Check for updates

Received: 22 April 2022 | Revised: 8 October 2022 | Accepted: 2 November 2022

DOI: 10.1002/dev.22355

RESEARCH ARTICLE

Developmental Psychobiology WILEY

A meta-analysis of mother–child synchrony in respiratory sinus arrhythmia and contextual risk

Jonas G. Miller[1,2] | Emma Armstrong-Carter[3] | Leah Balter[3] | Julie Lorah[4]

[1]Department of Psychology, Stanford University, Stanford, California, USA

[2]Department of Psychological Sciences, University of Connecticut, Storrs, Connecticut, USA

[3]Graduate School of Education, Stanford University, Stanford, California, USA

[4]Department of Education and Human Development, Clemson University, Clemson, South Carolina, USA

Correspondence
Jonas G. Miller, Department of Psychological Sciences, University of Connecticut, Weston A. Bousfield Psychology Building, Storrs, CT 06269, USA.
Email: jonas.miller@uconn.edu

Funding information
Stanford Center on Longevity New Map of Life Fellowship; Stanford Data Science Fellowship; Institute of Education Sciences, U.S. Department of Education, Grant/Award Number: R305B140009

Abstract

Biobehavioral frameworks of attachment posit that mother–child dyads engage in physiological synchrony that is uniquely formative for children's neurobiological, social, and emotional development. Much of the work on mother–child physiological synchrony has focused on respiratory sinus arrhythmia (RSA). However, the strength of the existing evidence for mother–child RSA synchrony during interaction is unclear. Using meta-analysis, we summarized results from 12 eligible studies comprising 14 samples and 1201 children ranging from infancy to adolescence (M_{age} = 5.68 years, SD = 4.13, range = 0.4–17 years) and their mothers. We found that there was a statistically significant, albeit modest, positive within-dyad association between mother and child fluctuations in RSA. There also was evidence for significant heterogeneity across studies. Less mother–child RSA synchrony was observed in high-risk samples characterized by clinical difficulties, history of maltreatment, or socioeconomic disadvantage. We did not find that mother–child RSA synchrony significantly differed by task context, mean child age, or by epoch length for computing RSA. Collectively, these findings suggest that mother–child dyads show correspondence in their fluctuations in RSA, and that RSA synchrony is disrupted in high-risk contexts. Future directions and implications for the study of parent–child physiological synchrony are discussed.

KEYWORDS
meta-analysis, parent–child, physiology, respiratory sinus arrhythmia, synchrony

1 | INTRODUCTION

Parent–child interactions are characterized by physiological changes in both partners. The extent that these physiological changes are coupled may reflect dyadic processes of mutual responsivity (Davis et al., 2018). By measuring child and parent physiology continuously and simultaneously, researchers can observe whether child and parent physiological responses dynamically fluctuate together—that is, *synchronize*—over time while they are interacting (Davis et al., 2018). Physiological synchrony is the extent to which increases or decreases in the child's physiological activation correspond to changes in the parent's physiological activation, and vice versa. According to the biobehavioral conceptual framework of attachment, parent–child physiological synchrony is uniquely formative for children's neurobiological, social, and emotional development (Feldman, 2017). Specifically, physiological synchrony is believed to influence children's brain maturation and ability to form interpersonal attachments, self-regulate, and engage positively with their environment (Feldman, 2017), and therefore is of increasing interest to developmental researchers.

In the past 25 years, several studies have investigated parent–child synchrony of fluctuations in the parasympathetic nervous system, primarily in mother–child dyads. The parasympathetic nervous system offers unique insight as a marker of physiological synchrony, because it responds dynamically to mild and moderate social and emotional experiences from moment to moment (Porges, 2007). Activity in the parasympathetic nervous system can be measured using respiratory

© 2022 Wiley Periodicals LLC.

sinus arrhythmia (RSA), reflecting the high-frequency heart rate variation controlled by efferent fibers of the vagus nerve during the respiratory cycle. To date, studies of parent–child RSA synchrony have yielded mixed findings (Davis et al., 2018), potentially due to differences in study samples and designs. A systematic meta-analysis is needed to clarify whether mother–child synchrony is consistently found in the literature thus far, and among which mother–child dyads and contexts it emerges. This meta-analysis investigated whether mothers and children show concurrent synchrony in RSA during dyadic interaction (i.e., simultaneous increases and decreases in RSA in mother and child), and whether the degree of synchrony differs depending on demographic and methodological factors, including high- versus low-risk samples, challenging versus nonchallenging tasks, child age, and epoch length used for computing RSA.

1.1 | Synchrony of RSA

The biobehavioral conceptual framework of attachment posits that parent–child physiological synchrony reflects, in part, the quality of parent–child relationships and coordinated behavioral and emotional responsivity (Feldman, 2007; Feldman et al., 1999). Positive parent–child relationships characterized by mutual responsivity, potentially rooted in physiological synchrony, help children to internalize self-regulated behavior and adjust positively across developmental domains (MacPhee et al., 2015). One way to measure physiological synchrony is through measures of the parasympathetic nervous system—the "rest and digest" branch of the autonomic nervous system. By measuring child and parent parasympathetic activity simultaneously and continuously during parent–child interaction, researchers can observe whether changes in child physiological arousal correspond to changes in parent physiological arousal over time (Davis et al., 2018). Polyvagal theory posits that decreases in RSA during challenge reflect positive coping and engagement in the moment, whereas maintaining or increasing RSA during interpersonal interaction reflects calm, social engagement (Porges, 2007). Therefore, assessing simultaneous changes in parent and child RSA may help illuminate the degree to which parent–child dyads are mutually responsive to each other during interaction. In addition, RSA responds dynamically to mild and moderate social and emotional experiences from moment to moment (Porges, 2007), and therefore offers insight into physiological synchrony during mild or moderately challenging interactive tasks involving parents and children.

1.2 | Variation among studies

Studies that investigated parent–child synchrony of the parasympathetic nervous system have yielded mixed findings (Davis et al., 2018). A meta-analysis of these mixed findings can determine the overall evidence for the hypothesis that parent–child dyads engage in physiological synchrony, and help to clarify what that physiological synchrony might look like. Some studies have found positive synchrony (e.g., mother RSA increases are associated with child RSA increases; Li et al., 2020), whereas others found negative synchrony (e.g., mother RSA increases are associated with child RSA decreases; Ostlund et al., 2017), and still others found no significant synchrony between child and parent RSA (e.g., Creaven et al., 2014). These differences in findings may be due to study characteristics, such as whether the sample is low risk versus high risk, whether the parent–child interaction task was challenging (e.g., a conflict discussion), the age range of the children in the study (e.g., preschoolers vs. adolescents), and the epoch length used for computing RSA. We now consider each of these in turn.

1.3 | Differences in synchrony by low- versus high-risk samples

One potential difference in empirical findings may be due to sample characteristics, in particular, whether studies investigated RSA synchrony in a low-risk, community sample versus a high-risk sample characterized by clinical difficulties, history of maltreatment, or socioeconomic disadvantage. In community samples, some studies have shown positive RSA synchrony among parent–child dyads with more positive relationships and emotional security. For example, in a community sample of 110 preschool-aged children and their mothers, only dyads that demonstrated high mutually responsive behavior displayed positive RSA synchrony during puzzle and pretend play tasks (Hu et al., 2021). Similarly, in a community sample of 191 12-year-olds and parents, only adolescents with relatively higher levels of emotional security displayed positive RSA synchrony with their mother during a family conflict discussion (Li et al., 2020).

