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Regular Article

Dyadic resilience after postpartum depression: The protective role of mother-infant respiratory sinus arrhythmia synchrony during play for maternal and child mental health across early childhood

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Abstract

Coordination in mothers' and their infants' parasympathetic nervous system functioning (i.e., respiratory sinus arrhythmia [RSA] synchrony) specifically during playful interactions may promote resilience against exposure to postpartum depressive symptoms (PPD), for both members of the dyad. To test biobehavioral synchrony theory-derived hypotheses, we evaluated whether positive mother-infant RSA synchrony during play attenuated associations between maternal PPD symptoms and future child behavior problems and maternal depressive symptoms. 322 low-income, Mexican-origin mothers and their children participated in 5-min resting baseline and free play interaction tasks when children were 24 weeks of age; mothers reported on their PPD symptoms and on child behavior problems and maternal depressive symptoms at 12- and 36-months child age. Results of multilevel structural equation models demonstrated that, though the associations between maternal PPD symptoms and future child behavior problems and maternal depressive symptoms differed depending on levels of RSA synchrony during play and non-interactive tasks, the protective benefits of positive RSA synchrony on 12-month maternal depressive symptoms and 36-month child internalizing problems were specific to its assessment during a playful interaction. Results suggest that the dyadic coordination of physiological capacities during playful interactions is an active mechanism that promotes resilience to emotional distress for mothers and their children.

Keywords: child behavior problems; dyadic synchrony; maternal depression; parent-child interaction; respiratory sinus arrhythmia

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Introduction

Postpartum depression (PPD) has wide-ranging consequences for both mother and child, including future maternal mental health difficulties (e.g., Cooper & Murray, 1995; Goodman, 2004; Philipps & O'Hara, 1991; Vliegen et al., 2014) and child internalizing (e.g., depression, anxiety) and externalizing (e.g., conduct problems) problems (for systematic review, see Slomian et al., 2019). Especially among low-income and ethnic minority families, PPD symptoms are associated with less warm, more intrusive, and more disengaged and withdrawn caregiving (Gueron-Sela et al., 2018; Lovejoy et al., 2000), which accounts in part for the adverse effects of maternal depression on youth mental health outcomes (for meta-analyses, see Goodman et al., 2020; Madigan et al., 2024). Attesting to the reciprocity between mothers and their infants, infant behavior problems also positively predict future maternal depressive symptoms, even after accounting for intra-individual stability in maternal depression (Curci et al., 2023). At the same time, early exposure to PPD symptoms does not determine a dyad's destiny; there is considerable variability in the effects of postpartum depression exposure on early childhood outcomes (Murray & Cooper, 1997; Walker et al., 2013) and the course of maternal depression (Goodman & Gotlib, 1999). Given the interdependence of maternal depression with youth behavior problems, it is imperative to evaluate *dyadic* factors that may be key sources of risk or resilience.

Biobehavioral synchrony theory and the broader clinical and developmental literatures underscore the interdependence between maternal and child functioning over time *and* in the moment (Bell, 1968; Feldman, 2012; Hudson & Rapee, 2001; Sameroff, 1975). During social interactions, mothers' and their infants' affect, behavior, and physiological functioning vary from one moment to the next; rapid changes in infants' biobehavioral signals influence and are influenced by corresponding changes in their mothers (a process known as synchrony; Feldman, 2007; Fogel, 1993). Over time, moment-to-moment mother-infant biobehavioral synchrony is internalized and shapes the evolving dyadic relationship (Atzil et al., 2014; Somers et al., 2024) and longer-term adjustment for both mother and child (Butler, 2011; King et al., 2021; Leclère et al., 2014; Somers et al., 2024). Positive mother-infant synchrony (i.e., in-phase coordination where mothers and their infants match moment-to-moment changes in each other's biobehavioral functioning) is thought to support offspring emerging emotion regulation and socioemotional competence (Beeghly & Tronick, 2011; Beebe et al., 2010, 2012; Feldman, 2007, 2009, 2012; Tronick, 1989; Tronick & Beeghly, 2011). Likewise, synchronous mothers may experience parenting

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as more emotionally rewarding and are more likely to engage in sensitive caregiving (Feldman, 2012), which in turn is associated with fewer child behavior problems (Cooke et al., 2022). Yet, it remains unclear whether mother-infant synchrony can confer resilience against the effects of early maternal mental health difficulties on longer-term adjustment (Lan et al., 2023; Lunkenheimer, 2024). To address this knowledge gap, the present study sought to evaluate whether mother-infant physiological synchrony specifically during playful interactions attenuates the longer-term effects of maternal postpartum depression (PPD) on offspring and their mothers, among low-income, Mexican-origin families who are disproportionately affected by maternal and child mental health problems relative those in the majority culture (Avila & Bramlett, 2013; Calzada et al., 2016; D'Anna-Hernandez et al., 2015; Flores et al., 2002; Ponting et al., 2020).

Mother-infant parasympathetic synchrony

Biobehavioral synchrony refers to the coordination of affect and social behavior with physiological biomarkers during ongoing interaction (Gordon & Feldman, 2015). According to the biobehavioral synchrony model (e.g., Feldman, 2012), early developmental changes in brainstem-mediated biological systems prepare the mother to initiate species-typical maternal behavior (e.g., "motherese" vocalizations, positive affect, gaze) and the child to detect social contingencies from birth (Feldman & Eidelman, 2007; Feldman, 2012). From their earliest interactions, mothers' and infants' temporally-coordinated behavior is mapped onto biological processes and shapes physiological and socioemotional development (Feldman, 2012). Notably, though several physiological pathways (e.g., autonomic, endocrine, and neural) undergird biobehavioral synchrony (Gordon & Feldman, 2015), parasympathetic processes are ideally suited for examining the synchronization of rapidly-changing emotions during mother-infant interactions because of the second-by-second timescale on which the parasympathetic nervous system can respond to environmental demands (Butler & Randall, 2013; DePasquale, 2020; Teti & Cole, 2011). Multiple theoretical perspectives (e.g., polyvagal theory, Porges & Furman, 2011; Porges, 2007; neurovisceral integration model; Thayer et al., 2009) converge upon the idea that rapid parasympathetically-mediated influences on cardiometabolic output support emotion regulation and harmonious social interaction (Beauchaine & Thayer, 2015; Porges, 2001), including effective communication and social engagement between infants and their caregivers (Kolacz & Porges, 2024).

Parasympathetic influences on cardiometabolic output are typically indexed by respiratory sinus arrhythmia (RSA), a measure of the normal ebb and flow in heart rate that is governed by the vagus nerve during a respiratory cycle (Porges et al., 1994). Greater RSA during rest is thought to support social engagement and calm behavioral states; in response to environmental challenges, rapid decreases in RSA are an efficient strategy for mobilizing physiological resources needed for active coping and regulatory behaviors (Porges, 2007). Dynamic changes in RSA during parent-child interaction, including second-by-second intra-individual variability in RSA, have been linked to maternal mental health and sensitive, well-regulated parenting behavior (Giuliano et al., 2015; Moore et al., 2009; Skoranski & Lunkenheimer, 2021; Skowron et al., 2013; Somers et al., 2021b) and child behavioral adjustment (Berry et al., 2019; Somers et al., 2021a). Further, these dynamic changes in parents' and children's RSA do not occur in isolation; rather, on average, parent-child dyads typically exhibit positive RSA synchrony (for reviews, see Davis et al., 2018; DePasquale, 2020; Miller et al., 2023). Yet, it is not clear whether the ability to establish typical patterns of positive RSA synchrony is adaptive in the context of maternal depression (e.g., Lan et al., 2023; West et al., 2020).

Variation in the effects of maternal depressive symptoms: the role of RSA synchrony

Research, including among the present sample, has demonstrated that individual biological factors, such as infant resting RSA, account in part for variation in the effects of PPD symptoms on child behavior problems (Somers et al., 2019) and in the course of maternal depressive symptoms (Somers et al., 2021a). Increasingly, theoretical and empirical perspectives have also posited that *dyadic* factors may account for variability in the outcomes of PPD (Lan et al., 2023). Following the biobehavioral synchrony model, positive RSA synchrony is generally conceptualized as a process that supports smooth dyadic interactions and facilitates child self-regulation (Davis et al., 2018; DePasquale, 2020; Feldman, 2012), which may be a protective factor that confers resilience for both members of the dyad (Feldman, 2020). Recent research lent empirical support for the biobehavioral synchrony model among families from a rural, under-resourced community in China: Children from dyads with weaker RSA synchrony, which may reflect poorer interaction quality or failures to co-regulate, were most vulnerable to PPD-associated risk for future internalizing problems. In contrast, greater levels of positive mother-infant RSA synchrony during playful interaction attenuated the adverse effects of maternal PPD symptoms on future offspring internalizing problems (Lan et al., 2023). Notably, conclusions that positive RSA synchrony may provide a relational foundation from which children can draw upon to overcome early adversity were strengthened by a prospective design, which accounted for early precursors of child internalizing problems (Lan et al., 2023). Nevertheless, it is not known whether the protective benefits of positive RSA synchrony during play would also confer resilience against child externalizing behavior problems or against persistent or worsening maternal depression after the postpartum period.

