Descriptive Statistics

Descriptive statistics and correlations for the sample are reported in Table 2. We noted significant correlations within the three measures of interest across timepoints, including infant positive emotionality (rs = 0.27–0.58), maternal positive emotion (rs = 0.51–0.68), and resting RSA (rs = 0.37–0.50). Across measures, maternal positive emotion at the 4-, 8-, and 18-month timepoints was significantly correlated with infant positive emotionality at 4-, 8-, and 12-month timepoints (rs = 0.14–0.28). Lastly, infant resting RSA at 18 months was significantly correlated with infant positive emotionality at 4 and 8 months. Intraclass correlations (ICCs) were calculated to assess the degree to which variability measurements over time are attributable to between- and within-person variations (Brose et al. 2020). ICCs indicated that 63% of variance in maternal positive emotion was attributable to between-person level, leaving 37% related to within-person variation. Likewise, ICCs for infant positive emotionality and infant RSA showed that 42% and 39% of variance, respectively, were due to between-person differences.

3.2 | Missing Data Analysis

Little's missing completely at random (MCAR) test (Little 1988) indicated that data were likely not missing completely at random (MCAR; $p < 0.001$). Considering prior studies demonstrating links to infant neurobiology (Zhou et al. 2023; Gemmel et al. 2018), child sex, prenatal medication use (including selective serotonin reuptake inhibitor use, anxiolytics, and psychotics), and data collection sites were investigated as potentially auxiliary variables to predict missing scores in the model. Data collection site was a significant predictor of missingness for infant positive emotionality, maternal positive emotion, and infant RSA at all timepoints. Site also showed significant semi-partial correlations above and beyond the model implied covariance structure for infant RSA across all timepoints and infant positive emotionality at 4 months. These patterns indicate that the inclusion of data collection sites is necessary to reduce bias in model estimates due to missingness (Collins, Schafer, and Kam 2001).

Data from the same variable at previous timepoints significantly predicted missingness as well as correlated with scores in infant positive emotionality across timepoints and maternal positive emotion across timepoints. Given that missingness for all modeled variables could be conditioned on existing variables in the model, data could be considered conditionally missing at random (MAR) and that bias due to missingness can be accounted for with FIML (Enders 2011). However, it is possible that other auxiliary variables or reasons for missingness may exist that were not considered in the present study.