In contrast to these findings from community samples, several studies of families considered at risk for emotional and behavioral problems have found either negative RSA synchrony or statistically nonsignificant RSA synchrony. One study of 105 mothers at risk for parenting difficulties and their 5-month-old infants found negative synchrony when parents and children were reunited after an emotionally challenging "still face" task (Ostlund et al., 2017). Another study of 82 3-year-olds at risk for externalizing problems found that children with high levels of externalizing problems displayed negative RSA synchrony during a parent-child challenge task (Lunkenheimer et al., 2021). In one study of 146 3- to 5-year-olds and their mothers, nonmaltreating dyads showed positive RSA synchrony during two problem-solving tasks, while maltreating dyads did not show RSA synchrony (Lunkenheimer, Busuito, et al., 2018). A study of 59 mother–adolescent dyads found that dyads with mothers who reported low levels of depressive symptoms displayed positive RSA synchrony during conflict and fun activity discussion tasks, whereas dyads with mothers who reported more severe depressive symptoms showed significantly weaker synchrony (McKillop & Connell, 2018). Notably, one study of 104 3 to 5-year-olds found no evidence of significant RSA synchrony among either maltreated or nonmaltreated dyads (Creaven et al., 2014). Although the literature has produced some inconsistent findings, overall, these studies may suggest that parents and children from community samples show positive synchrony in RSA during

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

interaction, whereas dyads at risk in relation to maltreatment, depression, or child behavioral problems either do not show synchrony or show weaker synchrony. Conceptually, according to biobehavioral theories of attachment, parent–child physiological synchrony may be weaker among dyads who have more difficult relationships because synchrony is a uniquely formative experience for children's positive neurobiological, social, and emotional development (Feldman, 2017). Evaluating this qualitative interpretation of the literature requires quantitative meta-analysis to determine whether synchrony is less positive or weaker among at-risk dyads.

1.4 | Differences in synchrony by task context

To investigate the contexts in which physiological synchrony occurs, researchers have also measured physiological synchrony across several different types of interactions. Specifically, prior studies have used a variety of tasks ranging from those that are low in challenge and emotionally neutral or positive (e.g., free play) to those that are emotionally laden, challenging, or negative (e.g., a discussion about a potential conflict between parent and child or emotionally laden film). At age 15, adolescents and parents showed concurrent RSA synchrony during a discussion of pleasant events, but not during a conflict discussion (Amole et al., 2017). In contrast, at age 10, concurrent RSA synchrony was strongest during a conflict discussion, compared to a baseline sitting task and a task in which the child performed a stressful speech while the parent observed (Suveg et al., 2019). In a study of preschoolers, positive RSA synchrony was strongest during free play and clean up, compared to a structured teaching task (Lunkenheimer, Busuito, et al., 2018). However, in another study of 94 5-year-old children and their parents, parent and child RSA synchronized positively on average during more structured tasks (i.e., problem-solving and puzzle teaching tasks) but not less-structured free play and clean up tasks (Armstrong-Carter et al., 2021). A study of 158 3- to 4-year-old children and their mothers who watched a short, emotional film clip together found positive synchrony only during seconds of the film when there was an increase in negative emotional content (Ravindran et al., 2021). These findings suggest that physiological synchrony may differ during tasks that are more emotionally challenging or negative compared to more neutral or positive, although the nature of these differences is unclear (e.g., RSA synchrony could be more positive or more negative in challenging contexts). Considering RSA synchrony across different tasks may reveal the social contexts in which RSA synchrony occurs or is strongest, and thereby shed light on the environmental circumstances in which RSA synchrony emerges.

1.5 | Differences in synchrony by child age

There may be developmental differences in the extent to which parent and child physiology are related. To shed light on developmental change, it is important to investigate whether child and parent synchrony differs across age ranges (Davis et al., 2018). Parent–child synchrony may be stronger during younger (e.g., preschool age) than older age periods given that young children are still closely attuned to and reliant on their parents. In contrast, older children and adolescents may show less synchrony as they transition toward increasing behavioral independence. Although most studies have not investigated age differences in RSA synchrony in the same sample, comparing studies that focused on different ages may reveal developmental differences in RSA synchrony between studies.

1.6 | Differences in synchrony by epoch length used to compute RSA

RSA has been computed using a range of epoch lengths. The majority of studies have considered RSA based on 30-s epochs of data, whereas some recent work has considered mother–child RSA synchrony based on shorter durations, including second-by-second estimates. The epoch length used represents an assumption about the temporal resolution and number of within-dyad RSA estimates that are necessary for uncovering synchrony. However, to our knowledge, prior studies have not examined whether mother–child RSA synchrony varies by epoch length.

1.7 | Current study

This study was a meta-analysis of mother–child RSA synchrony. We examined whether (1) mothers and children showed concurrent synchrony during dyadic interaction across empirical studies and (2) whether the degree of interaction varied depending on methodological and sample characteristics of risk status, task context, child age, and epoch length used to compute RSA. Our goals were to shed light on the degree of existing evidence for mother–child RSA synchrony, and to assess for whom is mother–child RSA synchrony strongest (either positive or negative synchrony).

2 | METHODS

2.1 | Procedure

2.1.1 | Literature review

We conducted a literature review of empirical research about parent–child physiological synchrony with no publication date limits. Pertinent articles were identified via PubMed, APA PsycNet, and Google Scholar. The search terms concerned three main categories: physiological measure, synchrony, and parent–child dyads. Physiology search terms included *physiology*, *respiratory sinus arrhythmia*, *RSA*, *heart rate variability*, *HRV*, *vagal tone*, *ECG*, and *physiological regulation*. Synchrony search terms included *concordance*, *synchrony*, *coregulation*, *covariation*, and *attunement*. Dyad search terms included *mother–child*, *father–child*, *parent–child*, *parent*, *adolescent*, *infant*, *child*, and *dyadic*. In addition to searching online databases, we examined references used in identified