Whether or not positive RSA synchrony attenuates the transmission of emotional difficulties between parents and children may also depend on the proximal contexts of parent-child interactions (Davis et al., 2020; Somers et al., 2024). Whereas positive RSA synchrony in neutral conditions may facilitate mutual engagement and fluent interactions, under stressful conditions, positive RSA synchrony may reflect empathic distress or impairments in co-regulation (e.g., failure to remain calm while one's partner experiences heightened arousal). When assessed during tasks designed to elicit negative emotions, there is evidence that positive RSA synchrony both acts as a diathesis for poor outcomes associated with maternal emotional risk (Creavy et al., 2020; West et al., 2020), and as a susceptibility factor that strengthens the relationship between parenting and youth emotion regulation and mental health problems, for better or for worse (Oshri et al., 2023; Xu et al., 2024). Taken together, these results underscore the importance of the proximal contexts of parent-child interactions in shaping the role of RSA synchrony, and raise questions about whether and in what contexts positive RSA synchrony during is a protective factor, a risk factor, or plasticity factor (i.e., whether patterns of interaction conform to stress-diathesis or differential susceptibility; Roisman et al., 2012).

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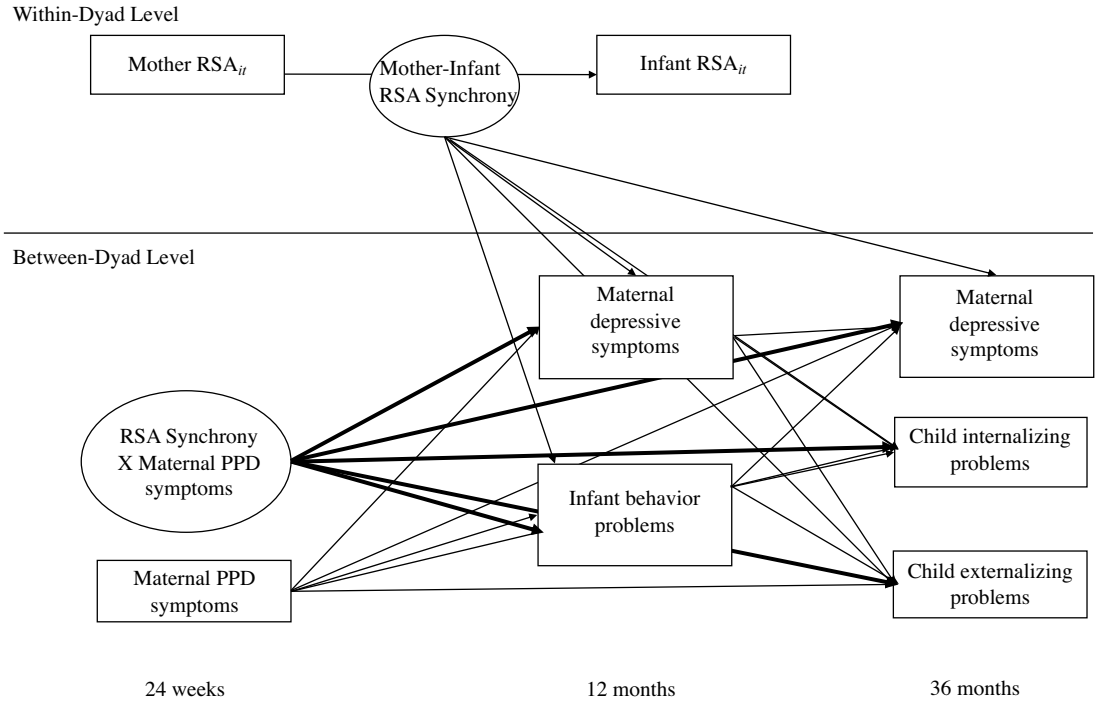

Figure 1. Conceptual model of the joint effects of within-dyad RSA synchrony and maternal PPD symptoms on subsequent maternal and child outcomes. *note*. PPD = postpartum depression. RSA = respiratory sinus arrhythmia. For visual clarity, covariate effects and covariances are not shown. Primary paths of interest are shown in bold.

In infancy, playful interactions are particularly important as they provide opportunities for the formation of attachment ties and facilitate children's developing emotion regulation (Feldman, 2012; Lan et al., 2023; Morris et al., 2018). Autonomic mother-infant synchrony that is framed by moments of simultaneous vocalization and positive affect (Feldman et al., 2011), such as those that frequently occur during play (Brazelton et al., 1975; Papoušek, 1995), may represent an active mechanism that fosters emotion co-regulation and lays the foundation for socioemotional development (Feldman, 2020). Despite calls to consider the proximal contexts of parent-child interactions when interpreting physiological synchrony (Davis et al., 2020; Somers et al., 2024), few studies have compared synchrony and its correlates across different conditions (for exception, see Creavy et al., 2020). Although physiological synchrony can occur in the absence of behavioral synchrony and even in the absence of interaction (Creavy et al., 2020; Suveg et al., 2016, 2019; Woltering et al., 2015), this may reflect passive, automatic influences that result in the coordination of mother and infant RSA. Understanding whether the protective benefits of mother-infant RSA synchrony are specific to mother-infant RSA synchrony during a playful interaction, relative to a non-interactive resting condition, offers a deeper understanding of how parents' effortful attempts to playfully interact with their child influence biobehavioral coordination and longer-term trajectories of risk and resilience, which can inform prevention and intervention efforts.

Current study aims

The current study sought to evaluate whether positive mother-infant RSA synchrony during free play attenuated associations between maternal PPD symptoms and future maternal depression and child mental health concerns, among a sample of low-income, Mexican-origin families. It is especially important to evaluate dyadic factors associated with risk and resilience among ethnic minority and low-income mothers, particularly those that recently immigrated to the United States, who are more likely to experience depressive symptoms (CDC, 2007; Chaudron et al., 2005; Ertel et al., 2011; Gavin et al., 2005; Gress-Smith et al., 2012; Howell et al., 2005; O'Hara & McCabe, 2013; Surkan et al., 2006). For economically-disadvantaged, Mexican-origin families living in the United States, stress associated with separation from family members, acculturative processes, poverty, and discrimination can exacerbate risk for both maternal depressive symptoms (Calzada et al., 2016; D'Anna-Hernandez et al., 2015; Ponting et al., 2020) and behavioral problems in children (Avila & Bramlett, 2013; Flores et al., 2002). At the same time, traditional Mexican cultural values that emphasize the importance of placing family members above one's own needs (e.g., *familismo*) and the primacy of the maternal role (e.g., *marianismo*) may be culturally salient, *dyadic* sources of resilience for both mothers and their children (Cabrera et al., 2022; Calzada et al., 2013; Stein & Polo, 2014).

Drawing on the biobehavioral synchrony model (Feldman, 2012, 2020), our first two aims were to evaluate whether positive mother-infant RSA synchrony during free play protected against the adverse effects of maternal PPD symptoms on future child behavior problems and maternal depressive symptoms. Consistent with theory and prior research (Lan et al., 2023), we hypothesized that associations between maternal PPD symptoms and (1) offspring behavior problems and (2) maternal depressive symptoms at 12 and 36 months would be attenuated in the presence of stronger positive RSA synchrony during a free play task at 24-weeks postpartum (see Figure 1 for conceptual model). We evaluated maternal and child outcomes at two time points – when children were 12 and 36 months – in order to assess potentially enduring benefits of synchrony beyond infancy. Extending prior

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work that demonstrated mother-infant RSA synchrony during play confers resilience for child internalizing problems (Lan et al., 2023), we evaluated whether resilience-promoting effects of synchrony are specific to early childhood internalizing problems (Lan et al., 2023) or also generalize to externalizing behavior problems. Our final aim was to (3) evaluate specificity of our results to a free play task. We hypothesized that the stress-diathesis model where positive RSA synchrony confers resilience for both members of the dyad would be specific to a free play task relative to a non-interactive baseline.

Method

Participants

The sample included 322 mother-infant dyads who participated in a broader examination of maternal mental health and child socioemotional development in very low-income, Mexican-origin families, *Las Madres Nuevas*. Pregnant women were invited to participate in the study if they met the following eligibility criteria: 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 (family income below $25,000 or eligibility for Medicaid or Federal Emergency Services coverage for childbirth), and 5) anticipated delivery of a singleton baby with no significant health or developmental problems. The Arizona State University Institutional Review Board and the Maricopa Integrated Health System IRB approved all study procedures prior to recruitment or data collection.