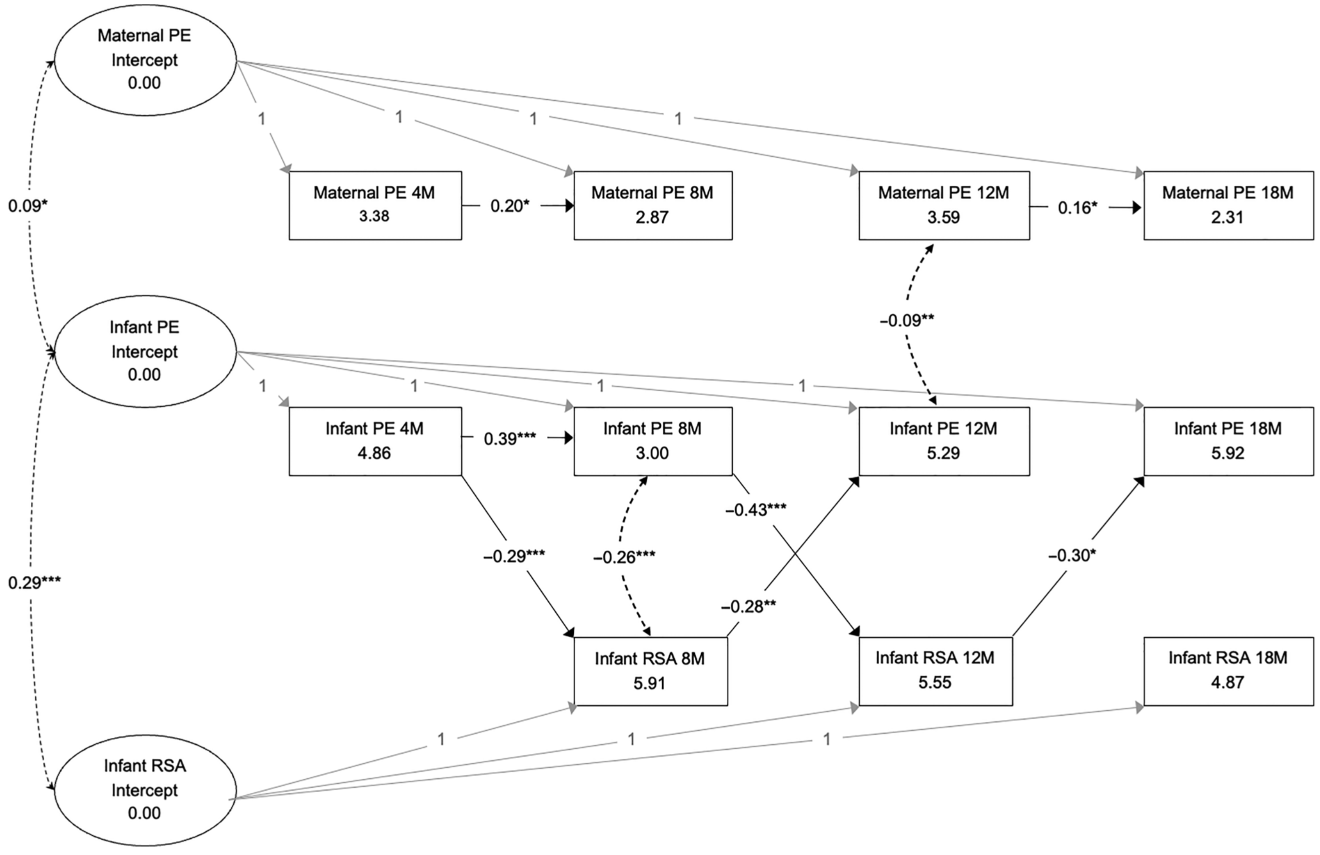

FIGURE 1 | Random-intercepts cross-lagged panel model of maternal positive emotion, infant positive emotionality, and infant physiological regulation across the first 18 months of life. *Note:* Significant across-time paths ($p < 0.05$) are indicated by estimates and solid black lines, and significant covariance are indicated by solid dashed line. The absence of arrows indicates non-significant relations. PE, positive emotionality; RSA, respiratory sinus arrhythmia.

3.3 | Random-Intercepts Cross-Lagged Panel Model

The RI-CLPM, including site as an auxiliary variable fit the data well ($\chi^2(15) = 19.311$, $p = 0.20$, CFI = 0.99, TLI = 0.97, RMSEA = 0.03, SRMR = 0.03). All three random-intercepts terms showed significant variance, indicating between-person differences in the three measures across timepoints (Figure 1). Positive associations among these trait-level differences indicated that greater trait infant positive emotionality was related to greater trait maternal positive emotion ($B = 0.09$, $p = 0.05$) and to higher infant resting RSA ($B = 0.29$, $p < 0.001$). Trait maternal positive emotion was not significantly related to trait infant RSA ($p = 0.23$).

Autoregressive effects within each study measure indicated significant carryover or inertia in deviation from trait-like latent averages in maternal positive emotion between 4 and 8 months ($B = 0.20$, $p = 0.02$) and again between 12 and 18 months ($B = 0.16$, $p = 0.05$). Additionally, there were significant autoregressive carryover effects in infant positive emotionality between 4 and 8 months ($B = 0.39$, $p < 0.001$).

The model indicated a significant negative concurrent covariance between maternal positive emotion at 12 months and deviations from the latent trait average in infant positive emotionality at 12 months ($B = -0.09$, $p = 0.04$). Similarly, the model indicated a significant negative covariance between infant positive emotionality and infant RSA at 8 months ($B = -0.26$, $p = 0.001$).