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

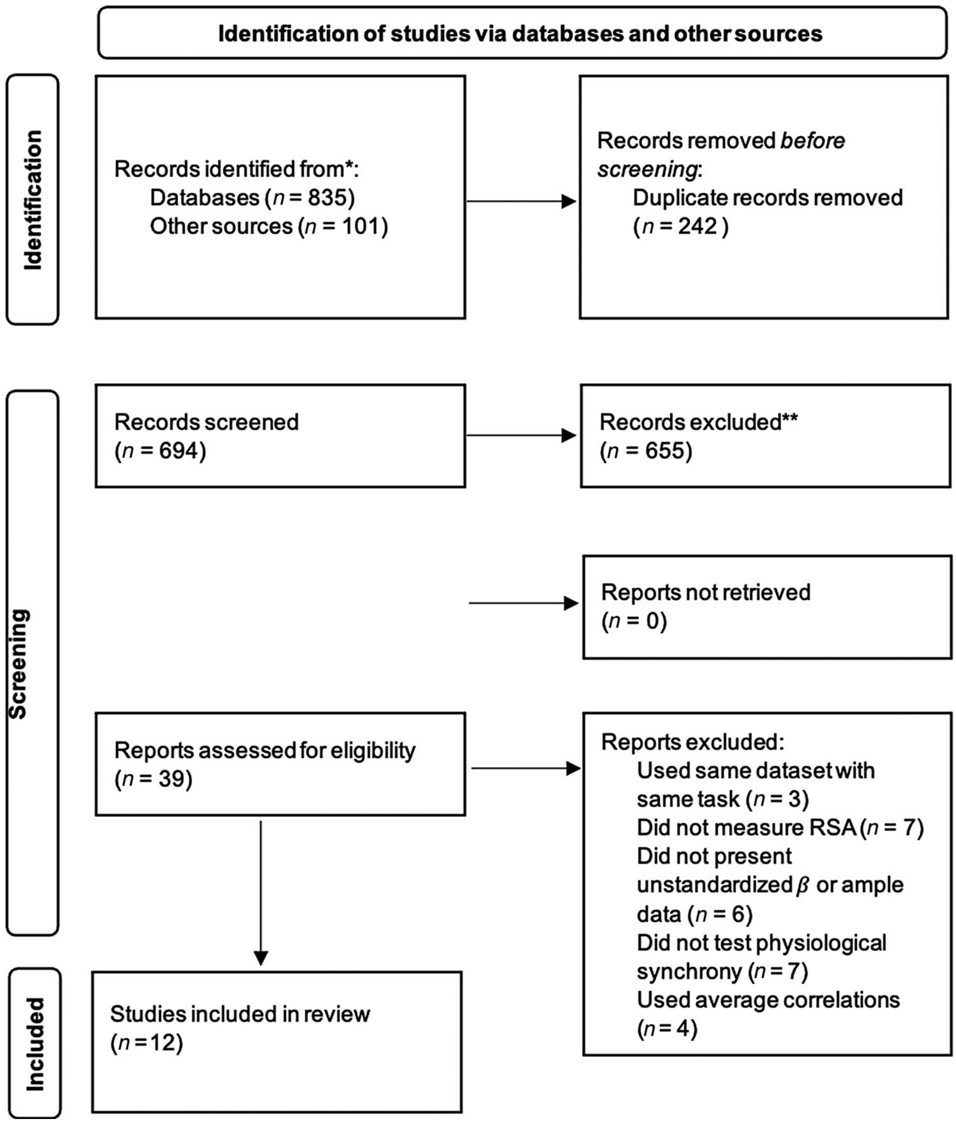

FIGURE 1 Identification of studies via databases and other sources

studies as well as existing systematic reviews of parent–child synchrony (Davis et al., 2018; DePasquale, 2020). The initial search yielded 835 results, of which 242 were duplicates. We narrowed down these results to 39 studies of interest through abstract reviews based on inclusion and exclusion criteria (see Figure 1).

2.1.2 | Inclusion and exclusion criteria

Our literature review identified 39 studies of interest. We completed full text reviews of all 39 studies, which yielded 12 studies with 14 independent samples ($N = 1201$ mother–child dyads) that satisfied our inclusion criteria. This sample size of publications and participants is comparable to what has been used in some prior meta-analyses of RSA and heart rate variability more broadly (Di Bello et al., 2020; Faurholt-Jepsen et al., 2017; Kemp et al., 2010; Shahrestani et al., 2014, 2015; Thayer et al., 2012). In terms of our inclusion criteria, first, studies had to measure RSA in both mothers and children. Second, studies had to use within-dyad analyses of repeated RSA observations (e.g., multilevel modeling) to measure concurrent synchrony in mother–child RSA. We excluded four studies that estimated a regression coefficient between average RSA values from parent and child, which does not capture the association between fluctuations in parent and child RSA within subjects over time. Third, studies had to report unstandardized coefficients of mother–child synchrony that are comparable across studies since all studies used physiological measurements in RSA units. Unstandardized coefficients of mother–child synchrony are typically reported in analyses that that take into account the dyadic structure of the data (e.g., multilevel modeling analyses). Studies that used standardized coefficients to represent mother–child synchrony (e.g., cross-correlation coefficients that are Fisher transformed), which are not directly comparable to unstandardized coefficients, were not included in the current meta-analysis (e.g., Abney et al., 2021; Motsan et al., 2021; Nguyen et al., 2021). Fourth, studies had to include

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

standard errors of unstandardized coefficients, or include enough information to compute standard errors. For example, for studies that reported a specific *p*-value for mother–child RSA synchrony but not a standard error, we computed a standard error by dividing the unstandardized coefficient by the *z*-score corresponding to the reported *p*-value. Six studies that did not report either standard errors or specific *p*-values (e.g., reporting $p < .05$) were excluded. Finally, when multiple published studies focused on the same sample, we selected one of them to include in our meta-analysis and excluded the rest. Three studies were excluded because they used the same participant sample and tasks as another study, but focused on different moderators of mother–child synchrony (Fuchs et al., 2021; Lunkenheimer et al., 2015; Skoranski et al., 2017). If there were multiple studies on the same sample, we chose the most recently published study for the analysis. In instances where two studies were published the same year drawing from the same sample, we chose the study with the larger sample size (e.g., including Lunkenheimer et al. [2021] over Fuchs et al. [2021]). The studies that met our inclusion criteria were published from 2014 to 2021. Children in the studies ranged from 0.4 to 17 years old ($M = 5.68$ years, $SD = 4.13$), and parents in the studies ranged from 20 to 58 years old ($M = 34.76$ years, $SD = 6.49$).

2.2 | Measures

2.2.1 | RSA synchrony

To obtain coefficients of synchrony, we extracted unstandardized coefficients for each sample. These coefficients represented the sample-specific overall effect of mother RSA on child RSA in concurrent epochs (i.e., fixed effect of concurrent synchrony). We also extracted the standard errors and *p*-values corresponding to each unstandardized coefficient. In studies that presented two models that assumed either directionality of concurrent synchrony from mother RSA to child RSA or from child RSA to mother RSA, we selected the findings from the analysis modeling mother predicting child RSA. We chose to focus on coefficients from mother RSA predicting child RSA because these were included in all the studies of interest (Davis et al., 2018). For studies that included multiple models that assessed RSA synchrony in different tasks, we computed the average unstandardized coefficient and average standard error across models and included those values in our meta-analysis. For two studies, we included two unstandardized coefficients (Creaven et al., 2014; Lunkenheimer, Busuito, et al., 2018) as a result of these studies including separate analyses on two different subsamples (low- vs. high-risk samples). This yielded 14 unstandardized coefficients drawn from 12 published studies.

2.2.2 | Moderators

We examined potential moderators of RSA synchrony, including sample risk status (0/1), task context (0/1), average child age, and epoch length used to compute RSA. For sample risk status, we categorized samples that targeted participants with clinical diagnosis or difficulties (e.g., depression, conduct disorder), maltreatment history, or low socioeconomic status as high risk (coded as 1); samples of participants that were not targeted for these characteristics were categorized as low risk (coded as 0). For task context, challenging or affectively negative task contexts (e.g., conflict discussion, fear film) were coded as 1; low-challenge, positive, or affectively neutral task contexts (e.g., calming video, storybook task) were coded as 0. For epoch length, we coded 1-s RSA estimates as 0; 5-s epochs as 1; 15-s epochs as 2; 30-s epochs as 3; and 60-s epochs as 4. Studies that conducted separate analyses on subsamples were split by subsample (Creaven et al., 2014; Lunkenheimer, Busuito, et al., 2018), with the corresponding data extracted for each moderator variable.

