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# Individual Differences in Parent and Child Average RSA and Parent Psychological Distress Influence Parent-Child RSA Synchrony

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## Abstract

Parent-child synchrony of respiratory sinus arrhythmia (RSA) varies by risk, but novel approaches are needed to capture individual contributions to synchrony. Multilevel state-trait modeling was applied to examine how parental psychological distress and parent and child average RSA during challenge (reflecting individual regulatory capacities) shaped RSA synchrony in mother-child (*n*=71) and father-child (*n*=47) interactions. RSA synchrony was curvilinear such that greater in-the-moment RSA reactivity in one partner prompted greater reactivity in the other. Higher risk (lower average RSA; higher distress) predicted in-the-moment RSA withdrawal to partner RSA changes, whereas lower risk (higher average RSA; lower distress) predicted in-the-moment RSA augmentation. In some models, one's higher average RSA prompted the partner's greater reactivity and thus synchrony when parental distress was higher. However, the presence and direction of synchrony was not consistently adaptive nor maladaptive across models, suggesting its meaning relies on theory and the parent and risk factors in question.

### Keywords

RSA; synchrony; psychopathology; self-regulation; fathers

In early childhood, parents undergo biobehavioral reorganization to attune and respond to infant needs while the infant depends on the caregiver for external regulation of physiological systems (Feldman, 2007). Adaptive physiological coregulation in parent-child interaction involves homeostasis – a process promoting stability in the respective partner by regulating within established functional ranges toward a set point – and allostasis, where these operating ranges are subject to change in response to internal and external demands

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(Atzil & Barrett, 2017; Beauchaine et al., 2011). Through consistent social care that maintains homeostasis in the child, parents facilitate the development of child self-regulation and help prevent allostatic load, which could cause maladaptive allostatic shifts such as chronic hyperactivity or hyporeactivity in the long term (Beauchaine et al., 2011; Feldman, 2012). Mounting evidence suggests this essential dyadic regulatory process manifests in parent-child synchrony in brain systems (Quiñones-Camacho & Davis, 2018), hypothalamic-pituitary-adrenal (HPA) axis functioning (Saxbe et al., 2017), and the parasympathetic nervous system (Lunkenheimer et al., 2015; Suveg et al., 2016).

In the preschool years, synchrony of respiratory sinus arrhythmia (RSA) has emerged as an important dyadic process related to child regulatory skills (Lunkenheimer et al., 2015). Considering parental attunement is needed to support homeostasis, a critical question is how parental psychological distress may alter RSA synchrony. Psychological distress alters RSA functioning in the parent (Beauchaine et al., 2019) and disrupts positive parent-child interactions and child self-regulatory development (Choe et al., 2013; Connell & Goodman, 2002), but we know little about how it shapes RSA synchrony (Lunkenheimer et al., 2018). Recent studies examining depressive symptoms and hostility in mothers have shown mixed findings of either weaker positive, negative, or absent parent-child synchrony depending on symptom type and sample characteristics (Amole et al., 2017; Lunkenheimer et al., 2018; Suveg et al., 2019). In line with hierarchical approaches to psychopathology (Martel et al., 2017), understanding relations between RSA synchrony and general psychological distress may bolster our understanding of RSA synchrony as a biomarker of psychopathology risk. Further, it may be important to examine these processes with both mothers and fathers given potential differences in how RSA underlies their respective symptoms (Skoranski & Lunkenheimer, 2020).

Another critical need in this area of research is modeling RSA synchrony in adequately dynamic ways, moving beyond more static measures of reactivity such as differences scores between resting and challenging tasks, and reflecting that RSA changes with time and in relation to a partner (Glackin et al., 2020). Thus, instead of correlating each partner's change scores or mean RSA levels only during social interaction, it is vital to capture dynamic changes across several time segments of an interaction. RSA synchrony is defined here as closely temporally related parent and child RSA during face-to-face interaction, including positive synchrony (related change in the same direction), negative synchrony (related change in opposite directions), or asynchrony (no related change). Another methodological need is to account for individual contributions to RSA synchrony with respect to both "trait" aspects, i.e., the influence of individual differences in regulatory capacities (Quiñones-Camacho & Davis, 2018), and "state" aspects, i.e., the individual's reactivity in a given moment. Accordingly, we examined how one partner's state RSA, operationalized as in-the-moment deviation from their average RSA within epoch, predicted the other partner's state RSA within the same epoch, repeatedly over the course of a challenging task. We further examined whether this synchrony was moderated by parent psychological distress and parent and child average RSA during the task, which reflected individual differences in physiological regulatory capacities. Further, considering that parent and child are theorized to regulate one another within an allostatic range, and heeding calls to examine nonlinearity in RSA reactivity (Holzman & Bridgett, 2017), we tested whether RSA synchrony was curvilinear such that greater change in one partner's state RSA prompted greater change in the other's state RSA.

## Respiratory Sinus Arrythmia as an Index of Self-Regulatory Capacity

In order to understand the meaning of RSA synchrony, one must first consider the role of RSA as a biomarker of self-regulation at the individual level. RSA, or changes in heart rate per respiration rate, represents inhibitory parasympathetic control that slows down heart rate (Thayer & Lane, 2000). A calm physiological state reflected in higher resting RSA is theorized to promote higher cognitive abilities, adaptive social behavior, and better emotion regulation (Holzman & Bridgett, 2017; Patriquin et al., 2015; Porges, 2007). Lower resting RSA has been linked with higher psychological distress in children and adults, suggesting impaired physiological and emotional regulation (Beauchaine et al., 2019). Resting RSA has been shown to be strongly positively related to average RSA over the course of parent-child interaction tasks (Lunkenheimer et al., 2021), thus reflecting individual differences in regulatory capacity during rest and during effortful social interaction, respectively.

RSA reactivity, or a change in RSA in response to challenge, also reflects self-regulation (Kahle & Hastings, 2015). An RSA decrease in response to challenge (withdrawal) is thought to reflect adaptive regulation and social engagement (Beauchaine, 2001) and is related to sensitive parenting (Sturge-Apple et al., 2020) and better child adjustment (Graziano & Derefinko, 2013; Shahrestani et al., 2015). However, excessive RSA withdrawal, labeled "hyperreactivity", has been observed in clinical samples, suggesting that RSA withdrawal may be maladaptive depending on degree of withdrawal, sample, and task context (Thayer & Lane, 2000). An RSA increase in response to challenge (augmentation) is thought to reflect disengagement or avoidance (Beauchaine, 2001); this maladaptive, "hyporeactive" response is found in clinical and higher-risk child and adolescent samples (Graziano & Derefinko, 2013). At the same time, some have theorized that RSA augmentation may be triggered by a partner's social support, buffering individuals from greater stress, and in this case could be linked with better social functioning and social engagement (Hastings & Kahle, 2019; Shahrestani et al., 2015; Zhang et al., 2020).

## Gaps in Parent-Child RSA Synchrony Research

### Capturing Dynamic RSA Synchrony and Parsing Within- and Between-Person Effects

The traditional assessment of RSA reactivity – the difference in RSA between a resting and challenging task – is a static measure that masks changes in RSA over time and thus the regulatory nature of RSA (Glackin et al., 2020). To align assessment and theory, RSA synchrony research needs to move toward modeling moment-to-moment within-person differences over time (Lunkenheimer et al., 2018; 2021). Accordingly, we employed state-trait models to examine dyadic processes in a time series, also termed intradyad dynamics modeling (Bolger & Laurenceau, 2013; Shanahan et al., 2014). This method allowed for parsing the effects of three factors of one's RSA functioning that potentially contribute to a partner's RSA functioning (Quiñones-Camacho & Davis, 2018). First, we examined one's state RSA, reflecting within-person deviations from the individual average RSA per time unit. A significant positive effect of one's state RSA on the partner's RSA indicates they are changing in the same direction over the course of the interaction, e.g., when one's RSA is higher than their average at a given moment, the partner's RSA is also higher than their average at a given moment (Merwin et al., 2017; Suveg et al., 2019). In addition, we examined trait-like average RSA, reflecting between-person differences in regulatory functioning during challenge. A significant effect of one's average RSA on the partner's average RSA captures the extent to which both partners have similar averages across the interaction (Merwin et al., 2017). Lastly, we examined an interaction between one's state RSA and average RSA on the partner's RSA. A significant effect indicates that the strength or direction of RSA synchrony differs depending on one's average RSA.