Cross-lagged effects between infant positive emotionality and infant RSA indicated negative associations between the two measures over time. Higher infant positive emotionality at 4 months predicted lower infant RSA at 8 months ($B = -0.29$, $p < 0.001$). Similarly, infant positive emotionality at 8 months predicted lower infant RSA at 12 months ($B = -0.43$, $p < 0.001$). However, there were no significant cross-lagged associations between positive emotionality at 12 months and infant RSA at 18 months. Additionally, higher infant RSA at 8 and 12 months was predictive of decreased levels of infant positive emotionality at 12 months ($B = -0.28$, $p = 0.01$) and 18 months ($B = -0.30$, $p = 0.02$), respectively. However, there were no significant cross-lagged associations between fluctuations from trait-like averages in maternal positive emotion and infant positive emotionality or infant RSA.

Constraining the model for measurement equivalence within variables presented a significantly worse fit to the data than the original model ($\chi^2(7) = 37.24$, $p < 0.001$). Thus, full measurement equivalence could not be assumed. This poor fit was mainly indicated by differences in variance across time for infant positive emotionality, potentially due to differences in the measure, and at the 18-month timepoint for resting RSA. We then fit a model that constrained measurement variance to be equal for maternal positive emotion across time and for infant resting RSA at the 8- and 12-month timepoints. This model resulted in a fit that was not significantly different from the original unconstrained model ($\chi^2(4) = 8.45$, $p = 0.08$). Thus, we could assume partial longitudinal measurement invariance (Mulder and Hamaker 2021). Results from this constrained model were consistent in direction and significance with the original unconstrained model.

When data were restricted to infants whose age fell into a window 1 month before or 2 months after the intended visit age, the model fit the data well ($\chi^2(15) = 16.09$, $p = 0.38$, CFI = 0.99, TLI = 0.99, RMSEA = 0.02, SRMR = 0.03). In comparison to the model fitting the full data, the association between the random intercepts for maternal and infant positive emotionality was no longer significant but remained in the same direction. Additionally, there was an additional significant carryover effect from infant positive emotionality at 12 months and infant positive emotionality at 18 months ($B = 0.23$, $p < 0.05$). All other associations remained the same.

4 | Discussion

In the current study, we examined the potential bidirectional relations between infant and maternal positive emotions and the development of physiological regulation during infancy. Using a longitudinal approach with a multisite cohort, we examined these relations across the first 18 months of life. Descriptive statistics indicated variable means and deviations that were consistent with prior work for infant positive emotionality (Bridgett et al. 2013), maternal positive emotion (Planalp et al. 2017), and infant resting RSA (Wagner et al. 2021). In addition, ICCs indicated a moderate degree of variability attributed to both between- and within-person variations across all three study variables. Gradual increases in the sample mean resting RSA across infancy is consistent with prior longitudinal work showing increases from 0 to 24 months of age using growth modeling techniques (Wagner et al. 2021). Our statistical approach, the RI-CLPM, allowed us to extend prior research on the development of positive emotion and physiological regulation by considering both between- and within-person variations and fluctuations across time. The between-person level represents the stable, time-invariant differences among individuals. Alternatively, the within-person level focuses on how fluctuations in a variable within a single person at a specific timepoint are associated with changes in another variable for the same person over time. At the between-person level, we found that infants with higher overall levels of positive emotionality exhibited greater overall levels of resting RSA, indicative of enhanced physiological regulation. Furthermore, these infants higher in positive emotionality tended to have parents who experienced higher overall levels of positive emotion. Interestingly, negative cross-lagged associations were observed at the within-person level between infant positive emotionality and resting RSA across time, indicating how deviating from one's own average may influence later outcomes. These data extend the prior literature by presenting an extended window of data across infancy while also disaggregating within- and between-person factors that were typically integrated in prior studies.