2.3 | Data analysis

We first conducted a random-effects meta-analysis with restricted maximum likelihood estimation to test the overall association between epoch-to-epoch (i.e., moment-to-moment) fluctuations in mother and child RSA (i.e., mother–child concurrent RSA synchrony). We assessed heterogeneity in RSA synchrony, or variation across studies, using the I^2 measure (Higgins & Thompson, 2002) and Cochran's *Q*-test statistic for heterogeneity (Cochran, 1954). Values for I^2 of 0%, 25%, 50%, and 75% indicate no heterogeneity, low, moderate, and high heterogeneity, respectively (Higgins, 2003). A significant *Q*-test statistic suggests meaningful heterogeneity across studies in mother–child RSA synchrony. We assessed publication bias, or the extent to which the literature is characterized by statistically significant findings being more likely to be published than nonsignificant findings, using Egger's regression test (Egger et al., 1997). We conducted outlier diagnostics to assess whether there were outlier effects for RSA synchrony (Viechtbauer & Cheung, 2010). In moderator analyses, we conducted separate mixed-effects meta-analyses using restricted maximum likelihood estimation to test whether sample-level moderator variables explain variability in mother–child RSA synchrony. We estimated these effects in four separate models to retain statistical power due to our relatively small sample size of studies. In addition, this approach is consistent with our study aim to assess moderator effects independently, without controlling for other variables. All analyses were conducted using the "metafor" package (Viechtbauer, 2010) in R. Using the same notation as Viechtbauer (2010), the random-effects model can be described as

$$\theta_i = \mu + u_i,$$

where θ_i is the true effect (unknown) in the *i*th study of mother RSA predicting child RSA (i.e., mother–child RSA synchrony), μ is the average true effect, and u_i is the degree of heterogeneity among the true effects of mother–child RSA synchrony. The mixed-effects models with sample-level moderator variables can be described as

$$\vartheta_i = \beta_0 + \beta_1 \chi_{i1} + u_i,$$

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

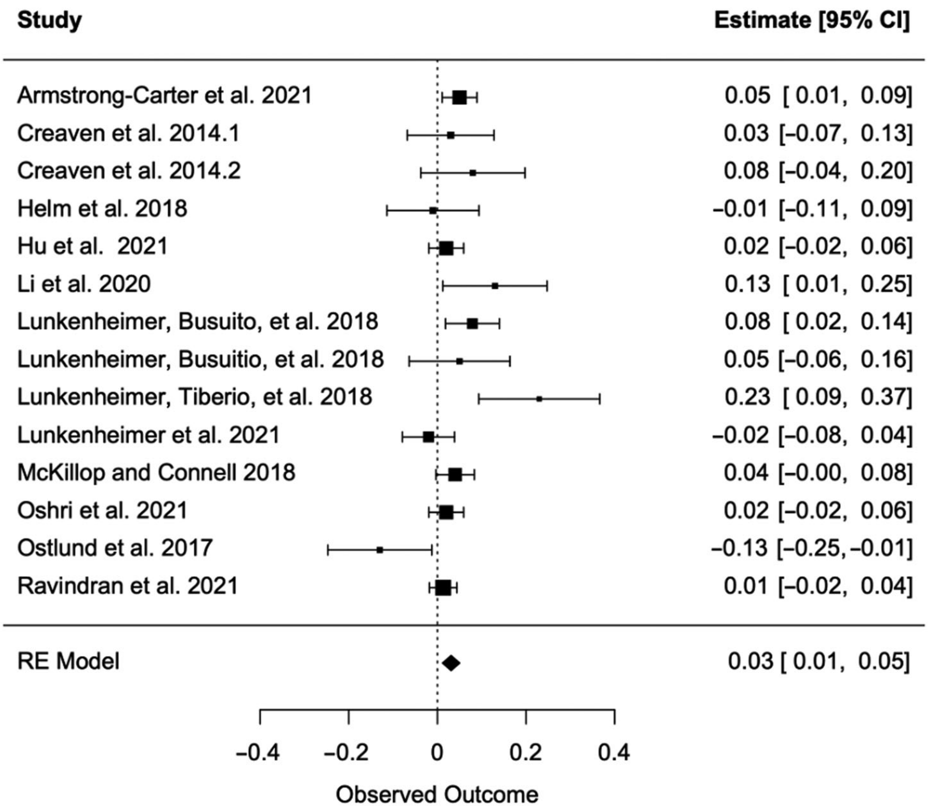

FIGURE 2 Estimated mother–child synchrony in RSA in unstandardized metric. Positive and negative values indicate positive and negative concurrent synchrony, respectively.

where χ_{i1} is the value of the moderator variable for the *i*th study. Thus, β_1 represents how the average true effect of mother RSA predicting child RSA changes for a 1-unit increase in the moderator variable, and β_0 represents the average true effect when the moderator variable is equal to zero.

3 | RESULTS

Table 1 presents information for each study.

3.1 | Mother–child RSA synchrony

Figure 2 presents the associations between mother RSA and child RSA for each study in the meta-analysis, as well as the summary estimate. Overall, there was a statistically significant positive association between mother and child fluctuations in RSA (see Figure 2 and Table 2). That is, across studies, there is evidence that mother and child RSA fluctuate in concert, albeit to a modest degree. There was evidence for significant heterogeneity across studies ($Q(13) = 27.63$, $p = .010$; $I^2 = 29.84$). Based on the I^2 measure, heterogeneity in estimates of mother–child RSA synchrony was in the low to moderate range. We did not find evidence for publication bias based on Egger's regression test ($z = 1.10$, $p = .273$). In addition, visual inspection of the funnel plot does not suggest asymmetry that would be expected in the presence of bias (see Figure S1; Sterne & Egger, 2001). Outlier diagnostics did not identify outlier effects (see Figure S2).

3.2 | Impact of moderators

We conducted a series of mixed-effects meta-analyses testing moderators of heterogeneity. The parameter estimates for each of the models are presented in Table 2. Given theory that physiological synchrony may indicate or relate to risk for psychopathology and exposure to adverse contexts (Feldman, 2012), we conducted a moderator analysis to test whether mother–child RSA synchrony differed in low- versus high-risk samples. Sample risk status was significantly and negatively related to variation in mother–child RSA synchrony. Thus, less mother–child RSA synchrony was observed in samples classified as high risk compared to those that were classified as low risk. Given prior work suggesting that mother–child physiological synchrony might vary across different task contexts, we also tested low- versus high-challenge tasks as potential moderator. We did not find that mother–child RSA synchrony significantly differed by task context. We also did not find that mother–child RSA synchrony differed by mean child age or epoch length used to compute RSA.