The first data collection occurred during the prenatal period, at which time women were 18-42 years old ($M = 27.8$, $SD = 6.5$ years). The majority of women (86.3%) were born in Mexico. On average, women had lived in the United States for 11.9 years (range 0-32 years). The modal family income was $10,001 - $15,000 for an average household of four people. Approximately 77.3% of women were married or living with a partner. Approximately one-quarter of the sample was first-time mothers (22.2%); among the rest of the sample, the number of biological children (not including the target child) ranged from zero to nine ($M = 2.0$; $SD = 1.7$). The sample included 149 (46.3%) male children and 173 (53.7%) female children.

Recruitment

Women were recruited from hospital-based clinics during prenatal care visits. Bilingual female interviewers explained the study, evaluated eligibility, and obtained permission for a prenatal home visit (26–38 weeks gestation). Interviews were conducted in the participant's choice of Spanish (86%) or English (14%).

Procedures

At the prenatal and 6-week home visits, mothers completed questionnaires. At the 24-week home visit, mothers completed interaction tasks with their infants, including a baseline and free play task. To minimize infants' and mothers' movement during the tasks, infants were placed in study-provided seats and seated upright, and mothers were seated next to their infants. During the 7-minute baseline period, mothers were instructed "Please relax quietly for the next seven minutes and breathe normally. Feel free to close your eyes if that makes you feel more comfortable." The first 5 minutes of the 7-minute baseline period were used. During the 5-minute free play task, mothers were given a small basket of toys and objects (e.g., plastic cookware and food, dolls, cars, farm animals, etc.) and told to play with their infants as they normally would if alone. Research assistants provided childcare for other children present in the home during the visit to minimize interruptions. Women were compensated with $75 and small gifts at the prenatal interview, and $50 and small gifts at the 24-week visit.

The 12-month and 36-month visits were conducted in the laboratory at Arizona State University. Women were compensated $100 for each laboratory visit and provided either free transportation to/from the laboratory or $50 for travel costs.

Measures

Maternal and infant RSA

At the 24-week visit, a research assistant placed electrodes on the mother's and infant's left shoulder and right and left waist in a standard lead configuration. Heart rate data were recorded at 256 Hz with electrocardiography (ECG) monitors (Forrest Medical, LLC; Trillium 5000; East Syracuse, NY, USA) during the baseline and free play periods. QRSTool software 1.2.2 (Allen et al., 2007) was used to process the data and automatically obtain R-spikes from the ECG data. Trained coders manually corrected misidentified or unidentified R-spikes. Time-varying RSA across the five minutes of baseline and of free play was estimated from the cleaned R-R interval data, using the MATLAB toolbox RSAseconds (Gates et al., 2015). RSA was estimated in the frequency band of respiration for adults (.12 – .40 Hz) and for infants (.30 – 1.30 Hz) (Porges, 1985). Prior published work with this sample demonstrates the validity of these time-varying estimates relative to estimates of RSA derived from the Porges method (Porges, 2007; Somers et al., 2021a). Following recommendations to remove any systematic time trends prior to synchrony analyses (Gates et al., 2015), mothers' and infants' RSA time series were first-differenced, yielding time series of reactive changes in RSA that were used in primary analyses.

Maternal depressive symptoms

Women reported on their postpartum depressive symptoms at 24-weeks child age using the 10-item Edinburgh Postnatal Depression Scale (EPDS; Cox et al., 1987). Women respond using a scale from 0 to 3, and higher scores correspond to more severe depressive symptoms. The EPDS has been validated in English and Spanish (Garcia-Esteve et al., 2003). An error in the response set rendered two items on the EPDS unusable for 43 participants at 24-weeks. For these participants, item-level multiple imputation (Mplus 7; Muthén & Muthén, 2012) was used to impute the missing values which were then used to calculate a full scale score. The imputation variables included parity, survey administration language, the two depression items, and parcels created by averaging the remaining eight EPDS items.

Women reported on their depressive symptoms at 12- and 36-months using the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977). Items are rated on a scale from 0-4, and higher scores indicate greater frequency of depressive symptoms. The CES-D has been validated in Spanish among Mexican Americans (Roberts et al., 1989). Internal consistency (a conservative estimate of scale reliability) of the original EPDS and CES-D at each time point was good; α's $> .82$. 5.9% of sample endorsed clinically significant (EPDS ≥ 13) depressive symptoms at 24-weeks postpartum; 21.5 and 14.5% of sample endorsed clinically significant (CES-D ≥ 16) depressive symptoms at 12- and 36-months, respectively.

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Infant behavior problems

Women reported on their infant's behavior problems at the 12-month visit using the 42-item Brief Infant-Toddler Social and Emotional Assessment (BITSEA; Briggs-Gowan et al., 2004). Thirty-one items comprised the behavioral problem subscale. Items are rated from 0-2, and higher scores indicate more behavioral problems. The BITSEA has been validated among low-income Hispanic/Latinx families (Hungerford et al., 2015). The internalizing (Cronbach's $\alpha = .55$) and externalizing behavior problem (Cronbach's $\alpha = .52$) subscales did not demonstrate acceptable reliability and were therefore not used in the present study. The total behavioral problems subscale demonstrated acceptable internal consistency (Cronbach's $\alpha = .81$). 9.7% of sample endorsed clinically significant (BITSEA $\geq$ 13 for girls, $\geq$ 15 for boys) infant behavior problems.

Child internalizing and externalizing behavior problems

Women reported on their child's behavior problems at 36 months using the 113-item Child Behavior Checklist (CBCL/1.5-5; Achenbach & Rescorla, 2000), yielding information on internalizing and externalizing behaviors. Items are rated from 0-2, and higher scores indicate more behavior problems. The CBCL is validated in English and Spanish (Achenbach & Rescorla, 2000; Rubio-Stipec et al., 1990). Gross and colleagues (2006) demonstrated equivalence across ethnic groups by income and language versions. The internalizing and externalizing behavior problems subscales demonstrated good internal consistency (Cronbach's α for internalizing problems = .87, externalizing problems = .90). In present analyses, T-scores for internalizing and externalizing problems were used; 10.2% of sample endorsed at-risk or clinically significant (T-scores $\geq$ 60) internalizing problems and 6.5% of sample endorsed at-risk or clinically significant externalizing problems.

Potential covariates

Child sex and birth outcomes (gestational age and birthweight) were obtained through medical record review. At the prenatal visit, women reported their country of birth and completed the 20-item Economic Hardship Scale (Barrera et al., 2001; $\alpha = .72$). Because parenting experience may shape mothers' physiological and socioemotional regulation during mother-infant interactions (Rutherford et al., 2015), we obtained the number of other children from mothers' report at the prenatal visit. In addition, mothers' perceptions of their infant's temperament may influence how mothers respond to their infant, at both physiological and behavioral levels (Kiff et al., 2011). Maternal ratings of infant temperament were obtained at the 6-week time point using the negativity dimension of the Infant Behavior Questionnaire-Revised (IBQ-R, Gartstein & Rothbart, 2003; $\alpha = .61$).

Analytic plan

Study hypotheses were tested using a Bayesian plausible values approach in which plausible values (i.e., latent variable scores) for within-dyad RSA synchrony were multiply-imputed in the first step and then effects of within-dyad RSA synchrony, maternal PPD symptoms, and their interaction were evaluated in a second step (Asparouhov & Muthén, 2010). In the context of multilevel structural equation modeling, the plausible values approach affords evaluation of latent moderated structural equations without requiring high-dimensional numerical integration, while still allowing for uncertainty in cross-product estimates (Asparouhov & Muthén, 2010; Zyphur et al., 2019). Within-dyad RSA synchrony was first evaluated with a multilevel structural equation model (MSEM). To yield within-dyad estimates, as desired, mothers' reactive RSA (i.e., first-differenced RSA) was person-mean centered. At the within-dyad level, concurrent RSA synchrony was calculated as the slope of the effect of maternal reactive RSA on infant reactive RSA (following Lan et al., 2023; Miller et al., 2023):

$$iRSADiff_{i,t} = B_{0i} + B_{1i}mRSA_{i,t} + r_{i,t}$$

Plausible values for within-dyad RSA synchrony were obtained by sampling from their posterior distribution 20 times, resulting in a distribution of factor scores (Zyphur et al., 2019). Consistent with prior work (e.g., Lan et al., 2023), the resulting assessment of concurrent synchrony lies on a spectrum from positive (i.e., in-phase coordination such that infants show changes in RSA in the same direction as their mothers) to negative (i.e., anti-phase coordination such that infants show changes in RSA in the opposite direction as their mothers) values of synchrony. All between-level information per imputation was saved and subsequently analyzed in a single-level structural equation model (SEM) with maximum likelihood estimation with robust standard errors, which is an appropriate strategy for handling missing data and nonnormality (Enders, 2001). Interaction effects between within-dyad RSA synchrony and maternal PPD symptoms on 12- and 36-month outcomes were computed for the plausible values to approximate latent interactions. Models adjusted for average levels of maternal and infant RSA and other identified covariates. Continuous predictors were grand-mean centered.