4.1 | Associations Between Infant Positive Emotionality and Resting RSA

We found a significant positive association between infant trait-like positive emotionality and trait-like resting RSA across the first 18 months of life, suggesting stable between-person differences in positive emotionality and resting RSA over time. Infants with higher overall levels of positive emotionality demonstrated greater overall levels of resting RSA across the study. This finding aligns with previous research that has established a link between positive emotionality and RSA during infancy (Beauchaine 2001; Calkins 1997; Kagan and Fox 2006) and supports the broaden-and-build theory (Fredrickson 2001). According to the broaden-and-build theory (Fredrickson 2001), positive emotions broaden an individual's attentional scope, encouraging them to engage in play, exploration, and active interaction with their surroundings. These expanded thought–action repertoires facilitate the acquisition of novel resources that can significantly shape personal development over time, guiding individuals toward growth and the establishment of enduring resources.

Through a functionalist perspective, all emotions serve different goals and motivations in particular circumstances by interacting with the environment (Campos et al. 1994). As the adaptive function of emotions varies depending on the specific context and desire, each emotion elicits distinct behavior tendencies, shaping unique emotional experience over time (Revord, Sweeny, and Lyubomirsky 2021). For example, in contrast to negative emotions, which provide immediate adaptive benefits in survival-threatening situations, such as the "fight or flee" response, positive emotions elicit broadened thought–action repertoires that contribute to longer term advantages by facilitating the development of personal resources (Fredrickson 2013). As such, infants who frequently experience positive emotions may have a higher likelihood of developing personal resources, potentially marked by enhanced parasympathetic function, as they accumulate new resources through their interactions with the environment over time (Fredrickson 2001; Kok and Fredrickson 2010). Given that all emotions serve distinct functions, regulatory mechanisms develop to support goals to promote adaptive behavior, preventing them from disrupting goal-oriented actions (Thompson 2011).

Consistent with literature that has examined individual differences in association between positive emotions and resting RSA (Lü and Wang 2018; Oveis et al. 2009), the between-person findings suggest that the cumulative impact of positive emotion may develop into stable, time-invariant resources. Alternatively, higher trait levels of resting RSA may reflect biological contributions to enhanced positive emotion in line with the polyvagal theory (Porges 1995). According to this theory, higher trait levels of resting RSA enable greater flexibility in the vagal brake, promoting physiological homeostasis and appropriate attending to the environment. This may lead to a positive association between RSA and infants' positive emotional reactivity over time. Our finding expands on existing research by identifying specific patterns over time in the between-person correlation between positive emotionality and resting RSA during infancy.

Although higher levels of overall infant positive emotionality were associated with higher levels of overall infant resting RSA, there were negative cross-lagged associations at the within-person level. Higher levels of infant positive emotionality relative to their mean at 4 and 8 months predicted lower levels of resting RSA relative to their mean at the subsequent timepoint at 8 and 12 months, which in turn was predictive of decreased levels, relative to their mean, of infant positive emotionality at 12 and 18 months. This negative relation between within-person change in positive emotionality and RSA is contrary to our hypotheses. This finding may be explained by the surgency or exuberance facets of positive emotionality, within the timescale of capturing fluctuations in emotionality. Surgency and exuberance, characterized by positive emotionality and approach tendencies (Putnam, Ellis, and Rothbart 2001), are associated with less effortful control, impulsivity, and engagement in risky activities (Polak-Toste and Gunnar 2006; Stifter, Putnam, and Jahromi 2008; Rothbart and Bates 2006). For example, high levels of stable exuberance during infancy and toddlerhood have been linked to increased externalizing behavior problems, suggesting exuberance may contribute to externalizing behavior problems through its association with low self-regulation and a tendency for risk taking (Degnan et al. 2011).

Given the link between surgency or exuberance and self-regulation, infants with high surgency or exuberance may have difficulty maintaining physiological balance and achieving calm behavioral states during periods of rest, especially within the novel setting of a laboratory. Moreover, a longitudinal study (Blandon et al. 2010) found higher levels of vagal suppression were associated with significant decreases in surgency over time. Vagal suppression represents reduced activity of the vagus nerve, associated with physiological homeostasis and relaxation (Porges 2001). The link between surgency and exuberance and lower self-regulation may reflect infants' adaptive responses to intermittent shifts in their positive emotionality and physiological regulation within individuals. Between-person differences, however, likely represent the cumulative relation between overall positive emotionality and physiological regulation. This divergence across within- and between-person levels suggests two distinct processes in infancy that contribute to shaping infants' emotional and physiological regulation. Although our study did not assess surgency or exuberance as specific constructs within positive emotionality, future research could explore the relations between positive affect and RSA through the lens of these dimensions. This exploration could focus on how impulsivity, a potential facet of surgency and exuberance, might influence the observed associations.