## Testing Nonlinear Models of RSA Synchrony

Parent-preschooler physiological synchrony is characterized by dynamic reciprocal relations (Lunkenheimer et al., 2018). If parents and children flexibly maintain physiological regulation by keeping each other within a homeostatic range (Saxbe et al., 2020), linear and unidirectional models of RSA synchrony may fall short. Linear models imply consistency in direction and strength of synchrony, failing to account for states where regulation or synchrony are inactive. The question remains whether RSA synchrony is present and needed when partners are in a well-regulated, calm state or close to their homeostatic baseline. Further, stronger RSA synchrony (in the same or opposite directions) may be prompted when one partner shows more marked physiological responses indexing dysregulation. Specifically, stronger reactivity in one individual in a given moment may prompt stronger reactivity in the partner, regardless of the direction of that reactivity (e.g., RSA increase or decrease). However, we have yet to examine whether stronger RSA change in the parent or child is associated with stronger RSA change in their interaction partner in the moment, and how risk factors may shape these processes.

Risk factors such as psychopathology symptoms or low average RSA have been found to be inconsistently related to RSA reactivity, and studies report both hyperreactivity and hyporeactivity in at-risk samples in response to environmental stimuli (Beauchaine et al., 2019; Graziano & Derefinko, 2013). Thus, based on prior research suggesting both excessive RSA withdrawal as well as lack of withdrawal or even RSA augmentation in higher risk samples, we may observe two forms of curvilinear relations between parent and child state RSA: Either a concave or U-shaped relationship, suggesting that parents or children respond with stronger augmentation to stronger in-the-moment changes in partner RSA, or a convex or inverted U-shaped relationship, suggesting that parents or children respond with stronger withdrawal to stronger in-the-moment changes in partner RSA. In both cases however, we would observe lower or even absent RSA reactivity as a response to lower or absent reactivity in the partner. Thus, in line with calls to move beyond linear associations of dynamic interaction processes (Granic & Hollenstein, 2003), the present study explored curvilinear models of RSA synchrony that accounted for the presence, direction, and strength of synchrony.

## Examining Father-Child RSA Synchrony

Mother-child RSA synchrony in early childhood has been demonstrated (Gray et al., 2018; Lunkenheimer et al., 2019; Suveg et al., 2016) and appears normative, adaptive, and bidirectional in low-risk community samples (Lunkenheimer et al., 2015). Despite evidence that fathers also demonstrate affective synchrony and show different patterns from mothers (Feldman, 2003; Lunkenheimer et al., 2020), few studies focus on father-child RSA synchrony. A recent study showed RSA synchrony was influenced by children's externalizing problems in similar ways for mother-child and father-child dyads, but that RSA synchrony in father-child dyads was more influenced by positive affect expressed during the interaction (Lunkenheimer et al., 2021). However, in related work with adolescents, two studies failed to find significant father-adolescent RSA synchrony (Li et al., 2020; Roman-Juan et al., 2020), and another study only showed father-child sympathetic nervous system synchrony when fathers were in an emotion suppression condition after experiencing a stressful situation with their children (Waters et al., 2020). More research on father-child RSA synchrony in early childhood is sorely needed given the importance of fathers for children's regulatory development (Rinaldi & Howe, 2012).

## Parental Psychological Distress as a Moderator of RSA Synchrony

Positive RSA synchrony appears adaptive in community samples and is associated with supportive parenting and better child self-regulation (Lunkenheimer et al., 2015; Lunkenheimer et al., 2019; Skoranski et al., 2017). However, the adaptiveness of RSA synchrony with higher-risk parents is unclear. Negative RSA synchrony has been associated with higher maternal hostility (Lunkenheimer et al., 2018), depressive symptoms (Suveg et al., 2019), and depressive disorder (Amole et al., 2017; Woody et al., 2016). However, weaker positive RSA synchrony (McKillop & Connell, 2018) and the absence of synchrony (Lunkenheimer et al., 2018) have also been linked with maternal depressive symptoms. Further, positive RSA synchrony may be a risk factor when mothers have higher clinical symptoms (Suveg et al., 2016). With the exception of one study (Lunkenheimer et al., 2018), this work has centered on older children and teens. Given mixed findings, variation by symptom type, and the lack of early childhood and paternal data, more work is needed on the effects of parental psychological distress on RSA synchrony.

Hierarchical approaches to psychopathology theorize a general distress factor that underlies comorbidity among different disorders (Beauchaine & Thayer, 2015). Lower resting RSA, excessive RSA withdrawal, and blunted RSA response during challenge, indexing emotion dysregulation, have been observed to be transdiagnostic markers across disorders (Beauchaine et al., 2019). Parental psychological distress, operationalized here as severity of overall symptoms, reflects emotion dysregulation and is associated with dysregulated RSA (Glackin et al., 2020; Shanahan et al., 2014). Though prior work has focused on parents' specific symptom types, a focus on how general psychological distress shapes parent-child RSA synchrony could inform transdiagnostic models as well as risk mechanisms in community samples.

## Average RSA and RSA Synchrony

Resting RSA, indexing individual differences in the capacity to regulate and socially engage (Holzman & Bridgett, 2017; Patriquin et al., 2015; Porges, 2007), may be an in important factor shaping RSA synchrony. In theory, it is suggested that an individual's higher regulatory capacities and better ability to socially engage should support adaptive dyadic synchrony (Shahrestani et al., 2015; Skoranski et al., 2017). However, despite its close association with resting RSA (Lunkenheimer et al., 2021), it is yet unclear whether higher average RSA supports RSA synchrony during challenging parent-child interactions. A recent study reported that high maternal average RSA during a challenging mother-child interaction task predicted negative RSA synchrony (Skoranski et al., 2017). The authors concluded that higher parental average RSA during a challenging task may reflect the parent's lack of engagement, who may not be adequately supporting their children (Skoranski et al., 2017). Thus, although higher *resting* RSA may indicate higher regulatory capacity, higher average RSA during *challenge* may reflect the lack of expected RSA withdrawal in response to a difficult task, either due to an atypical stress response or even a buffered response in relation to a partner's support (Shahrestani et al., 2015; Skoranski et al., 2017). More work is needed to examine the role of individual average RSA and whether it exacerbates or buffers the adverse effects of risk factors on parent-child RSA synchrony, especially in higher risk samples, as conditions of risk may alter baseline regulatory functioning (Quiñones-Camacho & Davis, 2018).

## Present Study

Our aim was to examine whether moment-to-moment changes in parent and child reactivity were dynamically related and whether this synchrony was moderated by parental psychological distress and parent and child average RSA. We applied intradyad dynamics modeling and examined within-dyad, between-dyad, and nonlinear effects in four multilevel models of RSA synchrony: mother predicting child, child predicting mother, father predicting child, and child predicting father. By separating these models, we were able to examine directional pathways of influence in predicting individual RSA reactivity and RSA synchrony. In each model, parental psychological distress and the respective partner's average RSA indexing partner regulatory capacities were examined as moderators of RSA synchrony.

In these models, we also accounted for covariates shown to be related to RSA reactivity in prior research, including parental history of childhood maltreatment, which is associated with parent psychological distress (Murphy et al., 2020), atypical RSA (Oosterman et al., 2019), and altered parent-child cortisol synchrony (Fuchs et al., 2017), and observed affect during the interaction, which acted as a proxy for affective climate and could reflect the degree of arousal experienced (Lunkenheimer et al., 2019), and which has been shown to shape father-child RSA synchrony (Lunkenheimer et al., 2021). We also controlled for time to account for the effects of elapsed task time on RSA reactivity, and also resting RSA of those individuals whose state RSA was predicted in each respective model to account for individual differences in resting RSA.

We hypothesized that individual differences in average RSA and psychological distress would moderate the association between child and parent state RSA. Based on prior work on maternal depressive symptoms (McKillop & Connell, 2018; Suveg et al., 2019), we expected RSA synchrony to be weaker or negative in dyads with higher parental psychological distress compared to lower distress. Based on theoretical considerations and findings suggesting that higher average RSA indexes self-regulatory and social engagement capacity (Porges, 2007), we also tentatively expected RSA synchrony to be weaker or negative if one's average RSA was lower, as low RSA indexes risk and weaker or negative RSA synchrony has been been found in dyads characterized by greater risk (Lunkenheimer et al., 2018; Suveg et al., 2019). An additional exploratory aim was testing whether RSA synchrony was curvilinear in nature, wherein we hypothesized that greater changes in RSA in one individual would prompt greater changes in the partner's RSA and vice versa. As both hyper- and hyporeactivity have been linked with higher risk factors (Beauchaine et al., 2019; Graziano & Derefinko, 2013), we expected to observe convex or concave curvilinear shapes of parent-child RSA synchrony under conditions of higher risk.