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Summary of studies included in the meta-analysis

Study	Sample (number of mother–child dyads)	Age (years) Mean ± SD	% Female	Task(s)	Epoch length for computing RSA	Statistical method	Sample risk status
Armstrong-Carter et al., 2021	94	5.6 ± 0.55	56	Teaching, free play, clean up, problem solving	30 s	Multilevel modeling	Low
Creaven et al., 2014	104	3.75 ± 0.75	53.8	Resting	30 s	Multilevel modeling	
	52	3.77 ± 0.73					Low
	52	3.73 ± 0.77					High
Helm et al., 2018	83	3.56 ± 0.12	55	Storybook	30 s	Multilevel modeling	Low
Hu et al., 2021	110	4.47 ± 0.65	50.9	Puzzle, pretend play	15 s	Coupled autoregressive models	Low
Li et al., 2020	191	12.4 ± 0.5	49.7	Conflict discussion	60 s	Multilevel modeling	Low
Lunkenheimer, Busuito, et al., 2018	146	3.78 ± 0.73		Puzzle	30 s	Multilevel coupled autoregressive analysis	
	77	3.78 ± 0.73					Low
	69	3.78 ± 0.73					High
Lunkenheimer, Tiberio, et al., 2018	47	3.4 ± 0.25	54	Free play, clean up, teaching task	30 s	Multilevel coupled autoregressive analysis	Low
Lunkenheimer et al.,	82	3.04 ± 0.11	53	Challenging parent–child puzzle task	30 s	Multilevel intra-dyad dynamic models	High
McKillop & Connell, 2018	59	13.71 ± 1.71	66	Discussion	15 s	ANOVAS, APIM	Low
Oshri et al., 2021	101	10.27 ± 1.19	50.5	Parent–child conflict	30 s	Multilevel modeling	High
Ostlund et al., 2017	95	0.4 ± 0.05		Re-engagement phases of still face	5 s	Hierarchal linear modeling	High
Ravindran et al., 2021	158	3.76 ± 0.68	49	Fear film	1 s	Multilevel modeling	Low

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 Meta-analysis results

	Child RSA						
	k	Unstandardized coefficient	SE	95% CI	Z	p	I^2
Testing overall synchrony (random-effects model)							
Concurrent mother RSA	14	.031	.0099	[.01, 05]	3.13	.002	30%
Moderator analyses (mixed-effects models)							
Low-risk versus high-risk sample							36%
Intercept		.045	.0126	[.02, .07]	3.56	<.001	
Low-risk versus high-risk		–.045	.0231	[–.09, –.00]	1.96	.0496	
Task context							32%
Intercept		.043	.0148	[.01, .07]	2.93	.003	
Low versus high challenge		–.023	.0206	[–.06, .02]	1.13	.258	
Child age							46%
Intercept		.012	.0222	[–.03, .06]	0.54	.592	
Average child age		.003	.0031	[–.00, .01]	1.08	.279	
Epoch length							45%
Intercept		–.012	.0282	[–.07, .04]	0.41	.679	
Epoch length		.019	.0110	[–.003, .04]	1.72	.085	

Note: K = number of studies; I^2 = total variability in random effects model and unaccounted variability in moderator models. Risk-status variable coded 0 = low-risk sample and 1 = high-risk sample. Task context variable coded 0 = low challenge task and 1 = high challenge task. RE Model = random-effects model. Larger squares represent more precise estimates than smaller squares.

3.3 | Sensitivity analyses

Although diagnostics did not indicate the presence of outlier effects (see Figure S2), visual inspection of the effects in Figure 2 led us to conduct sensitivity analyses exploring whether the results changed after removing either Lunkenheimer, Tiberio, et al. (2018) or Ostlund et al. (2017); the strongest positive and negative effects were reported in Lunkenheimer, Tiberio, et al. (2018) and Ostlund et al. (2017), respectively. After individually removing either of these studies ($k = 13$), the positive association between mother and child RSA remained statistically significant ($b = .027$, $SE = .0081$, 95% confidence interval [CI] [.0108, .0427], $p = .001$, and $b = .033$, $SE = .0088$, 95% CI [.0160, .0507], $p < .001$ after removing Lunkenheimer, Tiberio, et al. [2018] or Ostlund et al. [2017], respectively). In contrast, removing either of these studies resulted in heterogeneity in RSA synchrony that was not statistically significant ($Q(12) = 19.20$, $p = .084$, $I^2 = 8.38$, and $Q(12) = 20.49$, $p = .058$; $I^2 = 17.31$ after removing Lunkenheimer, Tiberio, et al. [2018] or Ostlund et al. [2017], respectively). In addition, in mixed-effects models, the previously observed negative effect of sample risk status on RSA synchrony was no longer statistically significant after removing either study ($b = -.0348$, $SE = .0197$, 95% CI [-.0733, .0037], $p = .077$, and $b = -.0298$, $SE = .0214$, 95% CI [-.0717, .0121], $p = .163$ after removing Lunkenheimer, Tiberio, et al. [2018] or Ostlund et al. [2017], respectively).

4 | DISCUSSION

Theoretical frameworks highlighting the importance of biobehavioral synchrony for attachment (Feldman, 2017), combined with advances in quantitative methods (Helm et al., 2018), have contributed to rapidly growing interest in studying physiological synchrony in parent–child dyads (Davis et al., 2018; DePasquale, 2020). Despite this interest, the literature contains mixed findings as to whether parent–child dyads, on average, consistently demonstrate physiological synchrony across different research samples, as well as the conditions under which physiological synchrony may be stronger or weaker. Here, we conducted a meta-analysis to examine whether mother–child dyads show correspondence in their moment-to-moment fluctuations in RSA, reflecting concurrent synchrony of mother and child parasympathetic nervous system activation. We identified 14 independent samples from 12 studies, consisting of 1201 mother–child dyads, that met our study inclusion criteria. We found evidence for statistically significant mother–child synchrony in RSA. Specifically, mothers and their children showed positive correspondence of their moment-to-moment RSA, such that increases and decreases in mother RSA corresponded to simultaneous increases and decreases in child RSA. It is important to note, however, that the degree of RSA synchrony in this meta-analysis was modest, which may be due to inconsistencies across studies, including in how RSA synchrony was measured. Further, moderator

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

analyses revealed that RSA synchrony was significantly reduced in samples of mother–child dyads who were considered high risk because they experienced clinical difficulties, socioeconomic disadvantage, or maltreatment exposures. In contrast, we did not find that RSA synchrony varied significantly by task context, child age, or epoch length used to compute RSA.

It is important to note that this meta-analysis focused on prior studies of RSA synchrony at the within-dyad level. The meta-analysis does not consider the question of whether mothers with high or low levels of average RSA tend to have children with similarly high or low RSA relative to other children, which reflects an average-level correlation that could be confounded by underlying shared genetics or environmental experiences between parent and child (Davis et al., 2018). We found evidence for positive mother–child RSA synchrony at the within-dyad level. That is, mothers and their children showed simultaneous increases and decreases in their RSA over the course of time as they engaged in various interaction tasks including free play, teaching tasks, and conflict-resolution discussions. This finding aligns with the hypothesis that mother–child interactions involve both partners coordinating their physiological states, potentially as a function of responding to each other's emotional, behavioral, and verbal cues (Feldman, 2012). Further, even after removing the studies that found the most extreme levels of mother–child RSA synchrony, the overall positive effect of mother RSA on child RSA remained statistically significant. Indeed, consistent with this meta-analytical finding, we observed in Figure 2 that the majority of prior studies have reported positive, although not statistically significant, mother–child RSA synchrony.