Furthermore, the negative cross-lagged associations at the within-person level suggest a co-developmental process between infant positive emotionality and physiological regulation during early infancy, which mutually influence each other over time. With development, temperamental reactivity may refine developing biological systems, and biological maturation may in turn elicit within-person change in temperamental reactivity (Gartstein et al. 2010; Zhou et al. 2023). These findings highlight the dynamic interplay between temperament and physiological processes in shaping emotional development and self-regulation during infancy. Future research probing the specific mechanism underlying the co-development process can provide valuable insights into these dynamic foundations in early childhood.

We found no evidence for a continued cross-lagged association between infant positive emotionality at 12 months and their RSA at 18 months. This result suggests that the influence of positive emotions on physiological regulation might vary depending on developmental stage. As toddlers become more independent and explore their environment, self-regulation becomes more complex (Calkins 2007). Although positive emotions can still be related to adaptation, managing frustration and controlling impulses might become a bigger challenge at this stage. Supporting this notion, Zhou et al. (2023) examined the same dataset and found that infant negative emotionality and maternal internalizing symptoms were significantly associated with infant resting RSA at 18 months. This suggests that other emotional and environmental factors might play a more prominent role in self-regulation in the second year of life. Another possible explanation could be that the relation between positive emotion and self-regulation is not linear. Increased motor and attention development, along with developing regulatory behavior strategies at 12 months (Mangelsdorf, Shapiro, and Marzolf 1995), could shape the relation between emotionality and self-regulation differently compared to earlier infancy.

4.2 | Infant Positive Emotionality and Maternal Positive Emotion

We found within-person stability in both infant positive emotionality and maternal positive emotion from 4 to 8 months. Consistent with previous research using maternal report, we observed stability in infant positive emotionality during early infancy (Carranza Carnicero et al. 2000; Gartstein, Hancock, and Iverson 2018). These findings suggest that mothers' perceptions of their children's positive emotionality remained relatively consistent during early infancy. However, considering the self-report nature of our data, incorporating multi-informant measures, including behavioral observation, would further elucidate the stability of positive emotionality during infancy. Additionally, we found within-person stability in maternal positive emotion from 12 to 18 months. Given that our measure assessed mothers' general emotional experiences, future studies employing measures that capture maternal positive emotion during mother–infant interactions could provide more nuanced insights into relation between mother and infant positive emotionality.

Consistent with findings from previous studies (Kochanska et al. 2004; Feldman 2007; Martin, Clements, and Crnic 2002), infants with higher overall levels of positive emotionality tend to have mothers with higher overall levels of positive emotion. This positive association between the trait-like levels of infant and maternal positive emotion was expected considering the genetic nature of temperamental positive emotionality and shared emotional context between persons (Eisenberg, Valiente, and Eggum 2010). Drawing on findings on maternal–infant emotional contagion (Feldman and Eidelman 2007), infants exposed to a positive emotional climate may mirror and reciprocate their mothers' positive emotions (Feldman 2012; Liew et al. 2011). This suggests that the emotions of mothers and their infants could be interrelated, mutually shaping each other within social contexts (Martin, Clements, and Crnic 2002). This would be evident in aggregated between-person comparisons.

In addition, mothers who frequently experience positive emotions are more likely to develop psychological resources, such as optimism and resilience, in line with the broaden-and-build theory (Salovey et al. 2000). These enhanced resources may subsequently help them in effectively coping with parenting stress and fostering a supportive caregiving context. These findings suggest a link between a positive emotional context and an infant's ability to experience and express positive emotions. However, another interpretation is that infants with higher positive emotionality may elicit maternal positive emotions, as studies have shown that higher levels of infant positive emotion reflect greater engagement into the environment (Beauchaine 2001). It may be that the infants with higher positive emotions were more actively engaged in their environment compared to their counterparts with lower levels of positive emotionality (Beauchaine 2001), and this increased engagement may be associated with mothers' higher positive emotion.