Model fit and parameter estimates of the SEM were analyzed using standard imputation methodology (Asparouhov & Muthén, 2010). Significant interaction effects were probed at the mean and 1 standard deviation (SD) above and below the mean on the moderator (Aiken & West, 1991). Following recommendations for adjudicating between different patterns of interaction effects (Roisman et al., 2012), the regions of significance on X (i.e., PPD symptoms), within 2 SD of the mean, were also computed and used to interpret the pattern of the interaction effect (differential susceptibility, vantage sensitivity, or stress-diathesis). If the effect of the moderator (i.e., synchrony) on the outcome is significant at both low and high ends (within 2 SD) from the mean on the environmental exposure (i.e., maternal PPD symptoms), there can be evidence of differential susceptibility; if the effect of synchrony on the outcome is significant only at low levels (indicating a relatively more positive environment) or high levels (indicating a relatively more adverse environment) of PPD symptoms, there is evidence for vantage sensitivity or stress-diathesis models, respectively (Roisman et al., 2012). Separate models were conducted for analyses of within-dyad RSA synchrony during the baseline task and during the free play interaction. Primary analyses were conducted in M*plus* version 8.10 (Muthén & Muthén, 2017).

Results

Preliminary analyses

Selection of covariates

Average levels of maternal and infant RSA were included as *a priori* covariates. Additional potential covariates (maternal country of origin, number of children, child sex, prenatal perceived economic

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Table 1. Descriptive statistics and bivariate correlations among primary observed variables

	N	M	SD	1	2	3	4	5	6	7	8	9
1. Maternal RSA (BL)	201	5.83	1.11	—								
2. Infant RSA (BL)	194	3.10	0.85	.09	—							
3. Maternal RSA (FP)	130	4.56	0.96	**.78**	.09	—						
4. Infant RSA (FP)	130	1.86	0.74	**.22**	**.72**	.18	—					
5. Maternal depressive symptoms (24-wks.)	321	3.66	4.38	.02	.00	−.11	.06	—				
6. Maternal depressive symptoms (12-mo.)	205	10.22	8.41	−.06	.06	−.13	−.02	**.48**	—			
7. Infant behavior problems (12-mo.)	195	6.61	4.86	−.10	−.05	−.11	−.15	**.20**	**.23**	—		
8. Maternal depressive symptoms (36-mo.)	214	7.79	8.11	.10	−.01	-.01	−.05	**.29**	**.38**	.11	—	
9. Child internalizing problems (36-mo.)	215	48.77	10.58	−.00	.04	.09	.05	.10	.07	.10	**.46**	—
10. Child externalizing problems (36-mo.)	215	46.04	10.21	.02	.14	.04	**.23**	.12	.12	.13	**.43**	**.76**

Note. RSA = Average respiratory sinus arrhythmia (RSA). BL = Baseline. FP = Free play. Maternal depressive symptoms at 24 weeks were assessed with the EPDS and depressive symptoms at 12 and 36 months were assessed with the CESD. Infant behavior problems were assessed with the BITSEA and child internalizing and externalizing behavior problems were assessed with the CBCL. Correlations shown in bold are statistically significant, $p < .05$.

hardship, and 6-week infant temperament) were identified based on the theoretical literature; covariates that were associated with missingness on primary study variables and/or associations with levels of observed primary study variables were retained in primary models (see Supplementary Material for more information on covariate selection).

Descriptive statistics

Descriptive statistics and bivariate correlations of primary study variables are presented in Table 1. All continuous study variables, except 12-month infant behavior problems, had acceptable skewness and kurtosis (skewness cutoff<2 and kurtosis cutoff<7; West et al., 1995); as noted above, maximum likelihood standard errors were computed using a sandwich estimator that is robust to non-normality. Because dyadic synchrony was a latent variable that can only be estimated within a multilevel model, it was not included in these preliminary analyses.

Multilevel SEMs

MSEMs were evaluated to obtain estimates of within-dyad RSA synchrony during the free play and baseline tasks. On average, in both tasks, there was no evidence of concurrent mother-infant RSA synchrony, although there was significant variability across families in RSA synchrony. For the free play task, the fixed effect of mother-infant RSA synchrony was null, $B_1 = -0.020$, 95% CrI: [−0.047, 0.011], such that, on average, mothers' reactive RSA was not associated with her infants' concurrent reactive RSA. However, the random effect for free play mother-infant RSA synchrony was significant, Est = 0.019, 95% CrI: [0.014, 0.027], indicating significant differences across our sample in the levels of RSA synchrony during free play.

For the baseline task, the fixed effect of mother-infant RSA synchrony was null, $B_1 = 0.022$, 95% CrI: [−0.005, 0.047], such that, on average, mothers' reactive RSA was not associated with her infants' concurrent reactive RSA. However, the random effect for baseline mother-infant RSA synchrony was significant, Est = 0.025, 95% CrI: [0.020, 0.035], indicating significant differences across our sample in the levels of RSA synchrony during the baseline period.

Primary analyses

Aims 1 & 2: Role of mother-infant RSA synchrony during free play

The free play model predicted maternal depressive symptoms and child internalizing and externalizing behavior problems at 36-months from levels of maternal depressive symptoms and child behaviors at 12 months and the interaction of maternal PPD symptoms and within-dyad RSA synchrony during the 24-week free play task, adjusting for covariates. Overall, model fit to the data was good (West et al., 2012): mean RMSEA = 0.08 (SD = 0.00); mean CFI = 0.96 (SD = 0.00); mean SRMR = 0.02 (SD = 0.00). Standardized parameter estimates are shown in Table 2 and unstandardized parameter estimates are reported in the text. Surprisingly, maternal PPD symptoms were *positively* correlated with mother-infant RSA synchrony, $\phi = 0.08$, SE $\phi = 0.03$, $p = 0.005$. Greater positive mother-infant RSA synchrony was associated with fewer 12-month maternal depressive symptoms, B = −8.72, SE (B) = 3.79, $p = .021$, although this association was qualified by a significant interaction effect with 24-week PPD symptoms (described below).

With respect to our first two aims, there were significant interaction effects between mother-infant RSA synchrony during free play and maternal PPD symptoms on 12-month behavior problems, B = −2.18, SE (B) = 0.39, $p < .001$; 12-month maternal depressive symptoms, B = −2.71, SE (B) = 0.90, $p = .003$; and 36-month internalizing problems, B = −3.04, SE (B) = 1.16, $p = .009$. Post-hoc probing of interaction effects is presented in Table 4. As hypothesized, at above average (+1 SD; $Est_{Synchrony} = 0.138$) values of free play RSA synchrony, maternal PPD symptoms were not associated with 12-month infant behavior problems, Est = 0.050, SE Est = 0.045, = .27; in contrast, at average ($Est_{Synchrony} = -0.02$), Est = 0.348, SE Est = 0.039, $p = .010$ and below average (−1 SD: $Est_{Synchrony} = 0.178$) values of free play RSA synchrony, Est = 0.646, SE Est = 0.085, $p < .001$, maternal PPD symptoms were positively associated with infant behavior problems (see Figure 2). At approximately average or greater values of maternal PPD symptoms, greater positive free play RSA synchrony was associated with fewer 12-month behavior problems. These results are consistent with a stress-diathesis model, where greater positive free play RSA synchrony attenuates PPD-related risk for 12-month child behavior problems.