# Method

## Participants

Mother-child and father-child dyads were part of a larger study on parent-child coregulation and familial risk in early childhood, in which 150 families were examined at three time points. Recruitment involved flyers, community events, and recruiting through agencies serving low-income families. Families were oversampled for risk, including low-income status (200% or less of the federal poverty level), Child Protective Services involvement, or higher life stress per the Social Readjustment Rating Scale (e.g., job loss, divorce; Holmes & Rahe, 1967). Children (53% girls) were on average 2.5 years old ($SD$=0.1) at Time 1 and 3.03 years ($SD$=0.1) at Time 2. Their race/ethnicity was 65% White, 22% Latinx, 2% Black, 2% Native American, 8% Multi-racial and 1% Other or Unknown. Parents were mostly married (66%); thirteen percent were living together, 9% were separated or divorced, and 12% were single. The mean level of education attained by mothers and fathers was an associate's degree. Average household income was $30,000 to $39,000 and most families used government assistance (82%). Data from Time 1 (surveys) and Time 2 (surveys, physiology, and affect) were used. For the current study, only 71 mother-preschooler and 47 father-preschooler dyads with complete RSA, affect, and survey data were included. However, mother-child dyads with complete data did not differ from those with incomplete data with respect to any primary or control variables, nor sociodemographic variables except for child age ($t(115) = 2.1$, $p<.05$.), with children with complete data ($M$=3.05, $SD$=0.11) being slightly older than children with incomplete data ($M$=3.01, $SD$=0.09). Father-child dyads were similar, where child age was the only significant difference ($t(78) = 2.1$, $p<.05$.) between families with complete ($M$=3.06, $SD$=0.10) vs. incomplete data ($M$=2.99, $SD$=0.19). Families were excluded if parents could not read, write, and speak in English, if participants had a cardiac condition that would alter RSA data, or if the child had a diagnosed developmental disability.

## Procedure

The study was approved by the Institutional Review Board at <blinded for review>, protocol # <blinded for review>. Parents provided informed consent for themselves and their children. At Time 1, survey data was collected and at Time 2, fathers and mothers visited the lab separately with their preschoolers. Mother-child visits lasted two hours and father-child visits one hour. Parent-child dyads were asked to wear electrodes and a respiratory belt over the course of several tasks. First, parents and children watched a 3-minute video of dolphins in the ocean (resting condition). They then engaged in dyadic tasks, where stimuli were counterbalanced across parents. Families were compensated $135 for mothers and $75 for fathers participating.

## Measures

**Parent-Child Challenge Task (PCCT)—**The PCCT is a challenging dyadic task designed to capture change in parent-child dynamics across conditions (Lunkenheimer et al., 2017). It includes a 4-minute baseline condition, a 3-minute challenge condition, and 3 minutes of recovery. During baseline, parents and children are asked to complete a puzzle and told that if they recreate all three designs, they will win a prize. Puzzles are above children's cognitive ability level and increase in difficulty with time, requiring parent involvement to complete. Parents are asked to use their words only to guide children and to refrain from interfering physically. During the challenge condition, parent-child dyads are interrupted by an experimenter and informed them that they only have two minutes left to finish. During the recovery condition, children receive praise and a prize from the experimenter regardless of whether they completed the task or not, and parent-child dyads are asked to play with the prize (art materials). The PCCT has been shown to reliably elicit affective, behavioral, and RSA responses in parent-child dyads (Lunkenheimer et al., 2017, 2018).

**RSA—**RSA was collected during the 3-minute resting condition and 10-minute PCCT at Time 2, recorded using Mindware wireless electrocardiograph MW1000A with disposable electrodes. A crystal respiratory effort belt was placed below the diaphragm to monitor respiration. RSA was measured as high frequency heart rate variability, i.e., the natural log of the variance of heart period within the frequency band related to respiration (range = 0.12–0.40 Hz for parents and 0.24–1.04 Hz for children; Fracasso et al., 1994). Data was processed using Mindware Heart Rate Variability 3.0 software. RSA was calculated for every 30-s interval, resulting in 20 data segments per individual for the PCCT and six segments for resting. Segments with 10% or greater noise were excluded from analysis. Respiration rate was considered as a covariate as it has been shown to affect RSA (Beauchaine et al., 2019). However, respiration rate was neither correlated with maternal RSA, $r(69)=.08$, $p=0.60$, nor child RSA, $r(69)=-0.15$, $p=0.18$, during mother child interactions, nor with paternal RSA, $r(45)=-0.08$, $p=0.54$, nor child RSA, $r(45)=-.17$, $p=0.18$, during father-child interactions. Given there were no relations with any of the variables of interest, it was excluded to preserve parsimony and analytic power of the models. Additionally, recent recommendations highlight that respiration rate should not routinely be included in analyses of RSA, as controlling for it may remove variability associated with neural control over the heartbeat (Laborde et al., 2017; Denver et al., 2007). As resting RSA is associated with RSA reactivity (Graziano & Derefinko, 2013) and was significantly correlated with our outcome of RSA, resting RSA of those individuals whose RSA was predicted as the outcome was included in each respective analytic model.

**Parental Psychological Distress—**Psychological distress was assessed with the Brief Symptom Inventory (BSI; Derogatis, 1993) at Time 2, a 53-item self-report inventory assessing psychological symptomatology on nine subscales, focusing on the preceding seven days. For the current study, the Global Severity Index was used to reflect distress, a measure of current severity of overall psychological symptoms. It was calculated by averaging the 53 items. In our sample, internal consistency of the Global Severity Index was high, with Cronbach's $\alpha$=.92 for mothers and $\alpha$=.96 for fathers.

## Covariates

**Parental History of Childhood Maltreatment.—**Parental history of childhood maltreatment (CM) was assessed at Time 1 with the 28-item Childhood Trauma Questionnaire short form (Bernstein et al., 2003), a retrospective measure of past abuse and neglect. Parents responded to items on a scale from 0 (*never true*) to 4 (*very true*). Scores for each of the five subscales assessing physical abuse, sexual abuse, emotional abuse, emotional neglect, and physical neglect range from 5 (no history) to 25 (severe history). A total abuse scale was created by calculating a sum of all subscales ranging from a minimum of 25 to a maximum of 125. The CTQ is a widely used measure and has shown appropriate psychometric properties in different sample types (Tonmyr et al., 2011). Internal consistency was excellent, with Cronbach's $\alpha$=.95 for mothers and $\alpha$=.94 for fathers.

**Dyadic Positive Affect.—**Dyadic positive affect was included as a covariate to reflect the affective climate of the PCCT. Parent and child affect was coded continuously second-by-second in real time using the Dyadic Interaction Coding System (Lunkenheimer, 2009) for parent-child interactions in early childhood within Noldus Observer XT 10.0 software. A five-dimension scale describing medium/high negative, low negative, neutral, low positive, and medium/high positive affect was used. Affect was coded for precisely the duration that each respective affective intensity level was displayed by participants throughout the entire interaction. For reliability, twenty percent of videos were double-coded and coders completed periodic tests for drift reliability. A confusion matrix was created for each reliability video containing coder agreements and disagreements. Reliability analysis was not only performed on content but also for the precise duration and timing of coding with respect to each code for the entire observation. Average interrater agreement for the entire coding system based on this method was 78%. *Dyadic positive affect* was defined as the total time spent in dyadic states in which either both partners expressed positive affect, or one partner expressed positive affect while the other partner expressed neutral affect.

## Analytic Plan

Dyadic data follow a hierarchical structure with observations nested within dyads (Raudenbush & Bryk, 2002). This clustering of data can, if ignored, result in underestimated standard errors and lead to inflated type-I error (McNeish, 2017). We addressed this issue by using intradyad dynamics modeling, which relaxes the independence assumption of traditional regression models by modeling the dependence of observations (McNeish, 2017). Four analytical models captured the bidirectionality of moment-to-moment RSA synchrony and the impact of parental psychological distress and average RSA on this process: child RSA predicting mother RSA and the reverse, and child RSA predicting father RSA and the reverse. ICCs were 64.7% for mothers, 69.3% for children interacting with mothers, 60.9% for fathers, and 66.9% for children interacting with fathers. Further, unconditional means models resulted in significant random effects, confirming the need for hierarchical modeling (Garson, 2019).