Strong affiliative bonds between parents and their children are believed to be formed, in part, on the basis of coordinating physiological states (Feldman, 2012, 2017). In contrast, social risk factors may adversely affect parent–child relationships and child outcomes via disrupted or discordant dyadic synchrony (Feldman, 2012). For example, prior theoretical and empirical work suggests that mother–child physiological synchrony is weakened in the context of maternal depression (Feldman, 2012; Woody et al., 2016), lower family income and higher household chaos (Hoyniak et al., 2021), and neglect (Lunkenheimer, Busuito, et al., 2018). Our meta-analysis found evidence that is consistent with the possibility that mother–child RSA synchrony is disrupted in high-risk contexts. It is important to note, however, that our finding of moderation by sample risk status was less robust to sensitivity analyses than was our finding of overall mother–child RSA synchrony. Specifically, the negative effect of sample risk status on mother–child RSA synchrony was no longer statistically significant after removing the most extreme effects from the meta-analysis. This reduction in statistical significance may have been due to reduced heterogeneity across studies, or reduced power, after removing Lunkenheimer, Tiberio, et al. (2018) or Ostlund et al. (2017) from the analysis. In addition, it is possible that some risk factors are stronger moderators of mother–child RSA synchrony than are others. Given the limited number of past studies on distinct risk factors, we categorized high-risk samples based on broad criteria, as specifying between different types of risk would have yielded too small cell sizes and insufficient statistical power for the meta-analysis. However, developmental researchers are increasingly emphasizing the importance of considering unique and specific effects of different dimensions of risk or adversity (Ellis et al., 2022). Interestingly, Lunkenheimer, Busuito, et al. (2018) found differential effects of physical abuse and neglect on mother–child RSA synchrony, but more research is needed in this area.

Although many different cardiac, hormonal, and neural measures offer promise for studying dyadic synchrony (Borelli et al., 2019; Davis et al., 2018; Endevelt-Shapira et al., 2021; Levy et al., 2021; Miller et al., 2019), we focused our meta-analysis on mother–child synchrony in RSA, a measure of cardiac parasympathetic response that has garnered significant attention (Davis et al., 2018). RSA is widely considered to be a measure of parasympathetic influence on heart rate with implications for social–emotional processes that are important for parent–child interactions and relationships, such as emotion regulation and empathy (Beauchaine & Thayer, 2015; Miller, 2018; Porges, 2007). For example, polyvagal theory posits that RSA response reflects active engagement and coping with mild social and emotional challenges in the moment (Porges, 2007). In addition to rich theoretical work pointing to the importance of studying RSA synchrony, RSA data are relatively inexpensive and easy to collect.

Despite the strengths of the RSA measure, one potential limitation in the RSA synchrony literature is the reliance on low temporal resolution estimates, at least relative to other physiological measures (e.g., skin conductance, interbeat intervals, neuroimaging measures); the majority of RSA synchrony studies have considered 60- or 30-s epochs for estimating RSA within dyads. This approach assumes that meaningful mother–child synchrony can be observed at this timescale, but we are not aware of theory supporting this assumption. Our meta-analysis suggests a significant, albeit modest, degree of average mother–child RSA synchrony. It is possible that mother–child RSA synchrony occurs, or is strongest, at specific temporal scales and epoch lengths. We did not find that epoch length significantly moderated synchrony, but systematically testing this possibility may require more studies that consider RSA estimates that are based on smaller time intervals. Some developmental studies have used epochs as short as 10 or 15 s to compute RSA (Calkins & Dedmon, 2000; Huffman et al., 1998; Kahle et al., 2018; Miller et al., 2020). Recent analytic approaches can estimate RSA at the second-by-second level, although it is worth noting that these estimates are still based on a sliding window method that considers a wider range of data (Gates et al., 2015). Nonetheless, this method may be particularly useful for capturing dynamic changes and links between mother and child RSA that more closely correspond to the dynamic nature of social interaction and behavior.

We note three limitations of this meta-analysis, and one broader limitation of the mother–child RSA synchrony literature that should be addressed and that could improve future meta-analyses. First, we focused on concurrent RSA synchrony, but researchers are increasingly considering lead–lag associations between mother and child RSA (Armstrong-Carter et al., 2021; Helm et al., 2018). As the field continues to grow, future meta-analytic work could evaluate the evidence for directional or bidirectional relations in mother–child RSA synchrony. Second, we focused our meta-analysis on studies that used multilevel modeling to estimate mother–child RSA synchrony, because this

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

approach is most commonly used in the literature and typically controls for between-dyad correlations of parent and child RSA (Davis et al., 2018). These studies used unstandardized betas to quantify synchrony in RSA scale, but standardized effect size measures would increase interpretability of the strength of mother–child RSA synchrony. Future studies that use multilevel models to quantify within-dyad synchrony should consider including appropriate effect size measures (Lorah, 2018). As a related point, the current meta-analysis is not an exhaustive representation of the literature, as it does not include studies that used standardized metrics of mother–child RSA synchrony, such as cross-correlations (e.g., Abney et al., 2021; Motsan et al., 2021; Nguyen et al., 2021). Using standardized effect sizes that can be compared across studies will improve the consistency and interpretability of the overall literature. Third, it is important to emphasize that our findings are specific to the literature on mother–child dyads. Recent work suggests that parent-child RSA synchrony differs for mothers and fathers (Fuchs et al., 2021; Lunkenheimer et al., 2021), but relatively few studies have included fathers. Lastly, an important limitation of the broader RSA synchrony literature is the relatively limited use of permutation approaches. These analyses involve randomly pairing mother and child RSA signals to create shuffled synchrony values to compare with RSA synchrony values obtained from real mother–child dyads. The extent to which these RSA synchrony values differ provides evidence that mother–child RSA synchrony is not due to chance or other factors such as the natural frequency of RSA signals. Widely adopting permutation analyses would complement current standards in the field, such as detrending RSA signals, and contribute to an overall stronger literature for future meta-analyses of parent–child RSA synchrony.

In conclusion, this is the first meta-analysis to examine mother–child RSA synchrony, a rapidly growing area of interest in developmental psychobiology. RSA synchrony is believed to partially reflect mother and child reciprocal engagement and responsivity during interactions (Feldman, 2012). We found support for the idea that RSA fluctuations in mothers and their children are positively associated with each other, but RSA synchrony may be reduced in high-risk samples characterized by clinical difficulties, maltreatment, or socioeconomic disadvantage. Collectively, these findings suggest that mother–child dyads synchronize their parasympathetic activity, and that the strength of synchrony is potentially moderated by contextual risk factors. Nevertheless, this field is still at a nascent stage. Methodological innovations in estimating RSA, assessment of multiple time scales and lagged associations, increased attention to father–child synchrony, and fuller consideration of moderators and mechanisms of RSA synchrony will be important for advancing further understanding of the contexts in which RSA synchrony occurs, and the significance of synchrony for child development. Further, gaining this understanding could provide important information for designing new, targeted interventions, and for determining the promise of RSA synchrony as a marker of intervention effectiveness.

ACKNOWLEDGMENTS

This manuscript was prepared with support from (1) the Institute of Education Sciences (R305B140009) to Stanford University (EAC), (2) the Stanford Data Science Fellowship (EAC), and (3) the Stanford Center on Longevity New Map of Life Fellowship (JGM).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data and syntax are available upon request.