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Table 2. Model predicting maternal depressive symptoms and child behavior problems from within-dyad RSA synchrony during free play task

Outcome	Predictors	Beta	SE Beta	*p*	R^2
Child internalizing behavior problems (36-months)					.073***
	12-month problems	−.080	.035	.021	
	12-month depressive symptoms	−.057	.035	.100	
	24-week RSA synchrony	−0.070	0.062	.262	
	24-week depressive symptoms	0.148	0.060	.013	
	24-week RSA synchrony × depressive symptoms	−0.190	0.072	.008	
	24-week maternal average RSA	0.129	0.012	< .001	
	24-week infant average RSA	−0.079	0.035	.024	
	Country of birth	0.096	0.021	< .001	
	Prenatal economic hardship	0.106	0.007	< .001	
	6-week infant temperament	0.143	0.017	< .001	
Child externalizing behavior problems (36-months)					.202***
	12-month problems	0.031	0.031	.308	
	12-month depressive symptoms	0.176	0.029	< .001	
	24-week RSA synchrony	−0.072	0.055	.193	
	24-week depressive symptoms	−0.112	0.053	.036	
	24-week RSA synchrony × depressive symptoms	−0.108	0.073	.142	
	24-week maternal average RSA	0.002	0.011	.843	
	24-week infant average RSA	0.182	0.031	< .001	
	Country of birth	−0.214	0.019	< .001	
	Number of other children	−0.050	0.006	< .001	
	6-week infant temperament	0.277	0.016	< .001	
Maternal depressive symptoms (36-months)					.114***
	12-month problems	−0.038	.037	.311	
	12-month depressive symptoms	0.368	0.031	< .001	
	24-week RSA synchrony	−0.003	0.073	.967	
	24-week depressive symptoms	−0.061	0.073	.401	
	24-week RSA synchrony × depressive symptoms	−0.058	0.102	.569	
	24-week maternal average RSA	0.049	0.012	< .001	
	24-week infant average RSA	0.005	0.032	.914	
	Country of birth	−0.056	0.019	.003	
	Prenatal economic hardship	−0.026	0.008	.002	
	6-week infant temperament	0.092	0.013	< .001	
Infant behavior problems (12 months)					.329***
	24-week RSA synchrony	−0.119	0.071	.091	
	24-week depressive symptoms	0.374	0.041	< .001	
	24-week RSA synchrony × depressive symptoms	−0.332	0.054	< .001	
	24-week maternal average RSA	−0.031	0.017	.065	
	24-week infant average RSA	−0.355	0.027	< .001	
	Country of birth	0.208	0.033	< .001	
	Number of children	−0.135	0.014	< .001	
	6-week infant temperament	0.233	0.023	< .001	
Maternal depressive symptoms (12 months)					.482***
	24-week RSA synchrony	−0.130	0.056	.020	
	24-week depressive symptoms	0.629	0.035	< .001	

(*Continued*)

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Table 2. (*Continued*)

Outcome	Predictors	Beta	SE Beta	*p*	R^2
	24-week RSA synchrony × depressive symptoms	−0.179	0.059	.002	
	24-week maternal average RSA	−0.036	0.014	.008	
	24-week infant average RSA	−0.086	0.025	.001	
	Country of birth	0.062	0.018	< .001	
	Child sex	−0.051	0.013	< .001	
	Prenatal economic hardship	0.228	0.019	< .001	
	6-week infant temperament	−0.178	0.021	< .001	

Note. RSA = Respiratory Sinus Arrhythmia. *** $p \leq .001$. 36-month internalizing problems were correlated with 36-month externalizing problems, Est = 0.749, SE Est = 0.007, $p < .001$, and 36-month maternal depressive symptoms, Est = 0.366, SE Est = 0.018, $p < .001$. 36-month externalizing problems were also correlated with 36-month maternal depressive symptoms, Est = 0.358, SE Est = 0.016, $p < .001$. 12-month child behavior problems were correlated with 12-month maternal depressive symptoms, Est = 0.060, SE Est = 0.037, $p = .031$. For visual clarity, covariances between exogenous variables are not shown.

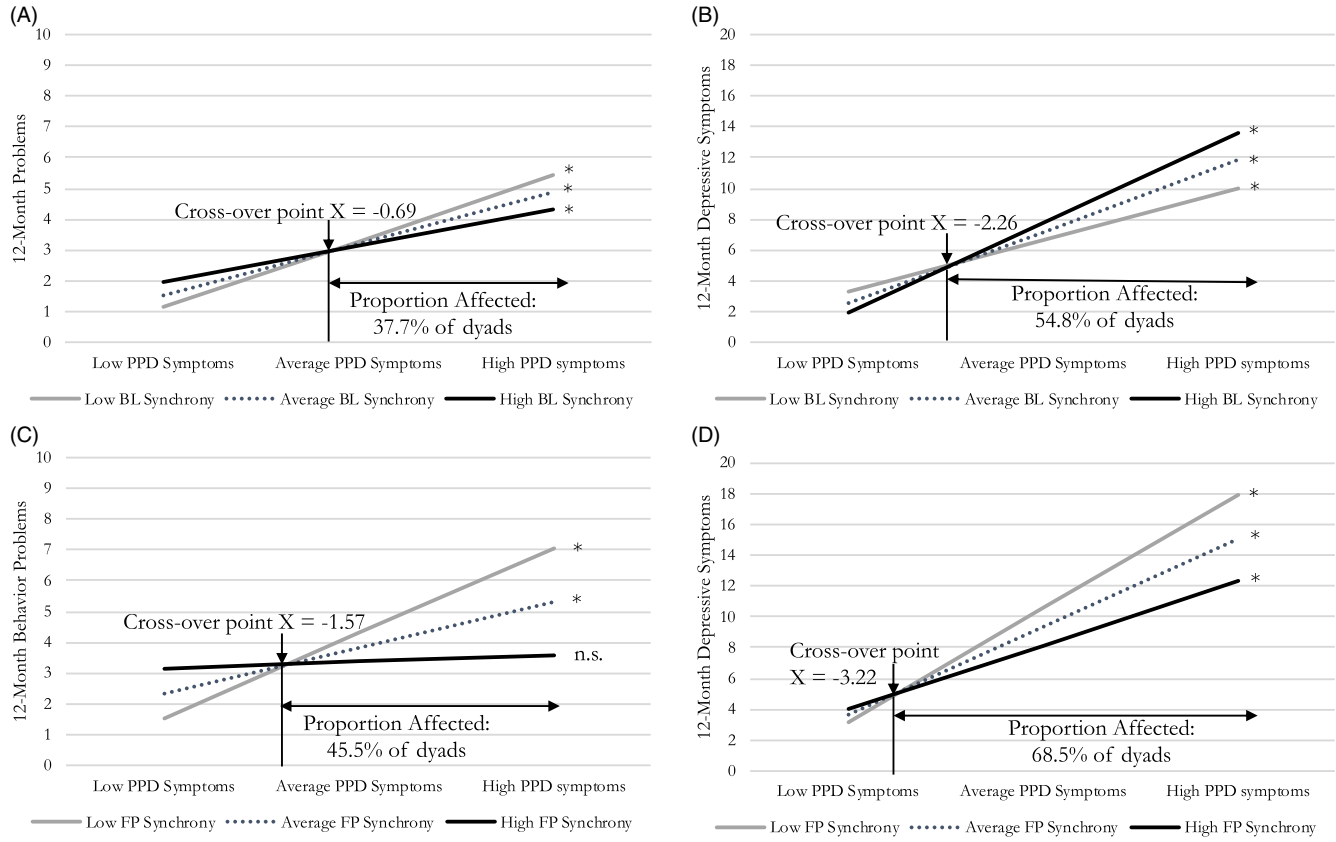

Figure 2. Interactive effects between mother-infant RSA synchrony and postpartum depressive symptoms on 12-month outcomes. *note*. BL = baseline. FP = free play. PPD = postpartum depressive symptoms. Low = -1 SD. High = + 1 SD. * $p < .05$. n.s. = not statistically significant ($p > .05$). Cross-over points are on grand-mean centered values of X.

Maternal PPD symptoms were positively associated with 12-month maternal depressive symptoms at above average, average, and below average levels of free play RSA synchrony; however, this effect was weaker at above average levels of free play RSA synchrony (above average: Est = 0.982, SE Est = 0.091, $p < .001$; average: Est = 1.353, SE Est = 0.078, $p < .001$; below average: Est = 1.724, SE Est = 0.193, $p < .001$). At approximately average or greater values of maternal PPD symptoms, greater positive free play RSA synchrony was associated with fewer 12-month maternal depressive symptoms. These results are consistent with a stress-diathesis model, where greater positive free play RSA synchrony attenuates PPD-related risk for future 12-month maternal depressive symptoms.