To examine synchrony at a within-person level, the predictors of child RSA or parent RSA, respectively, were split into two orthogonal predictors, a time-varying variable (state RSA, within-dyad; WD) and a time-invariant variable (average RSA, between-dyad; BD) (Bolger & Laurenceau, 2013). Average RSA (BD) is the grand-mean centered average RSA during the PCCT. State RSA (WD) represents the fluctuations of child's or parent's RSA from their own average RSA in each 30-second segment during the PCCT. Estimation of WD effects allowed us to examine in-the-moment synchrony and thereby address dynamic relations (Suveg et al., 2019), whereas estimation of BD effects allowed a test of whether one partner's average RSA was related to the other's average RSA. A quadratic state RSA term was included in all models to assess whether greater reactivity in one partner was related to greater reactivity in the other partner in the moment. Thus, our interest was not on quadratic changes over time, but whether at any given moment in time, parents and children showed deviations from their average RSA values that were curvilinearly related.

To account for potential changes to RSA reactivity as a function of task length, time was included as a covariate. The first observation was set to zero so that model intercepts represented the model-implied mean at the first observation point. Further, parental psychological distress and all covariates except time (resting state RSA, dyadic positive affect, parental history of CM) were grand-mean centered so that values of zero represented the average sample level, allowing more meaningful interpretations based on the model parameters. We analyzed the data using the lme4 package in R (Bates et al., 2015). Random intercept models were estimated and model specification followed the subsequent equations:

### Within-dyad RSA: Level 1

$$\text{Parent:}\quad Y_{P}ij = \beta 0j_{P} + \beta 1.1j_{CP} * (\text{state RSA}_{CP})i + \beta 1.2j_{CP} * (\text{state RSA}^{2}_{CP})ij + \beta 2j_{P} * (\text{time})ij + \varepsilon_{P}ij \tag{1.1}$$

$$\text{Child:}\quad Y_{C}ij = \beta 0j_{C} + \beta 1.1j_{PC} * (\text{state RSA}_{PC})i + \beta 1.2j_{PC} * (\text{state RSA}^{2}_{PC})ij + \beta 2j_{C} * (\text{time})ij + \varepsilon_{C}ij \tag{1.2}$$

Equation 1.1 depicts WD effects for the parental model specifying parent state RSA ($Y_{P}ij$) during PCCT at time i in dyad j as a function of: an intercept for parent RSA specific to the respective dyad j ($\beta 0j_{P}$), a linear slope specific to parent-child dyad j representing the effect of within-variation in child state RSA ($\beta 1.1j_{CP}$), a quadratic slope for child state RSA ($\beta 1.2j_{CP}$), a slope representing the passage of time ($\beta 2j_{P}$), and a residual specific to time i for dyad j ($\varepsilon_{P}ij$). In this equation, synchrony is represented by both the linear and quadratic slopes for child state RSA ($\beta 1.1j_{CP}$ and $\beta 1.2j_{CP}$, respectively) in relation to parent state RSA ($Y_{P}ij$). Similarly, equation 1.2 depicts WD effects for the child model specifying child state RSA ($Y_{C}ij$) during the PCCT at time i in dyad j as a function of an intercept for child RSA ($\beta 0j_{C}$), a linear ($\beta 1.1j_{PC}$) and a quadratic ($\beta 1.2j_{PC}$) slope for within-variation in parent state RSA, a time slope ($\beta 2j_{C}$), and a residual term ($\varepsilon_{C}ij$). Synchrony is represented by both the linear and quadratic slopes for parent state RSA ($\beta 1.1j_{PC}$ and $\beta 1.2j_{PC}$, respectively) in relation to child state RSA ($Y_{C}ij$).

**Between-dyad RSA: Level 2—**Parent:

$$\begin{aligned} &\beta 0_{jP} = \gamma 00 + \gamma 01 * (\text{Resting RSA}_{P})j + \gamma 02 * (\text{Dyadic Positive Affect})j + \gamma 03 * \\ &(\text{CM}_{P})j + \gamma 04 * (\text{Distress}_{P})j + \gamma 05 * \\ &(\text{Average RSA}_{CP})j + \gamma 07 * (\text{Average RSA}_{CP} * \text{Distress}_{P})j + \mu 0_{jP} \\ &\beta 1.1_{jCP} = \gamma 06.1 + \gamma 06.11 * (\text{Average RSA}_{CP})j + \gamma 06.12 * (\text{Distress}_{P})j + \gamma 06.13 \\ &* (\text{Average RSA}_{CP} * \text{Distress}_{P})j \\ &\beta 1.2_{jCP} = \gamma 06.2 + \gamma 06.21 * (\text{Average RSA}_{CP})j + \gamma 06.22 * (\text{Distress}_{P})j + \gamma 06.23 \\ &* (\text{Average RSA}_{CP} * \text{Distress}_{P})j \\ &\beta 2_{j}P = \gamma 20 \end{aligned} \tag{2.1}$$

Child:

$$\begin{aligned} &\beta 0_{jC} = \gamma 00 + \gamma 01 * (\text{Resting RSAc})j + \gamma 02 * (\text{Dyadic Positive Affect})j + \gamma 03 * \\ &(\text{CM}_{P})j + \gamma 04 * (\text{Distress}_{P})j + \gamma 05 * \\ &(\text{Average RSA}_{PC})j + \gamma 07 * (\text{Average RSA}_{PC} * \text{Distress}_{P})j + \mu 0_{jC} \\ &\beta 1.1_{jPC} = \gamma 06.1 + \gamma 06.11 * (\text{Average RSA}_{PC})j + \gamma 06.12 * (\text{Distress}_{P})j + \gamma 06.13 \\ &* (\text{Average RSA}_{PC} * \text{Distress}_{P})j \\ &\beta 1.2_{jPC} = \gamma 06.2 + \gamma 06.21 * (\text{Average RSA}_{PC})j + \gamma 06.22 * (\text{Distress}_{P})j + \gamma 06.23 \\ &* (\text{Average RSA}_{PC} * \text{Distress}_{P})j \\ &\beta 2_{j}P = \gamma 20 \end{aligned} \tag{2.2}$$

Equation 2 models specify the BD-variations in the coefficients of the Level-1 equations. Specifically, for the equation 2.1 parental model, variations in intercepts are a function of an intercept ($\gamma$00), parental resting RSA ($\gamma$01), dyadic positive affect ($\gamma$02), parental history of CM ($\gamma$03), parental psychological distress ($\gamma$04) and child average RSA ($\gamma$05), an interaction term between parental psychological distress and child average RSA ($\gamma$07), and a residual component specific to each parent-child-dyad ($\mu 0j_{P}$). Accordingly, this equation investigates whether between-dyad variations in slopes $\beta 1.1j_{CP}$ and $\beta 1.2j_{CP}$ are a function of intercepts and effects of child average RSA, psychological distress scores, and the parental psychological distress-average RSA interaction. $\beta 2j_{P}$ is again represented by a constant value on level 2. For the equation 2.2 child model depicting BD-effects, variations in intercepts are a function of an intercept ($\gamma$00), child resting RSA ($\gamma$01), dyadic positive affect ($\gamma$02), parental history of CM ($\gamma$03), parental psychological distress ($\gamma$04) and parent average RSA ($\gamma$05) scores, an interaction term between parental psychological distress and parent average RSA ($\gamma$07), and a residual component ($\mu 0j_{C}$). Slope variations are a function of intercepts and effects of parent average RSA, parent psychological distress scores, and the psychological distress-average RSA-interaction.

Both sample size and the number of repeated measures per person determine statistical power in time series analysis (Maxwell & Delaney, 2004). For the "child predicting maternal RSA" model ($n$=71 dyads) and "mother predicting child RSA" model ($n$=72 dyads), 1295 and 1315 observations were included in analyses, respectively. For the "child predicting paternal RSA" model ($n$=47) and "father predicting child RSA" model ($n$=45), observation totals were 884 and 850, respectively. Thus, models offered sufficient power to detect within-person effects. Simulation studies using dyadic data MLM in smaller samples indicate that even with smaller sample sizes, given a high ICC, reliable and valid estimates can be obtained (Du & Wang, 2016).

## Results

### Preliminary Analyses

Means, standard deviations and intercorrelations of study variables are shown in Table 1 for mother-child dyads and Table 2 for father-child dyads. There were no significant correlations between primary study variables and sociodemographic factors. Average RSA was positively correlated with resting RSA for mothers, children interacting with their mothers, fathers, and children interacting with their fathers, supporting the use of average RSA as an index of individual differences in regulatory functioning.