Yet, although we found a significant between-person association between infant positive emotionality and maternal positive emotions, in line with the literature, this association was not found at the within-person level. There were no significant cross-lagged associations between infant positive emotionality and mothers' positive emotions, indicating that within-person changes in infant positive emotionality are not related to subsequent within-person changes in maternal positive emotions. These results suggest that although infants with higher positive emotionality tend to have parents with higher overall levels of positive emotion, there is no evidence of a causal or temporally linked relation between the two at the within-dyad level over time.

Although a concurrent negative correlation between infant positive emotionality and maternal positive emotions emerged at 12 months, it is important to interpret this result with caution, as it appeared only at one of the four timepoints examined. This finding contrasts with our initial hypotheses and prior research suggesting positive associations between infant positive emotion and higher levels of maternal positive emotion (Bridgett et al. 2013; Morgan et al. 2023; Kochanska et al. 2004). One potential explanation for our finding may be that infants use positive emotions as a strategy to elicit responses from their mothers, particularly when mothers express fewer positive emotions themselves. Given infants' ability to recognize and respond to the emotional states of others (Heck et al. 2018; Safar and Moulson 2020) and the emotionally stimulating and rewarding nature of shared positive emotional experiences for both mothers and infants (Beebe et al. 2016; Feldman 2012), infants might develop the capacity to intentionally prompt positive emotional responses from their mothers through social interactions during their first year of life. Indeed, Backer, Ram, and Stifter (2022) observed increased positive emotion expression in toddlers with higher temperamental positive emotionality as their mothers transitioned from free play to the still-face episode. This finding suggests that infants with higher levels of positive emotionality may strategically employ positive emotions to engage socially with their unresponsive caregiver. However, as this correlation was only observed at one timepoint, further research is needed before drawing broader conclusions.

4.3 | Cross-Lagged Associations Among Maternal Positive Emotion, Infant Positive Emotionality, and Resting RSA

Consistent with transactional models of parent–child interactions (e.g., Patterson and Reid 1970), we expected higher levels of infant positive emotionality would predict increases in maternal positive emotions and an increase in subsequent infant positive emotionality and resting RSA over time. Contrary to our hypothesis, there were no significant cross-lagged relations among maternal positive emotion and infant resting RSA, at either the between- and within-person levels in our sample. This lack of association at both between- and within-person levels linking all three core variables together contrasts with the findings of Zhou et al. (2023), who observed bidirectional relations among maternal internalizing symptoms, infant negative emotionality, and infant resting RSA across four timepoints using the same dataset. This discrepancy highlights potential differences in the developmental trajectories of physiological regulation related to positive and negative emotions, particularly within the context of maternal internalizing symptoms. Although Zhou et al. (2023) demonstrated mother-to-infant and infant-to-mother influences over time for negative emotionality, our results suggest that the development of physiology regulation shaping individual infant and maternal positive emotion in infancy unfolds differently from negative emotionality.

The lack of significant findings among three variables at both the between- and within-person levels may be attributable to the methodology used to assess maternal positive emotion in our study. Specifically, we used maternal self-reports to measure the extent of their general experience of positive emotions, which is different from other studies that have used measures, such as positive emotional expressivity (Delgadillo et al. 2021), emotional availability (Volling et al. 2002), or observations of positive emotional expression during interactions with children. Consistent with this, our study's hypotheses were initially informed by previous research that primarily involved the observation of maternal positive emotion in controlled laboratory settings (e.g., Calkins et al. 2008; Delgadillo et al. 2021; Liew et al. 2011; Shin et al. 2023). Thus, it is possible that there is a discrepancy between a mother's general tendency to experience positive emotions and the expression of these emotions in a specific context, particularly when directed toward her child.