As hypothesized, at above average values of free play RSA synchrony, maternal PPD symptoms were not associated with 36-month child internalizing problems, Est = −0.077, SE Est = 0.087, $p = .38$. In contrast, at average, Est = 0.336, SE Est = 0.135, $p = 0.013$, and below average, Est = 0.749,

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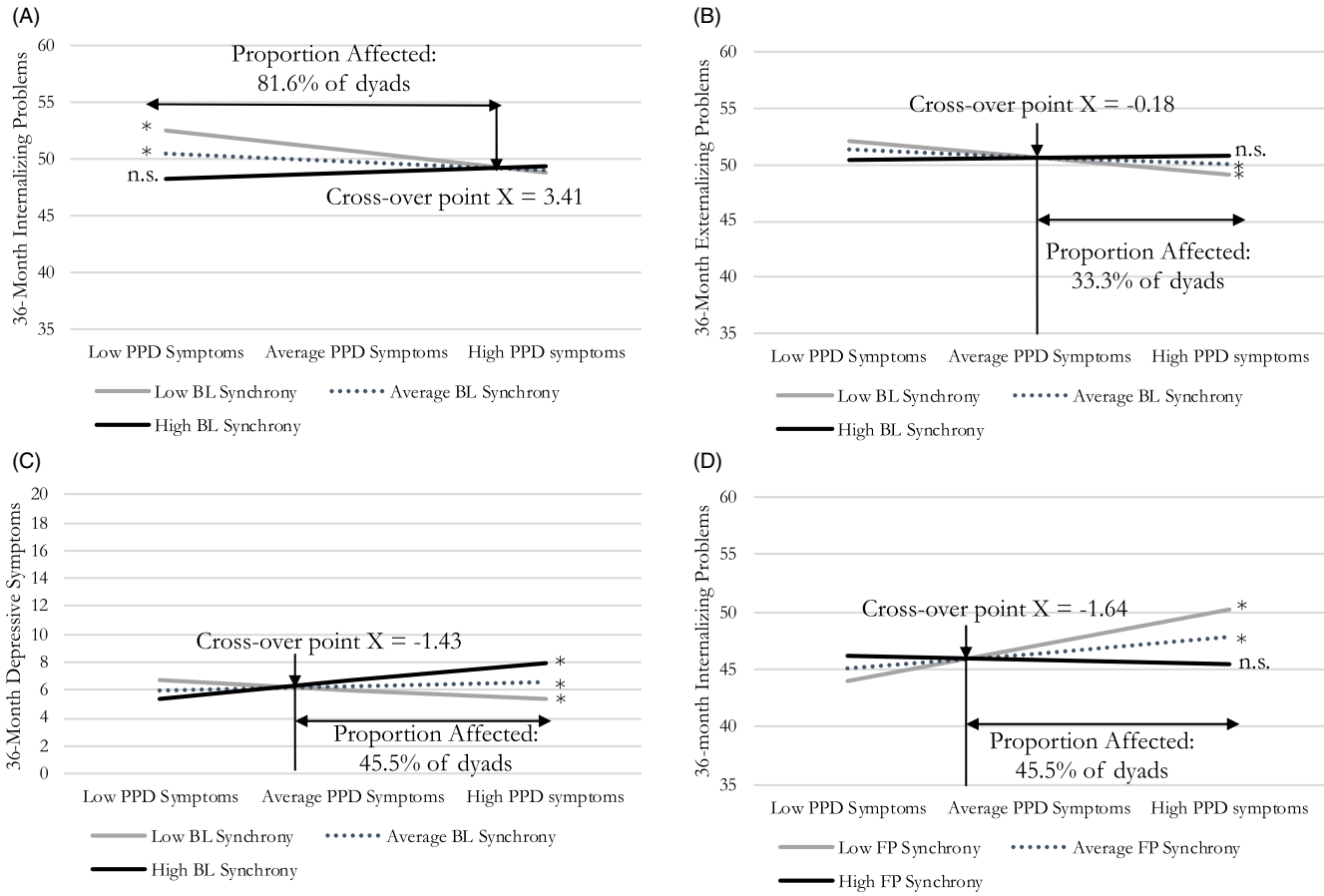

Figure 3. Interactive effects between mother-infant RSA synchrony and postpartum depressive symptoms on 36-month outcomes. *Note*. BL = baseline. FP = free play. PPD = postpartum depressive symptoms. Low = -1 SD. High = + 1 SD. * $p < .05$. n.s. = not statistically significant ($p > .05$). Cross-over points are on grand-mean centered values of X.

SE Est = 0.278, $p = .007$, values of free play RSA synchrony, maternal PPD symptoms were positively associated with child internalizing problems (see Figure 3).

At approximately average or greater values of maternal PPD symptoms, greater positive free play RSA synchrony was associated with fewer 36-month child internalizing problems. These results are consistent with a stress-diathesis model, where greater positive free play RSA synchrony attenuates PPD-related risk for 36-month child internalizing behavior problems.

Aim 3: Specificity of results to free play relative to a non-interactive baseline

The baseline model was identical to the free play model, except that it included within-dyad RSA synchrony during the 24-week baseline task. Overall, model fit to the data was good (West et al., 2012): mean RMSEA = 0.09 (SD = 0.00); mean CFI = 0.96 (SD = 0.00); mean SRMR = 0.03 (SD = 0.00). Standardized parameter estimates are shown in Table 3 and unstandardized parameter estimates are reported in the text. Maternal PPD symptoms were not correlated with mother-infant RSA synchrony during the baseline task, φ = -0.02, SE φ = 0.02, $p = 0.32$. Baseline mother-infant RSA synchrony was also not associated with 12- or 36-month outcomes (all p's > 0.07).

With respect to our third aim, we surprisingly demonstrated statistically significant interaction effects between mother-infant RSA synchrony and maternal PPD symptoms on 12-month behavior problems, B = −0.67, SE $B = 0.26$, $p = .011$; 12-month maternal depressive symptoms, $B = 1.68$, SE $B = 0.33$, $p \leq .001$; 36-month internalizing problems, $B = 1.69$, SE $B = .47$, $p = .001$; 36-month externalizing problems, $B = 1.14$, SE $B = 0.38$, $p = .003$; and 36-month maternal depressive symptoms, $B = 1.38$, SE $B = 0.33$, $p \leq .001$. Post-hoc probing of interaction effects is presented in Table 4. As shown in Table 5 and described in the text below, the pattern of interaction effects between mother-infant RSA synchrony and maternal PPD symptoms on 12- and 36-month outcomes differed for free play and RSA synchrony (with the exception of effects on 12-month child behavior problems).

Maternal PPD symptoms were positively associated with 12-month infant behavior problems at above average (Est = 0.459, SE Est = 0.035, $p < .001$), average (Est = 0.354, SE Est = 0.015, $p < .001$), and below average (Est = 0.249, SE Est = 0.050, $p < .001$) levels of RSA synchrony; this effect was weaker at below average (−1 SD; $Est_{Synchrony} = -0.182$) levels of baseline RSA synchrony. At above average or greater values of PPD symptoms, greater positive baseline RSA synchrony was associated with fewer infant behavior problems. Consistent with a stress-diathesis model, at very high levels of maternal PPD symptoms, greater positive baseline RSA synchrony attenuated PPD-related risk for 12-month child behavior problems.

Likewise, maternal PPD symptoms were positively associated with 12-month maternal depressive symptoms at above average

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Table 3. Model predicting maternal depressive symptoms and child behavior problems from within-dyad RSA synchrony during baseline task

Outcome	Predictors	Beta	SE Beta	*p*	R^2
Child internalizing behavior problems (36-months)					.108***
	12-month problems	0.006	0.014	.671	
	12-month depressive symptoms	0.129	0.016	< .001	
	24-week RSA synchrony	−0.087	0.050	.078	
	24-week depressive symptoms	−0.067	0.019	< .001	
	24-week RSA synchrony × depressive symptoms	0.138	0.039	< .001	
	24-week maternal average RSA	0.103	0.014	< .001	
	24-week infant average RSA	−0.008	0.014	.554	
	Country of birth	−0.107	0.012	< .001	
	Prenatal economic hardship	0.138	0.006	< .001	
	6-week infant temperament	0.122	0.011	< .001	
Child externalizing behavior problems (36-months)					.219***
	12-month problems	0.010	0.012	.433	
	12-month depressive symptoms	0.175	0.016	< .001	
	24-week RSA synchrony	0.003	0.052	.955	
	24-week depressive symptoms	−0.063	0.020	.002	
	24-week RSA synchrony × depressive symptoms	0.097	0.033	.003	
	24-week maternal average RSA	−0.067	0.010	< .001	
	24-week infant average RSA	0.236	0.009	< .001	
	Country of birth	−0.267	0.009	< .001	
	Number of other children	−0.061	0.007	< .001	
	6-week infant temperament	0.165	0.009	< .001	
Maternal depressive symptoms (36-months)					.246***
	12-month problems	−0.049	0.012	< .001	
	12-month depressive symptoms	0.378	0.013	< .001	
	24-week RSA synchrony	0.040	0.026	.124	
	24-week depressive symptoms	0.039	0.017	.019	
	24-week RSA synchrony × depressive symptoms	0.147	0.033	< .001	
	24-week maternal average RSA	−0.023	0.007	.001	
	24-week infant average RSA	−0.063	0.010	< .001	
	Country of birth	−0.081	0.008	< .001	
	Prenatal economic hardship	0.107	0.008	< .001	
	6-week infant temperament	0.061	0.010	< .001	
Infant behavior problems (12 months)					.225***
	24-week RSA synchrony	−0.013	0.035	.713	
	24-week depressive symptoms	0.302	0.013	< .001	
	24-week RSA synchrony × depressive symptoms	−0.103	0.040	.011	
	24-week maternal average RSA	0.034	0.019	.076	
	24-week infant average RSA	−0.157	0.016	< .001	
	Country of birth	0.253	0.010	< .001	
	Number of children	0.013	0.010	.173	
	6-week infant temperament	0.234	0.009	< .001	
Maternal depressive symptoms (12 months)					.447***
	24-week RSA synchrony	0.067	0.036	.067	
	24-week depressive symptoms	0.514	0.010	< .001	