### Intradyad Dynamics Modeling Results

Intradyad dynamics (state-trait) models revealed that there were significant differences in the effects of parental psychological distress on RSA synchrony by parent; differences also emerged by direction, i.e., from parent to child or child to parent. In all four multilevel models, interaction terms including linear vs. quadratic state RSA were either both significant, or only the interaction including quadratic state RSA was significant. Thus, quadratic term results are reported. The findings for each model are described below in turn. Table 3 shows results for child-to-mother and mother-to-child models, and Table 4 shows results for child-to-father and father-to-child models. Significant random intercept coefficients revealed considerable intercept variability between dyads in all models (see Tables 3 and 4).

**Child-to-Mother Synchrony Moderated by Child Average RSA and Psychological Distress—**Child-to-mother synchrony, i.e., child state RSA predicting maternal state RSA, was observed and was moderated by both maternal psychological distress and child average RSA. There was a significant two-way interaction between quadratic child state RSA and maternal psychological distress as well as a three-way-interaction between quadratic child state RSA, child average RSA, and maternal psychological distress (Table 3). Similar patterns were found for both the three-way (Figure 1) and two-way interactions involving child state RSA and maternal psychological distress: Mothers with *higher* psychological distress (+1SD; Figure 1) showed state RSA withdrawal when children were either increasing or decreasing their state RSA levels. Thus, results show positive synchrony when children had lower state RSA (i.e., deviation below their own average RSA), and negative synchrony when children had higher state RSA (i.e., deviation above their own average RSA). Mothers with *lower* psychological distress (−1 SD; Figure 1), however, showed RSA augmentation when their children showed either RSA increases or decreases, reflecting negative synchrony when children had higher state RSA values and positive synchrony when children had lower state RSA values. Asynchrony was observed if children remained at their own average state RSA values. Lastly, simple slopes to probe regions of significance for the three-way interaction revealed that these quadratic synchrony patterns were only present if children had *mean to higher average RSA* (+>/=1SD; Figure 1). In sum, these findings indicate that maternal psychological distress, children's regulatory functioning, and child RSA reactivity interacted to shape mothers' RSA reactivity to their children.

**Mother-to-Child Synchrony Moderated by Maternal Average RSA and Psychological Distress—**Similar to results from the child-to-mother model, significant mother-to-child synchrony was observed; mother quadratic state RSA predicted child state RSA and was moderated by maternal average RSA (Figure 2). Post-hoc probing of this two-way state-trait interaction revealed that maternal state RSA predicted child state RSA when maternal average RSA was *higher* (>2.41, centered average RSA) or *lower* (<−1.45, centered average RSA) during the PCCT. There was no significant synchrony when maternal state RSA values were in the average range. Specifically, if mothers had *higher* average RSA values and showed either an increase or decrease compared to their average RSA, children showed RSA augmentation. If mothers had *lower* average RSA values and showed either an increase or decrease compared to their average RSA, children showed RSA withdrawal. Thus, dynamic synchrony from mother to child was present but could be either positive or negative: it was not systematically associated with levels of maternal average RSA. For example, for mothers with higher average RSA, dyads could experience either negative synchrony (mother RSA withdrawal, child RSA augmentation) or positive synchrony (joint RSA augmentation). For mothers with lower average RSA, the pattern was reversed, but dyads could still experience negative synchrony (mother RSA augmentation, child RSA withdrawal) or positive synchrony (joint RSA withdrawal). Additionally, maternal psychological distress did not moderate RSA synchrony in this model.

### Maternal Average RSA and Psychological Distress Interacted to Predict Child RSA.

In addition to the findings for mother-to-child synchrony above, child average RSA was predicted by a two-way interaction between maternal average RSA and maternal psychological distress (Table 3). Johnson-Neyman regions of significance revealed significant links between maternal average RSA and child average RSA if maternal psychological distress scores were lower (<−0.22, centered BSI scores) or higher (>0.69, centered BSI scores), but there was no association if psychological distress was around the sample mean. If mothers reported *higher* psychological distress, maternal average RSA was positively associated with the child's average RSA across the time series, and if mothers had *lower* psychological distress, maternal average RSA was negatively associated with the child's average RSA across the time series (Figure 3a).

**Child-to-Father Model: Average RSA and Paternal Psychological Distress Interacted to Predict Paternal Average RSA—**The child-to-father model was the only model not to show significant synchrony in dynamic reactivity. There was no main effect of child state RSA predicting paternal state RSA, nor were there moderation effects suggesting paternal psychological distress or average child RSA shaped child-to-father synchrony of state RSA. However, although synchrony in state RSA was not found, father RSA averaged across the time series was influenced by an interaction between child average RSA and paternal psychological distress (Table 4). For fathers with *higher* (>0.36, centered BSI scores) psychological distress, child average RSA was positively associated with father average RSA. There was no association if fathers' psychological distress was at the *mean or lower* (Figure 3b). This result aligns with the mother-child finding of mother average RSA and psychological distress interacting to predict child average RSA across the time series, where maternal average RSA was positively linked with child RSA when maternal psychological distress was high. However, whereas these associations were observed in the direction of mothers influencing children in the mother-to-child model, they were observed as children influencing fathers in the child-to-father model.

**Father-to-Child Synchrony Moderated by Paternal Average RSA and Psychological Distress—**Results showed significant father-to-child RSA synchrony, i.e., father quadratic state RSA predicting child state RSA, which was moderated by both paternal average RSA and paternal psychological distress via both two-way and three-way interactions (Table 4). Children of fathers with *higher* psychological distress showed RSA augmentation when fathers showed either RSA augmentation or withdrawal in the moment. Consequently, we found positive synchrony (joint RSA augmentation) if fathers showed RSA augmentation, and negative synchrony (paternal RSA withdrawal, child RSA augmentation) if fathers showed RSA withdrawal. In contrast, if fathers had lower psychological distress, there was no synchrony between children's and fathers' RSA. Probing of the significant three-way interaction indicated that these synchrony patterns with more distressed fathers were only present if fathers also had *mean to higher* average RSA (>/= 1SD, Figure 4). Thus, this finding indicated that paternal psychological distress, regulatory functioning, and RSA reactivity interacted to shape children's RSA reactivity to their fathers.

## Discussion

This work offers new insights into mother-child and father-child RSA synchrony in early childhood and how it is shaped by parent and child average RSA and parental psychological distress. First, results show that incorporating individual differences in "trait" RSA functioning and dynamic "state" RSA reactivity offers new information about parent-child RSA synchrony. Overall, one's average RSA played an important role in predicting reactivity and average RSA across the time series in the partner, suggesting synchrony should be examined in the context of individual regulatory capacities. Results illustrate the utility of teasing apart reactivity and average RSA to account for homeostatic processes and baseline states in which regulation or synchrony may be inactive. Second, results suggest RSA synchrony follows a curvilinear shape, suggesting stronger RSA change in one partner may prompt stronger change in the other. This supports notions of parent-child RSA synchrony as a homeostatic process (Saxbe et al., 2020).

Third, mother-child RSA synchrony was shaped by both average RSA and maternal psychological distress. Across models, lower maternal average RSA and higher maternal psychological distress, suggesting higher maternal risk, were linked with RSA withdrawal in mother and child when the other showed stronger reactivity, i.e., when they deviated significantly (increase or decrease) from their average RSA. In contrast, maternal higher average RSA and lower distress were linked with dynamic RSA augmentation in child and mother, respectively, in response to partner reactivity. These findings suggest that when mothers were at higher risk due to current psychological distress or lower physiological regulatory capacity, both mother and child were more likely to experience challenge as indexed via RSA withdrawal in any given moment of a difficult parent-child task. These effects were present even after accounting for critical covariates such as resting RSA, interaction time, distal risk in the form of parents' childhood maltreatment, and expressed affect during the interaction.

Fourth, different findings were observed for mother-child vs. father-child dyads. Dynamic RSA Synchrony was present when fathers reported higher psychological distress and had higher average RSA. In these dyads, changes in father state RSA were associated with dynamic RSA augmentation in the child. Higher average RSA can reflect a capacity to socially engage (Shahrestani et al., 2015). Thus, it is possible that higher average RSA facilitated RSA synchrony under conditions of paternal psychological distress. Notably, the child-to-father model was the only one of the four not to show significant relations between child and parent RSA reactivity in the moment. There was, however, a significant positive prediction of father average RSA by child average RSA when fathers had higher psychological distress. Interestingly, in both models, from child-to-father and father-to-child, significant associations between father and child RSA were only observed when fathers psychological distress was higher, whereas for mother-child dyads, RSA values were associated when mothers had higher or lower psychological distress. These findings suggest differences in the way fathers respond physiologically to their children compared to mothers and may point to differences in the role of risk in mother- vs. father-child RSA synchrony.