REFERENCES

Abney, D. H., daSilva, E. B., & Bertenthal, B. I. (2021). Associations between infant–mother physiological synchrony and 4- and 6-month-old infants' emotion regulation. *Developmental Psychobiology*, *63*(6), e22161. https://doi.org/10.1002/dev.22161

Amole, M. C., Cyranowski, J. M., Wright, A. G. C., & Swartz, H. A. (2017). Depression impacts the physiological responsiveness of mother-daughter dyads during social interaction. *Depression and Anxiety*, *34*(2), 118–126. https://doi.org/10.1002/da.22595

Armstrong-Carter, E., Miller, J. G., & Obradović, J. (2021). Parent-child physiological synchrony: Concurrent and lagged effects during dyadic laboratory interaction. *Developmental Psychobiology*, *63*(7), e22196. https://doi.org/10.1002/dev.22196

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International Journal of Psychophysiology*, *98*(2), 338–350. https://doi.org/10.1016/j.ijpsycho.2015.08.004

Borelli, J. L., Shai, D., Smiley, P. A., Boparai, S., Goldstein, A., Rasmussen, H. F., & Granger, D. A. (2019). Mother-child adrenocortical synchrony: Roles of maternal overcontrol and child developmental phase. *Developmental Psychobiology*, *61*(8), 1120–1134. https://doi.org/10.1002/dev.21845

Calkins, S. D., & Dedmon, S. E. (2000). Physiological and behavioral regulation in two-year-old children with aggressive/destructive behavior problems. *Journal of Abnormal Child Psychology*, *28*, 103–118. https://doi.org/10.1023/A:1005112912906

Cochran, W. G. (1954). The combination of estimates from different experiments. *Biometrics*, *10*(1), 101–129. https://doi.org/10.2307/3001666

Creaven, A.-M., Skowron, E. A., Hughes, B. M., Howard, S., & Loken, E. (2014). Dyadic concordance in mother and preschooler resting cardiovascular function varies by risk status: Cardiovascular concordance in mother-child dyads. *Developmental Psychobiology*, *56*(1), 142–152. https://doi.org/10.1002/dev.21098

Davis, M., West, K., Bilms, J., Morelen, D., & Suveg, C. (2018). A systematic review of parent-child synchrony: It is more than skin deep. *Developmental Psychobiology*, *60*(6), 674–691. https://doi.org/10.1002/dev.21743

DePasquale, C. E. (2020). A systematic review of caregiver-child physiological synchrony across systems: Associations with behavior and child functioning. *Development and Psychopathology*, *32*(5), 1754–1777. https://doi.org/10.1017/S0954579420001236

Di Bello, M., Carnevali, L., Petrocchi, N., Thayer, J. F., Gilbert, P., & Ottaviani, C. (2020). The compassionate vagus: A meta-analysis on the connection between compassion and heart rate variability. *Neuroscience and Biobehavioral Reviews*, *116*, 21–30. https://doi.org/10.1016/j.neubiorev.2020.06.016

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ*, *315*(7109), 629–634. https://doi.org/10.1136/bmj.315.7109.629

Ellis, B. J., Sheridan, M. A., Belsky, J., & McLaughlin, K. A. (2022). Why and how does early adversity influence development? Toward an integrated model of dimensions of environmental experience. *Development and Psychopathology*, *34*(2), 447–471. https://doi.org/10.1017/S0954579421001838

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Endevelt-Shapira, Y., Djalovski, A., Dumas, G., & Feldman, R. (2021). Maternal chemosignals enhance infant-adult brain-to-brain synchrony. *Science Advances*, *7*(50), eabg6867. https://doi.org/10.1126/sciadv.abg6867

Faurholt-Jepsen, M., Kessing, L. V., & Munkholm, K. (2017). Heart rate variability in bipolar disorder: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, *73*, 68–80. https://doi.org/10.1016/j.neubiorev.2016.12.007

Feldman, R. (2007). Parent–infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry*, *48*(3–4), 329–354. https://doi.org/10.1111/j.1469-7610.2006.01701.x

Feldman, R. (2012). Parent-infant synchrony: A biobehavioral model of mutual influences in the formation of affiliative bonds. *Monographs of the Society for Research in Child Development*, *77*(2), 42–51. https://doi.org/10.1111/j.1540-5834.2011.00660.x

Feldman, R. (2017). The neurobiology of human attachments. *Trends in Cognitive Sciences*, *21*, 80–99. https://doi.org/10.1016/j.tics.2016.11.007

Feldman, R., Greenbaum, C. W., & Yirmiya, N. (1999). Mother–infant affect synchrony as an antecedent of the emergence of self-control. *Developmental Psychology*, *35*(1), 223–231. https://doi.org/10.1037/0012-1649.35.1.223

Fuchs, A., Lunkenheimer, E., & Lobo, F. (2021). Individual differences in parent and child average RSA and parent psychological distress influence parent-child RSA synchrony. *Biological Psychology*, *161*, 108077. https://doi.org/10.1016/j.biopsycho.2021.108077

Gates, K. M., Gatzke-Kopp, L. M., Sandsten, M., & Blandon, A. Y. (2015). Estimating time-varying RSA to examine psychophysiological linkage of marital dyads. *Psychophysiology*, *52*(8), 1059–1065. https://doi.org/10.1111/psyp.12428

Helm, J. L., Miller, J. G., Kahle, S., Troxel, N. R., & Hastings, P. D. (2018). On measuring and modeling physiological synchrony in dyads. *Multivariate Behavioral Research*, *53*(4), 521–543. https://doi.org/10.1080/00273171.2018.1459292

Higgins, J. P. T. (2003). Measuring inconsistency in meta-analyses. *BMJ*, *327*(7414), 557–560. https://doi.org/10.1136/bmj.327.7414.557

Higgins, J. P. T., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539–1558. https://doi.org/10.1002/sim.1186

Hoyniak, C. P., Quiñones-Camacho, L. E., Camacho, M. C., Chin, J. H., Williams, E. M., Wakschlag, L. S., & Perlman, S. B. (2021). Adversity is linked with decreased parent-child behavioral and neural synchrony. *Developmental Cognitive Neuroscience*, *48*, 100937. https://doi.org/10.1016/j.dcn.2021.100937

Hu, Y., McElwain, N. L., & Berry, D. (2021). Mother–child mutually responsive orientation and real-time physiological coordination. *Developmental Psychobiology*, *63*(7), e22200. https://doi.org/10.1002/dev.22200

Huffman, L. C., Bryan, Y. E., Carmen, del, R., Pedersen, F. A., Doussard-Roosevelt, J. A., & Porges, S. W. (1998). Infant temperament and cardiac vagal tone: Assessments at twelve weeks of age. *Child Development*, *69*, 624–635. https://doi.org/10.2307/1132194

Kahle, S., Miller, J. G., Helm, J. L., & Hastings, P. D. (2018). Linking autonomic physiology and emotion regulation in preschoolers: The role of reactivity and recovery. *Developmental Psychobiology*, *60*, 775–788. https://doi.org/10.1002/dev.21746

Kemp, A. H., Quintana, D. S., Gray, M. A., Felmingham, K. L., Brown, K., & Gatt, J. M. (2010). Impact of depression and antidepressant treatment on heart rate variability: A review and meta-analysis. *Biological Psychiatry*, *67*(11), 1067–1074. https://doi.org/10.1016/j.biopsych.2009.12.012

Levy, J., Lankinen, K., Hakonen, M., & Feldman, R. (2021). The integration of social and neural synchrony: A case for ecologically valid research using MEG neuroimaging. *Social Cognitive and Affective Neuroscience*, *16*(1–2), 143–152. https://doi.org/10.1093/scan/nsaa061

Li, Z., Sturge-Apple, M. L., Liu, S., & Davies, P. T. (2020). Parent-adolescent physiological synchrony: Moderating effects of adolescent emotional insecurity. *Psychophysiology*, *57*(9), e13596. https://doi.org/10.1111/psyp.13596