4.4 | Limitations and Future Directions

Our findings should be interpreted with caution due to the following limitations. First, mothers' positive emotions and infants' temperamental positive emotionality were both reported by the mother, which may be biased due to social desirability and reference bias (Donaldson and Grant-Vallone 2002). Additionally, previous research has criticized the validity of parental reports on infant temperament, as they show low correlations with observational ratings of temperament and high correlations with parents' own personal characteristics (Stifter and Dollar 2016). However, here we found that mother–child concordance in positive affect was not pervasive across our analytic model.

Observational measures in future research could capture different aspects of positive emotion and provide diverse insight into maternal positive emotion and infant positive emotionality.

Another potential limitation of our study is the measure of maternal positive emotion. Although the PANAS is a widely used measure, it does not account for variations in the intensity and arousal level of rated emotions. For example, an individual experiencing multiple positive emotions at a moderate intensity might obtain the same overall score as someone experiencing fewer positive emotions but at a high intensity. In addition, the PANAS includes both high- and low-arousal positive affect states, yet the scoring system does not distinguish between these different arousal levels. Future research might benefit from employing measures that capture both the intensity and arousal level of affective states. Moreover, as mentioned in the discussion, the experience of positive emotions does not necessarily mean that mothers express these emotions toward their children. Considering empirical studies that have found associations between parental positive emotion expression and child self-regulation (Delgadillo et al. 2021; Liew et al. 2011; Shin et al. 2023), it may be beneficial to use measures of parental positive emotion socialization, including expression of positive emotion and positive emotion coaching specifically with the child, to disentangle transactional dynamics between infant and maternal positive emotion and infant RSA at the within-person level. Future work should aim to replicate our findings using measures of parental positive emotion socialization or external observer scores of parental positive emotions.

Furthermore, our findings are specific to mothers and their infants due to the absence of fathers and other caregivers in our sample. Fathers play an important role in the development of self-regulation in early childhood. Research has shown that fathers' engagement with their infants is associated with a variety of positive outcomes, including improved self-regulation (Bocknek et al. 2017; Bridgett et al. 2018; Nikolińe et al. 2022). For example, Bendel-Stenzel, An, and Kochanska (2024) found that fathers' ability to appropriately understand and interpret infants' mental states at 8 months predicted better self-regulation at 3 years. Including fathers in studies of infants' emotional and regulatory development could facilitate a comprehensive understanding of the factors that influence it. This inclusive approach ensures that both maternal and paternal contributions are recognized, ultimately benefiting children's self-regulation skills.

Lastly, a statistical limitation of the RI-CLPM is that it can only be used on discrete time panel data. Although participants in the present sample were invited to participate during fixed windows (4, 8, 12, 18 months), their study visit dates often fell in a range around these timepoints. This misalignment between scheduled and actual study visit dates could potentially introduce noise into the analysis.

Nevertheless, our findings extend existing research by identifying specific between-person correlations between infants' positive emotionality and resting RSA during infancy. Individual differences between positive emotionality and resting RSA over time support the broaden-and-build theory (Fredrickson 2001) in infants, suggesting the role of positive emotions in physiological self-regulation. In addition, infants with higher overall levels of positive emotionality tend to have parents with higher levels of positive emotion. This positive association between the trait-like levels of infant and maternal positive emotion was expected considering the genetic nature of temperamental positive emotionality and shared emotional context between persons. Exploring positive emotion socialization strategies of caregivers could inform practitioners about the benefits of a strength-based approach on children's positive emotions. Supporting positive emotional environments can broaden and build children's resources, enabling them to use emotions more functionally.

The bidirectional relations between infant positive emotionality and resting RSA suggest that within-person dynamics may unfold differently from stable between-person differences during infancy. The observed differences in within- and between-person dynamics suggest that individualized and dynamic approaches to intervention design and implementation could be effective in promoting positive emotionality and self-regulation in infants. Our findings highlight the importance of considering each child's unique patterns of emotional and physiological regulation when conceptualizing developmental trajectories and designing interventions.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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