## New Insights into RSA Synchrony

Parent-child RSA synchrony showed a curvilinear pattern such that parent and child state RSA relations were only significant when parents or children deviated from their average RSA. This aligns with theoretical considerations highlighting homeostasis as a central process in parent-child physiological coregulation (Saxbe et al., 2020) such that the presence, direction, and strength of synchrony may vary by the range of individual RSA reactivity (Lunkenheimer et al., 2018). Coregulatory processes appear more critical in the context of changes to the system, such as one partner changing from one state to another and the other partner responding, suggesting that without change we may not observe synchrony (Granic et al., 2016). Stronger RSA changes in either direction (increase or decrease) may reflect dysregulation and could prompt the partner to respond to keep the other within allostatic range (Saxbe et al., 2020). Prior research suggests healthy parent-child behavioral synchrony is characterized by both brief ruptures and successful repairs, echoing the importance of parent and child coregulating within an allostatic range (Skowron et al., 2010; Tronick, 1989). Overall, our results unveil complex patterns of RSA that support the further examination of nonlinear patterns of synchrony (Creavey et al., 2020).

The present findings also suggest that positive and negative RSA synchrony are not inherently adaptive or maladaptive, at least in the way synchrony is modeled herein, and that their adaptiveness may need to be evaluated based on relations to specific risk and protective factors. In prior research, the coupling of parent RSA augmentation and child RSA withdrawal in challenging tasks has been considered a risk factor, related to child externalizing problems and parent physical abuse (Lunkenheimer et al., 2015; Lunkenheimer et al., 2018); this pattern may reflect that parents are not engaging in expected ways to support their children. However, this particular pattern did not manifest in the present analyses, in which we examined a general distress factor in parents that could include the presence of externalizing or internalizing symptomology. Thus, in light of the extant evidence to date, our results suggest that the specific nature of RSA synchrony is likely to vary by the parent (mother or father), the type of risk factor in question, and the person for whom the risk is indicated (parent or child).

## Psychological Distress and Average RSA Associated with RSA Withdrawal

Lower average RSA and higher psychological distress are considered risk factors for poorer coregulation (Patriquin et al., 2015; Suveg et al., 2019). Our results suggest these factors shaped RSA functioning in mothers, fathers, and children. For mother-child dyads, higher average RSA or lower parental psychological distress (indicative of lower risk) aligned with RSA augmentation in relation to changes in partner RSA, whereas lower average RSA or higher parental psychological distress (indicative of higher risk) aligned with RSA withdrawal in relation to changes. Higher maternal distress was associated with mothers' own RSA withdrawal, and higher maternal distress and lower average RSA were associated with children's RSA withdrawal with mothers; additionally, higher paternal distress and children's lower average RSA were associated with fathers' lower average RSA, suggesting more RSA withdrawal in those fathers across the time series.

RSA withdrawal to challenge in typical samples has been theorized to reflect effort, engagement, or stress (Porges, 2007) and is the expected response in a task designed to elicit challenge for parents and children (Lunkenheimer et al., 2017). Comparatively, excessive RSA withdrawal in clinical samples may reflect hyperreactivity or stress that is disproportionate to the challenge (Beauchaine, 2001; Porges, 2007). Findings generally suggested that when maternal or paternal distress was higher, dyads were influenced by those difficulties and the task was more effortful or stressful as indicated by RSA withdrawal. It is possible that for parents with higher distress, greater withdrawal on average reflected that the task was more effortful due to their own greater dysregulation levels (Beauchaine et al., 2019). Future research may benefit from person-centered approaches that can better parse groups for whom the degree of withdrawal is moderate versus excessive. It is interesting that for maternal reactivity, these patterns were observed only when children had higher regulatory capacities. In line with Polyvagal Theory (Porges, 2007), higher average RSA is thought to represent the capacity to self-regulate and engage socially with others (Geisler et al., 2013). Perhaps in families oversampled for higher risk, higher regulatory capacity in children facilitated maternal responding and/or child-to-mother synchrony.

## Higher Average RSA as a Protective or Risk Factor?

Another theme across certain analyses was that effects on reactivity and therefore synchrony were stronger when the predictor partner in the model had mean to higher average RSA, suggesting greater regulatory capacity (e.g., see the middle and rightmost panel in Figures 1 and 4). In other words, higher parental distress coupled with higher average RSA was associated with the partner's dynamic RSA augmentation in the moment. Specifically, when either mothers or fathers experienced higher psychological distress, children showed patterns of dynamic RSA augmentation when their parents also had higher average RSA, and mothers showed patterns of dynamic RSA augmentation when their children had mean to higher average RSA. Additionally, fathers with higher distress showed higher average RSA across the time series when their children had higher average RSA. In clinical samples, RSA augmentation to challenge has been linked with disengagement and avoidance (Beauchaine, 2001). However, RSA augmentation during challenge may also reflect calm social interaction if the task is not stressful, perhaps due to that potential stress being buffered by the partner's engagement or support (Balzarotti et al., 2017; Butler et al., 2006; Shahrestani et al., 2015; Skoranski et al., 2017; Zhang et al., 2020). Thus, it is possible that these consistent relations between one's higher average RSA and the partner's higher or augmented RSA indicate a buffering effect in terms of the effects of parental psychological distress on the partner's RSA reactivity.

An alternative explanation is that RSA augmentation patterns found in distressed parents and their children did in fact represent disengagement or avoidance (Beauchaine, 2001). Although this is often considered atypical RSA functioning in relation to challenge, it may be a potentially adaptive and protective response when a child is confronted with a distressed or dysregulated parent (Creavey et al., 2020; Suveg et al., 2019). RSA augmentation was also observed in mothers low in psychological distress responding to children with higher average RSA; this could reflect that these mothers trusted in their child's ability to successfully meet task goals, thus were less challenged by or engaged in the task themselves (Balzarotti et al., 2017; Hastings & Kahle, 2019). The present analyses do not allow for distinguishing the reasons for augmentation or withdrawal of RSA and thus more research is needed to interpret the meaning of RSA changes across levels of risk. Future studies may benefit from adding self-report measures of stress experienced by parents during challenging tasks to better interpret these findings.

## Limitations and Considerations

This study builds on gaps in prior research and expands knowledge on parent-child RSA synchrony, but it is not without limitations. Families were oversampled for lower socioeconomic status, stressful life events, and child maltreatment risk, so these findings may not generalize to low-risk or clinical samples. The rigor of accounting for multiple relevant covariates in this analysis, such as time, resting RSA, expressed affect, and historical risk was a strength, however, the complexity of the current models makes replication in future studies challenging. Yet, replication is all the more needed to validate these findings. Even though our sample sizes were adequately powered for within-person analysis via multilevel intradyad dynamics modeling, a larger sample size, especially with respect to father-child dyads, could have increased the power to detect effects at Level 2 of the multilevel models.

In line with hierarchical approaches to psychopathology (Beauchaine & Thayer, 2015; Martel et al., 2017), we chose to examine a broad measure of psychological distress and not to focus on a specific symptom type for this analysis. However, due to the transdiagnostic nature of RSA dysregulation (Beauchaine et al., 2019), we believe that RSA synchrony research will benefit from attention to both general psychological distress and specific symptom types to inform the role of RSA synchrony in psychopathology risk (Beauchaine & Thayer, 2015). Future work could benefit from the inclusion of concurrent observed affect or behavior as well as subjective reports of stress to better inform the meaning of RSA reactivity and RSA synchrony in parent-child interaction tasks.

## Conclusions

In sum, these findings provide preliminary evidence that parent-child RSA synchrony could be better described and modeled as a dynamic and nonlinear process. They also show that RSA reactivity and synchrony patterns differ by specific risk factors, the direction of synchrony (parent to child or child to parent), and mother-child versus father-child interactions. Higher risk as indicated by greater parent psychological distress and lower average RSA were associated with dynamic RSA withdrawal in mothers, fathers, and children; additionally, one’s higher average RSA appeared to facilitate greater reactivity and thus stronger positive or negative RSA synchrony with the partner under conditions of higher parental distress. Further work is needed to inform our understanding of the meaning of RSA synchrony as characterized by dynamic parent and child RSA withdrawal and augmentation patterns and its role in children’s regulatory development.