(*Continued*)

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Table 3. (*Continued*)

Outcome	Predictors	Beta	SE Beta	*p*	R^2
	24-week RSA synchrony × depressive symptoms	0.158	0.032	< .001	
	24-week maternal average RSA	0.005	0.010	.587	
	24-week infant average RSA	−0.088	0.013	< .001	
	Country of birth	0.163	0.008	< .001	
	Child sex	−0.039	0.008	< .001	
	Prenatal economic hardship	0.264	0.008	< .001	
	6-week infant temperament	0.009	0.007	.185	

Note. RSA = Respiratory Sinus Arrhythmia. *** $p \leq .001$. 36-month internalizing problems were correlated with 36-month externalizing problems, Est = 0.749, SE Est = 0.06, $p < .001$, and 36-month maternal depressive symptoms, Est = 0.353, SE Est = 0.011, $p < .001$. 36-month externalizing problems were also correlated with 36-month maternal depressive symptoms, Est = 0.292, SE Est = 0.009, $p < .001$. 12-month child behavior problems were correlated with 12-month maternal depressive symptoms, Est = 0.164, SE Est = 0.012, $p < .001$. For visual clarity, covariances between exogenous variables are not shown.

(Est = 1.250, SE Est = 0.058, $p < .001$), average (Est = 0.986, SE Est = 0.022, $p < .001$), and below average (Est = 0.722, SE Est = 0.056, $p < .001$) levels of RSA synchrony, and this effect was weaker at below average levels of baseline RSA synchrony (see Figure 2). At average or greater values of PPD symptoms, greater positive baseline RSA synchrony was associated with *more* maternal depressive symptoms. These results are consistent with a stress-diathesis model, where greater positive baseline RSA synchrony operates as a diathesis (rather than protective factor) for PPD-related risk for future 12-month maternal depressive symptoms.

At above average (+1 SD; $Est_{Synchrony} = 0.138$) levels of baseline RSA synchrony, maternal PPD symptoms were not associated with 36-month child internalizing problems (Est = 0.116, SE Est = 0.109, $p = 0.29$) or child externalizing problems (Est = 0.045, SE Est = 0.099, $p = 0.65$). Surprisingly, at average (Est = −0.150, SE Est = 0.032, $p < .001$) and low (Est = −0.315, SE Est = 0.052, $p < .001$) levels of baseline RSA synchrony, maternal depressive symptoms were associated with fewer child internalizing problems. Only at average or below values of maternal PPD symptoms, greater positive baseline RSA synchrony was related to fewer child internalizing problems at 36-months. These results are consistent with a vantage sensitivity model, where greater positive baseline RSA synchrony promotes the beneficial effects of maternal psychological adjustment (i.e., low PPD symptoms) for 36-month child internalizing problems.

Likewise, at average (Est = −0.134, SE Est = 0.042, $p = .001$) and low (Est = −0.314, SE Est = 0.037, $p < .001$) levels of baseline RSA synchrony, maternal depressive symptoms were associated with fewer child externalizing problems (see Figure 3). At above average values of PPD symptoms, greater positive baseline RSA synchrony was related to more child externalizing problems at 36-months. These results are consistent with a stress-diathesis model, where greater positive baseline RSA synchrony operates as a diathesis for PPD-related risk for 36-month child externalizing problems.

Maternal PPD symptoms were positively associated with maternal depressive symptoms at 36-months at above average (Est = 0.284, SE Est = .070, $p < .001$) and average (Est = 0.066, SE Est = 0.029, $p = 0.020$) levels of baseline RSA synchrony. In contrast, maternal PPD symptoms were negatively associated with maternal depressive symptoms at below average (Est = −0.151, SE Est = 0.044, $p = .001$) levels of RSA synchrony (see Figure 3). At average or above values of PPD symptoms, greater positive baseline RSA synchrony was related to more maternal depressive symptoms. These results are consistent with a stress-diathesis model, where greater positive baseline RSA synchrony operates as a diathesis for PPD-related risk for future 36-month maternal depressive symptoms.

Discussion

Extending recent theoretical advances in biobehavioral synchrony research, which recognize the interdependence between parents and their children across multiple timescales of development (Feldman, 2012), the current study evaluated a novel, *dyadic* model of the protective role of mother-infant parasympathetic nervous system synchrony during play following exposure to maternal PPD symptoms, for both mothers and their children. As expected, among low-income, Mexican-origin families, associations between maternal PPD symptoms and (1) greater offspring total behavior problems at 12 months and internalizing problems at 36 months and (2) worse maternal depressive symptoms at 12 months were attenuated for families with stronger positive RSA synchrony during a free play task at 24-weeks. Further, protective aspects of positive RSA synchrony were generally specific to a playful mother-infant interaction and not evident during a non-interactive resting task. Our results suggest that dyadic sources of resilience reflect *active* mechanisms that support emotion co-regulation during play, rather than passive entrainment of children's and parents' physiological rhythms that occur without parents' effortful attempts to influence or interact with their child (Wass et al., 2024).

Dyads who were exposed to elevated PPD symptoms but had stronger positive RSA synchrony during play exhibited fewer behavior problems in infancy and fewer internalizing problems in early childhood than their counterparts with weaker (or negative) RSA synchrony. Our results extend recent evidence of the protective benefits of RSA synchrony during mother-infant play for toddler internalizing problems (Lan et al., 2023) by demonstrating that these results are in fact specific to childhood internalizing problems and also are evident for both members of the dyad. During playful interactions, which are characterized by simultaneous vocalization and positive affect (Feldman et al., 2011), positive RSA synchrony may operate with a broader, multimodal form of biobehavioral synchrony that fosters emotion co-regulation (Feldman, 2020). In contrast, negative RSA synchrony may co-occur with poorly coordinated or dysregulated behavioral interaction patterns during play (e.g., withdrawn or intrusive behavior). Though internalizing problems are

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Table 4. Post-hoc probing of significant interaction effects

		Simple slopes for the effect of PPD symptoms on outcome			Regions of significance for the effect of synchrony on outcome	
Task	Outcome	Low (−1 SD) Synchrony	Average Synchrony	High (+1 SD) Synchrony	Value of PPD symptoms	Simple slope at region
12-Month Outcomes						
Free play	Infant behavior problems	0.646***	0.348**	0.050	≥0.04 SD	−3.826
Baseline	Infant behavior problems	0.249***	0.354***	0.459***	≥0.97 SD	−3.297
Free play	Maternal depressive symptoms	1.724***	1.353***	0.982***	≥−0.10 SD	−7.495
Baseline	Maternal depressive symptoms	0.722***	0.986***	1.250***	≥0.04 SD	4.09
36-Month Outcomes						
Free play	Child internalizing problems	0.749**	0.336*	−0.077	≥0.33 SD	−9.314
Baseline	Child internalizing problems	−0.315***	−0.150***	0.116	≤−0.08 SD	−6.33
Free play	Child externalizing problems	—	—	—	—	—
Baseline	Child externalizing problems	−0.314***	−0.134***	0.045	≥1.63 SD	8.38
Free play	Maternal depressive symptoms	—	—	—	—	—
Baseline	Maternal depressive symptoms	−0.151***	0.066*	0.284***	≥.08 SD	2.48

Note. SD = standard deviation. ***$p \leq .001$. **$p \leq .01$. *$p < .05$. — Non-significant interaction effect.