Lorah, J. (2018). Effect size measures for multilevel models: Definition, interpretation, and TIMSS example. *Large-Scale Assessments in Education*, *6*(1), 8. https://doi.org/10.1186/s40536-018-0061-2

Lunkenheimer, E., Brown, K. M., & Fuchs, A. (2021). Differences in mother-child and father-child RSA synchrony: Moderation by child self-regulation and dyadic affect. *Developmental Psychobiology*, *63*(5), 1210–1224. https://doi.org/10.1002/dev.22080

Lunkenheimer, E., Busuito, A., Brown, K. M., & Skowron, E. A. (2018). Mother–child coregulation of parasympathetic processes differs by child maltreatment severity and subtype. *Child Maltreatment*, *23*(3), 211–220. https://doi.org/10.1177/1077559517751672

Lunkenheimer, E., Tiberio, S. S., Buss, K. A., Lucas-Thompson, R. G., Boker, S. M., & Timpe, Z. C. (2015). Coregulation of respiratory sinus arrhythmia between parents and preschoolers: Differences by children's externalizing problems. *Developmental Psychobiology*, *57*(8), 994–1003. https://doi.org/10.1002/dev.21323

Lunkenheimer, E., Tiberio, S. S., Skoranski, A. M., Buss, K. A., & Cole, P. M. (2018). Parent-child coregulation of parasympathetic processes varies by social context and risk for psychopathology. *Psychophysiology*, *55*(2), e12985. https://doi.org/10.1111/psyp.12985

MacPhee, D., Lunkenheimer, E., & Riggs, N. (2015). Resilience as regulation of developmental and family processes. *Family Relations*, *64*, 153–175. https://doi.org/10.1111/fare.12100

McKillop, H. N., & Connell, A. M. (2018). Physiological linkage and affective dynamics in dyadic interactions between adolescents and their mothers. *Developmental Psychobiology*, *60*(5), 582–594. https://doi.org/10.1002/dev.21630

Miller, J. G. (2018). Physiological mechanisms of prosociality. *Current Opinion in Psychology*, *20*, 50–54. https://doi.org/10.1016/j.copsyc.2017.08.018

Miller, J. G., Kahle, S., Troxel, N. R., & Hastings, P. D. (2020). The development of generosity from 4 to 6 years: Examining stability and the biopsychosocial contributions of children's vagal flexibility and mothers' compassion. *Frontiers in Psychology*, *11*, 590384. https://doi.org/10.3389/fpsyg.2020.590384

Miller, J. G., Vrtička, P., Cui, X., Shrestha, S., Hosseini, S. M. H., Baker, J. M., & Reiss, A. L. (2019). Inter-brain synchrony in mother-child dyads during cooperation: An fNIRS hyperscanning study. *Neuropsychologia*, *124*, 117–124. https://doi.org/10.1016/j.neuropsychologia.2018.12.021

Motsan, S., Bar-Kalifa, E., Yirmiya, K., & Feldman, R. (2021). Physiological and social synchrony as markers of PTSD and resilience following chronic early trauma. *Depression and Anxiety*, *38*(1), 89–99. https://doi.org/10.1002/da.23106

Nguyen, T., Abney, D. H., Salamander, D., Bertenthal, B. I., & Hoehl, S. (2021). Proximity and touch are associated with neural but not physiological synchrony in naturalistic mother-infant interactions. *Neuroimage*, *244*, 118599. https://doi.org/10.1016/j.neuroimage.2021.118599

Ostlund, B. D., Measelle, J. R., Laurent, H. K., Conradt, E., & Ablow, J. C. (2017). Shaping emotion regulation: Attunement, symptomatology, and stress recovery within mother-infant dyads. *Developmental Psychobiology*, *59*(1), 15–25. https://doi.org/10.1002/dev.21448

Oshri, A., Liu, S., Suveg, C. M., Caughy, M. O., & Goodgame Huffman, L. (2021). Biological sensitivity to context as a dyadic construct: An investigation of child-parent RSA synchrony among low-SES youth. *Development and Psychopathology*, 1–14. https://doi.org/10.1017/s095457942100078x

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology*, *74*(2), 116–143. https://doi.org/10.1016/j.biopsycho.2006.06.009

Ravindran, N., Zhang, X., Green, L. M., Gatzke-Kopp, L. M., Cole, P. M., & Ram, N. (2021). Concordance of mother-child respiratory sinus arrythmia is continually moderated by dynamic changes in emotional content of film stimuli. *Biological Psychology*, *161*, 108053. https://doi.org/10.1016/j.biopsycho.2021.108053

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Shahrestani, S., Stewart, E. M., Quintana, D. S., Hickie, I. B., & Guastella, A. J. (2014). Heart rate variability during social interactions in children with and without psychopathology: A meta-analysis. *Journal of Child Psychology and Psychiatry*, *55*(9), 981–989. https://doi.org/10.1111/jcpp.12226

Shahrestani, S., Stewart, E. M., Quintana, D. S., Hickie, I. B., & Guastella, A. J. (2015). Heart rate variability during adolescent and adult social interactions: A meta-analysis. *Biological Psychology*, *105*, 43–50. https://doi.org/10.1016/j.biopsycho.2014.12.012

Skoranski, A. M., Lunkenheimer, E., & Lucas-Thompson, R. G. (2017). The effects of maternal respiratory sinus arrhythmia and behavioral engagement on mother-child physiological coregulation. *Developmental Psychobiology*, *59*(7), 888–898. https://doi.org/10.1002/dev.21543

Sterne, J. A. C., & Egger, M. (2001). Funnel plots for detecting bias in meta-analysis: Guidelines on choice of axis. *Journal of Clinical Epidemiology*, *54*(10), 1046–1055. https://doi.org/10.1016/S0895-4356(01)00377-8

Suveg, C., Braunstein West, K., Davis, M., Caughy, M., Smith, E. P., & Oshri, A. (2019). Symptoms and synchrony: Mother and child internalizing problems moderate respiratory sinus arrhythmia concordance in mother–preadolescent dyads. *Developmental Psychology*, *55*(2), 366–376. https://doi.org/10.1037/dev0000648

Thayer, J. F., Ahs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, *36*(2), 747–756. https://doi.org/10.1016/j.neubiorev.2011.11.009

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, *36*(3), 1–48. https://doi.org/10.18637/jss.v036.i03

Viechtbauer, W., & Cheung, M. W.-L. (2010). Outlier and influence diagnostics for meta-analysis. *Research Synthesis Methods*, *1*(2), 112–125. https://doi.org/10.1002/jrsm.11

Woody, M. L., Feurer, C., Sosoo, E. E., Hastings, P. D., & Gibb, B. E. (2016). Synchrony of physiological activity during mother-child interaction: Moderation by maternal history of major depressive disorder. *Journal of Child Psychology and Psychiatry*, *57*(7), 843–850. https://doi.org/10.1111/jcpp.12562

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Miller, J. G., Armstrong-Carter, E., Balter, L., & Lorah, J. (2023). A meta-analysis of mother–child synchrony in respiratory sinus arrhythmia and contextual risk. *Developmental Psychobiology*, *65*, e22355. https://doi.org/10.1002/dev.22355

10982302, 2023, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/dev.22355 by Emma Armstrong-Carter - Tufts University , Wiley Online Library on [06/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License