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**Highlights:**

- Parent-child RSA synchrony could be better modeled as a dynamic, nonlinear process
- RSA synchrony should be examined in relation to partner's average RSA
- Partner average RSA and parent psychological distress interacted to shape synchrony
- Higher distress and lower average RSA prompted dynamic decreases in RSA
- Mother- and father-preschooler dyads showed different RSA synchrony patterns

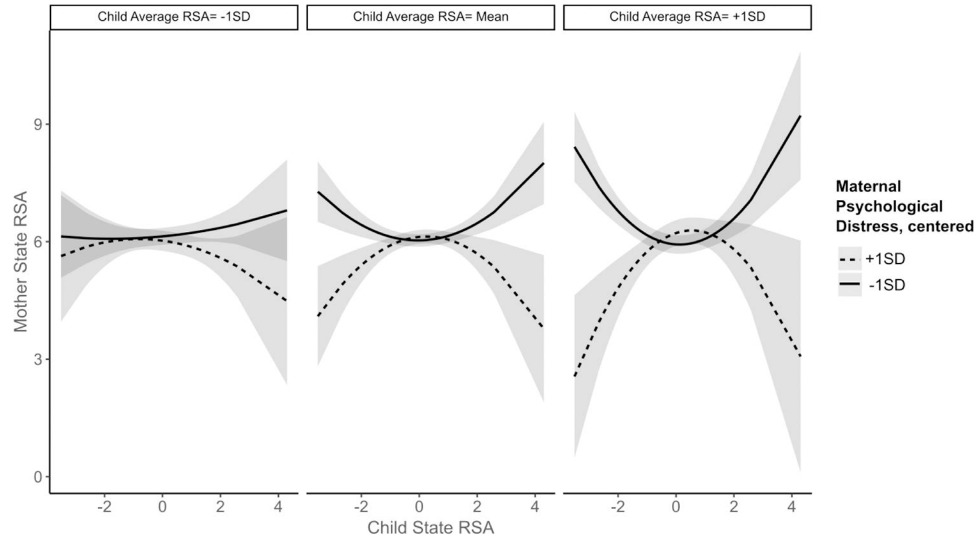


**Figure 1.**

Maternal Psychological Distress and Child Average RSA Moderating Child-to-Mother Synchrony

*Note.* As indicated in the middle and rightmost panels, child state RSA significantly predicts mother state RSA when child average RSA is mean to higher (+1SD) and when maternal psychological distress is either higher (+1SD) or lower (−1SD).

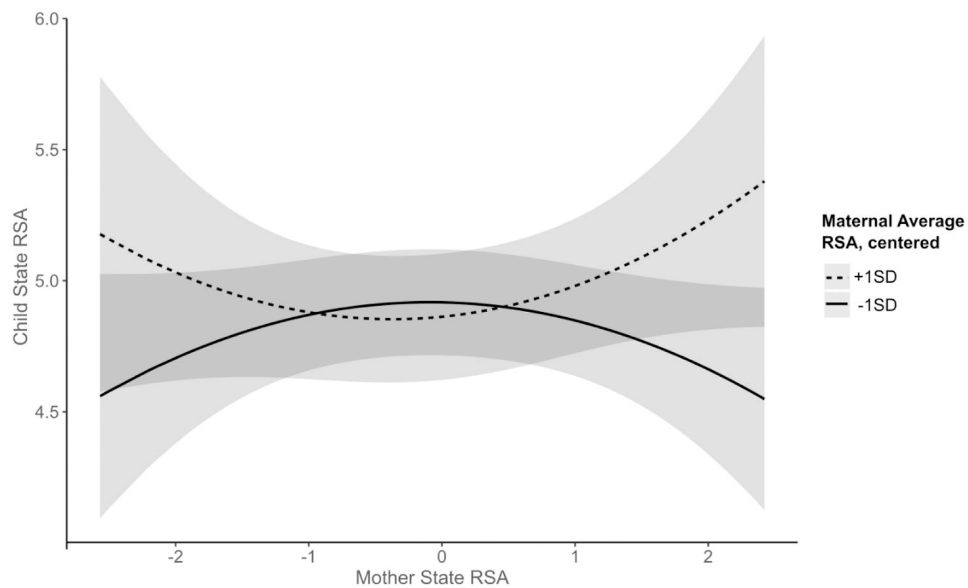


**Figure 2.**

Maternal Average RSA Moderating Mother-to-Child Synchrony

*Note.* Mother state RSA significantly predicts child state RSA when maternal average RSA is higher (+1SD) or lower (−1SD), but not when at mean levels.

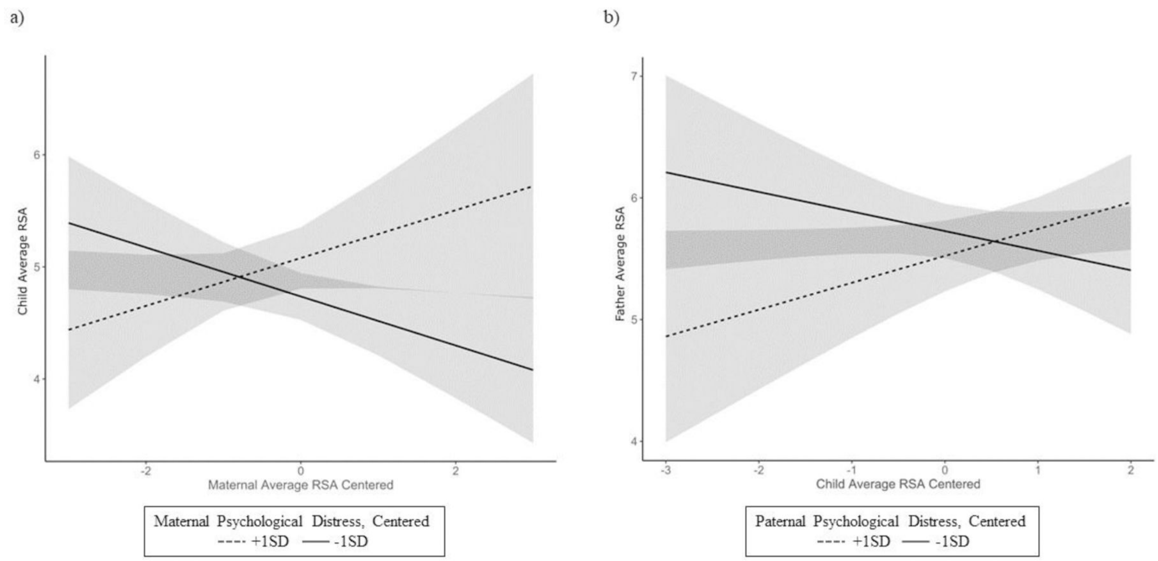


**Figure 3.**

Parent Psychological Distress Moderating the Relation Between Average RSA and State RSA

*Note.* Maternal average RSA significantly predicts child average RSA when maternal psychological distress is *higher or lower* than the sample mean. Child average RSA significantly predicts father average RSA when paternal psychological distress is *higher* than the sample mean.

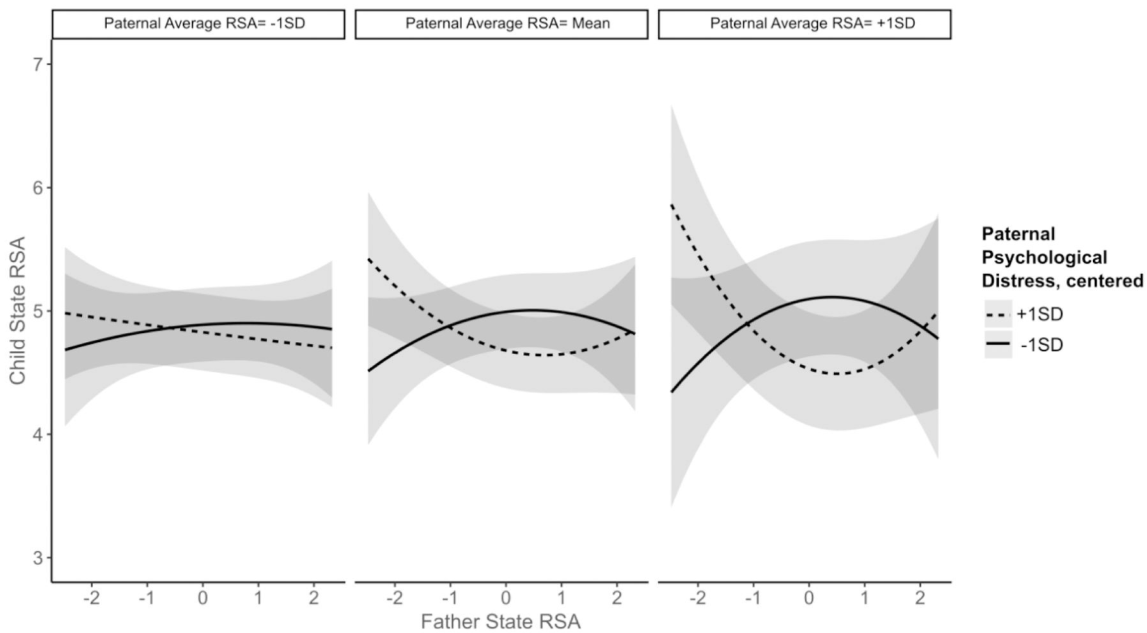


**Figure 4.**

Paternal Psychological Distress and Average RSA Moderating Father-to-Child Synchrony

*Note.* As indicated in the middle and rightmost panels, father state RSA significantly predicts child state RSA when father average RSA is mean to higher (+1SD) and when paternal psychological distress is higher (+1SD).