Table 5. Pattern of interaction effects between mother-infant RSA synchrony and maternal postpartum depressive symptoms on outcomes

	Free Play RSA Synchrony		Baseline RSA Synchrony	
Outcome	Pattern of Interaction	Interpretation	Pattern of Interaction	Interpretation
12-Month Outcomes				
Infant behavior problems	Stress-diathesis	Low synchrony = diathesis	Stress-diathesis	Low synchrony = diathesis
Maternal depressive symptoms	Stress-diathesis	Low synchrony = diathesis	Stress-diathesis	High synchrony = diathesis
36-Month Outcomes				
Child internalizing problems	Stress-diathesis	Low synchrony = diathesis	Vantage sensitivity	High synchrony = vantage factor
Child externalizing problems	—	—	Stress-diathesis	High synchrony = diathesis
Maternal depressive symptoms	—	—	Stress-diathesis	High synchrony = diathesis

Note. The pattern of the interaction effect was interpreted based on Roisman et al. (2012). — Indicates there was not a statistically significant interaction effect on the outcome. Stress-diathesis = Adverse developmental experiences (i.e., elevated levels of postpartum depressive symptoms) are most likely to impact those who possess a diathesis. Vantage sensitivity = Salutary developmental experiences (i.e., low levels of postpartum depressive symptoms) are most likely to impact those who carry a vantage factor.

characterized by high levels of negative affect, recent theoretical models highlight the role of positive affect in the etiology of internalizing problems (Breaux et al., 2022; Kujawa & Burkhouse, 2017; Nusslock & Alloy, 2017). Our results extend these theoretical models by tracing the importance of the socialization and regulation of positive affect in the etiology of internalizing problems to *dyadic* physiological co-regulation during playful interactions characterized by relatively more frequent expressions of positive affect. Further, positive RSA synchrony during play, especially in the context of maternal mental health problems, may enhance mothers' ability to reap the affective rewards of parenting, which in turn may attenuate risk for worsening depressive symptoms across infancy. For women who hold traditional values of *familismo* and *marianismo*, which encompass implicit values of prioritizing motherhood and caring for children (Castillo & Cano, 2007), the ability to attune with and co-regulate their babies may help mothers to overcome perinatal mental health challenges. The protective benefits of positive RSA synchrony during play on maternal mental health were only apparent during infancy, suggesting the perinatal period (i.e., from pregnancy throughout the first year after her child's arrival) may be a time of unique plasticity in maternal mental health that maximizes the potential benefits of positive dyadic co-regulatory experiences.

Rather than acting as a buffer against the effects of PPD symptoms, stronger positive RSA synchrony during a non-interactive baseline task acted as a diathesis and amplified risk associated with maternal PPD symptoms on maternal depressive symptoms at 12 and 36 months and on child externalizing problems at 36 months. In contrast, stronger positive RSA synchrony during the baseline task attenuated depression-related risk on 12-month child behaviors (similar to the pattern obtained for free play synchrony) and amplified the salutary effects of low levels of maternal PPD symptoms on 36-month child internalizing problems. Whereas synchrony that occurs during an unstructured play context may reflect coordinated biobehavioral processes that serve to maintain an optimal level of arousal for the dyad (i.e., active co-regulation), synchrony during the resting baseline task may reflect entrainment to each partner's biobehavioral rhythms that unfolds over a longer time course (Wass et al., 2024). Early in life, this passive entrainment may reflect a child's attunement to maternal biobehavioral signals. Youth with lower-risk mothers may reap the salutary benefits of maternal sensitivity and emotional availability on internalizing problems. However, close attunement to depressed mothers, who tend to be less sensitive and responsive (Goodman et al., 2020) and may exhibit more volatile physiological signals (Somers et al., 2021b), may lead children to adapt to a harsh or unpredictable environment in ways that heighten their vigilance to threat cues, distractibility, and impulsivity and increase risk for children's externalizing problems (Glover, 2011; Monk et al., 2019; Sandman et al., 2012) and in turn for poorer maternal wellbeing. The results of the present study suggest that the effects of dyadic synchrony may be context- and domain-specific; yet, we were only able to reliably assess internalizing and externalizing problems in childhood, and earlier assessments of child internalizing and externalizing problems are needed to inform the timing of these effects, including both the duration of effects on maternal mental health and the emergence of differential effects on child internalizing and externalizing problems. Future research is also needed to evaluate how maternal mental health and the history of dyadic interactions shapes synchrony during *and* in the absence of interaction, which each influence the longer-term effects of the mother-child relationship on both members of the dyad.

Associations between postpartum depressive symptoms and RSA synchrony

Surprisingly, in the present study, PPD symptoms were *positively* associated with positive mother-infant RSA synchrony during play, and were not associated with RSA synchrony during the non-interactive baseline. These results add to a mixed literature on maternal mental health correlates of RSA synchrony. Prior work with infants and young children failed to detect associations between maternal depressive symptoms and RSA during play tasks (Lan et al., 2023; Lunkenheimer et al., 2018). However, elevated maternal emotion dysregulation has been associated with attenuated mother-driven RSA synchrony during and immediately after a relational challenge (Gao et al., 2023). Likewise, among older children and adolescents, there is some evidence that maternal depression may contribute to dampened or negative RSA synchrony across negative tasks (Amole et al., 2017; Woody et al., 2016; McKillop & Connell, 2018; Suveg et al., 2019). Dyads with mothers who face mental health difficulties may not show typical patterns of positive RSA synchrony specifically during challenging interpersonal interactions; by contrast, less stressful interactions (e.g., play) may offer these dyads unique opportunities for cultivating resilience. Among low-income, Latina women, more severe PPD symptoms are associated with more frequent and severe exposures to stressors, which may be due to inequalities in access to community resources and racial discrimination (Krieger, 2008) that predate the birth of their child (Roubinov et al., 2021). The arrival of their baby may present a unique period of plasticity in maternal adjustment, and mothers may actively seek out opportunities for synchrony and co-regulation to improve their own wellbeing. Pending replication of our results, longitudinal research on how maternal depression influences the development of mother-child RSA synchrony is warranted.

Strengths and limitations

Our study design assessed dyadic factors involved in resilience at multiple timescales, including second-by-second assessment of maternal and infant RSA during interactive and non-interactive tasks, as well as repeated measures of both maternal depression and child behavior problems collected from infancy through early childhood. Extending prior child-focused research on the effects of mother-infant RSA synchrony, our study is one of few studies to assess long-term effects of synchrony and the first to our knowledge to assess its effects on both members of the dyad. Further, the results held after adjusting for infant difficult temperament, a well-established risk factor for later child behavior problems and maternal stress/mental health (Kiff et al., 2011), strengthening our interpretation that RSA synchrony accounts for variation in later maternal and child outcomes. Our focus on low-income, Mexican-origin families addressed a critical gap in the literature, which has typically focused on White populations with relatively low levels of environmental risk (e.g., Graziano & Derefinko, 2013; van IJzendoorn & Bakermans-Kranenburg, 2015), despite the higher likelihood of postpartum mental health problems and child behavior problems among low-income, Latina families in the United States (e.g., Chaudron et al., 2005), for whom dyadic factors may be especially salient source of resilience (Cabrera et al., 2022; Perreira & Allen, 2021).

Nevertheless, the results must be understood in the context of our study's limitations. Our results may not generalize to more challenging social interactions, different developmental periods,

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families with greater socioeconomic resources, or families from other ethnic backgrounds. Our evaluation of concurrent mother-infant RSA synchrony was based on simultaneous moment-to-moment changes between mothers' and infants' physiology, which is the most common model of synchrony in the literature (e.g., Lan et al., 2023; Miller et al., 2023); however, time-lagged models are needed to evaluate potentially causal positive and negative feedback loops that regulate each dyad member's emotional states (Somers et al., 2024; Wass et al., 2024). Supporting our vagal interpretation of RSA, we set the frequency band for RSA using age-appropriate values for infants and mothers; however, because respiration was not directly assessed, obtained RSA values may reflect cardiac parasympathetic control rather than parasympathetic activity (Quigley et al., 2024). Our sample size also precluded assessment of sex differences in the effects of RSA synchrony; as sex differences in behavior problems begin to emerge in later childhood and adolescence (Jose & Brown, 2008), future research could address how early synchrony, in concert with environmental factors, contributes to the development of internalizing versus externalizing behavior problems. Future work with multi-informant assessments of maternal internalizing problems (e.g., depression and anxiety), along with assessments of biobehavioral synchrony across different physiological systems and in a range of ecologically-valid contexts (including challenging conditions; Somers et al., 2024), would advance our understanding of what types of synchrony can promote dyadic resilience, which may vary depending on the units of analysis and interaction context in which synchrony is assessed and the timing and domains of mental health problems (e.g., Somers et al., 2024).

Conclusions

The current study extends child-focused perspectives on synchrony by demonstrating *context-specific* processes in which physiological synchrony can confer resilience for both low-income, Mexican-origin mothers and their young children. Rather than reflecting passive entrainment of physiological regulatory capacities, reciprocal coordination of mothers' and their infant's parasympathetic functioning during play may protect infants and their mothers against the adverse consequences of postpartum depressive symptoms on maternal depression and early childhood internalizing problems. Our results suggest that attention to the interdependence in maternal and child functioning, from moment-to-moment physiological fluctuations to longer-term developmental trajectories, is necessary for early prevention and intervention efforts.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954579424001950.

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Competing interests. The author has no conflicts of interest to declare.

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