## Table 1

Correlations, Means and Standard Deviations of Maternal Study Variables

| Variable | M (SD) | 1) | 2) | 3) | 4) | 5) | 6) | 7) | 8) |
|---|---|---|---|---|---|---|---|---|---|
| **1) Psychological Distress m** | 0.37 (0.31) | | | | | | | | |
| **2) History of CM m** | 41.01 (17.81) | 0.20* | | | | | | | |
| **3) Dyadic Positive Affect** | 75.38 (53.73) | 0.00 | 0.12 | | | | | | |
| **4) Resting RSA m** | 6.10 (1.32) | −0.01 | −0.10 | 0.19 | | | | | |
| **5) Resting RSA cm** | 5.48 (1.25) | −0.08 | 0.07 | −0.01 | 0.22* | | | | |
| **6) Average RSA m** | 6.22 (1.03) | −0.06 | −0.08 | 0.22* | 0.86*** | 0.15 | | | |
| **7) Average RSA cm** | 4.92 (1.12) | 0.05 | 0.05 | −0.02 | 0.18 | 0.85*** | 0.12 | | |
| **8) State RSA m** | 0 (0.73) | −0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | −0.01 | |
| **9) State RSA cm** | 0 (0.72) | 0.00 | 0.00 | 0.01 | −0.01 | 0.02 | 0.00 | 0.02 | 0.02 |

*Note.* m=mother, cm=child with mother; Psychological Distress=Global Severity Index of the Brief Symptom Inventory; History of CM=history of childhood maltreatment, Childhood Trauma Questionnaire; Dyadic Positive Affect=Duration (in seconds) of dyadic positive affect for mother-child interactions;

* $p<.05$

** $p<.01$.

*** $p<.001$. State RSA represents the deviation of the individual's RSA from their average RSA; this variable is mean-centered such that a value of 0 represents the individual's average RSA.

## Table 2

Correlations, Means and Standard Deviations of Paternal Study Variables

| Variable | M (SD) | 1) | 2) | 3) | 4) | 5) | 6) | 7) | 8) |
|---|---|---|---|---|---|---|---|---|---|
| **1) Psychological Distress f** | 0.27 (0.29) | | | | | | | | |
| **2) History of CM f** | 38.88 (14.07) | 0.01 | | | | | | | |
| **3) Dyadic Positive Affect** | 70.37 (56.77) | 0.18 | 0.09 | | | | | | |
| **4) Resting RSA f** | 6.13 (1.32) | 0.05 | −0.05 | 0.19 | | | | | |
| **5) Resting RSA cf** | 5.50 (1.23) | 0.36** | 0.01 | 0.09 | 0.18 | | | | |
| **6) Average RSA f** | 5.84 (1.01) | 0.00 | 0.06 | 0.30** | 0.83*** | 0.12 | | | |
| **7) Average RSA cf** | 4.81 (1.01) | 0.30* | −0.05 | 0.10 | 0.00 | 0.79*** | −0.02 | | |
| **8) State RSA f** | 0 (0.78) | 0.00 | −0.01 | −0.01 | 0.00 | 0.00 | 0.01 | 0.00 | |
| **9) State RSA cf** | 0 (0.69) | 0.01 | 0.00 | −0.02 | −0.01 | 0.01 | −0.02 | 0.02 | −0.03 |

*Note.* f=father, cf=child with father; Psychological Distress=Global Severity Index of the Brief Symptom Inventory; History of CM=history of childhood maltreatment, Childhood Trauma Questionnaire; Dyadic Positive Affect=Duration (in seconds) of positive dyadic affect for father-child interactions;

* $p<.05$

** $p<.01$.

*** $p<.001$. State RSA represents the deviation of the individual's RSA from their average RSA; this variable is mean-centered such that a value of 0 represents the individual's average RSA.

**Table 3**

Mother-Child Models

| | (a) Child RSA Predicting Maternal RSA | | | (b) Maternal RSA Predicting Child RSA | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Estimate (SE)** | **95% CI** | **p-value** | **Estimate (SE)** | **95% CI** | **p-value** |
| ***Fixed effects*** **(Intercept)** | 6.196 (0.067) | [6.068, 6.323] | <0.001 *** | 5.004 (0.087) | [4.840, 5.168] | <0.001 *** |
| **Time** $\gamma_{20}$ | −0.008 (0.004) | [−0.015, −0.001] | 0.035 * | −0.004 (0.004) | [−0.012, 0.003] | 0.230 |
| **Resting RSA** $\gamma_{01}$ | 0.790 (0.049) | [0.696, 0.883] | <0.001 *** | 0.763 (0.061) | [0.648, 0.878] | <0.001 *** |
| **Dyadic Positive Affect** $\gamma_{02}$ | 0.001 (0.001) | [−0.001, 0.004] | 0.310 | −0.001 (0.002) | [−0.004, 0.002] | 0.643 |
| **History of Childhood Maltreatment** $\gamma_{03}$ | −0.002 (0.003) | [−0.008, 0.004] | 0.563 | −0.006 (0.004) | [−0.014, 0.002] | 0.159 |
| **Parent Psychological Distress** $\gamma_{04}$ | 0.153 (0.219) | [−0.260, 0.567] | 0.487 | 0.592 (0.327) | [−0.026, 1.209] | 0.074 † |
| **Average RSA** $\gamma_{05}$ | −0.002 (0.056) | [−0.108, 0.103] | 0.965 | −0.003 (0.076) | [−0.147, 0.142] | 0.973 |
| **State RSA** $\gamma_{06.1}$ | 0.042 (0.030) | [−0.016, 0.101] | 0.160 | 0.022 (0.030) | [−0.036, 0.080] | 0.463 |
| **State RSA2** $\gamma_{06.2}$ | −0.020 (0.028) | [−0.075, 0.035] | 0.483 | 0.006 (0.028) | [−0.049, 0.061] | 0.830 |
| **Average RSA * Psych. Distress** $\gamma_{07}$ | 0.309 (0.252) | [−0.166, 0.785] | 0.224 | 0.745 (0.326) | [0.129, 1.360] | 0.025 * |
| **Average RSA * State RSA** $\gamma_{06.11}$ | 0.051 (0.028) | [−0.003, 0.105] | 0.067 † | 0.029 (0.026) | [−0.021, 0.078] | 0.262 |
| **Average RSA * State RSA**$^2$ $\gamma_{06.21}$ | 0.000 (0.024) | [−0.046, 0.047] | 0.985 | 0.053 (0.023) | [0.009, 0.098] | 0.019 * |
| **State RSA * Psych. Distress** $\gamma_{06.12}$ | 0.109 (0.111) | [−0.108, 0.325] | 0.325 | 0.069 (0.121) | [−0.166, 0.305] | 0.566 |
| **State RSA**$^2$ *** Psych. Distress** $\gamma_{06.22}$ | −0.428 (0.109) | [−0.641, −0.215] | <0.001 *** | 0.052 (0.117) | [−0.174, 0.283] | 0.654 |
| **State RSA * Psych. Distress * Average RSA** $\gamma_{06.13}$ | 0.357 (0.115) | [0.133, 0.581] | 0.002 ** | 0.050 (0.109) | [−0.164, 0.263] | 0.649 |
| **State RSA**$^2$ *** Psych. Distress * Average RSA** $\gamma_{06.23}$ | −0.259 (0.097) | [−0.450, −0.071] | 0.008 ** | −0.105 (0.093) | [−0.287, 0.078] | 0.259 |
| ***Random effects*** | | | | | | |
| **Intercept** $\mu_{0j}$ | 0.191 (0.437) | [0.340, 0.502] | <0.001 *** | 0.350 (0.592) | [0.470, 0.675] | <0.001 *** |

*Note.* Unstandardized beta estimates for mother-child models are represented in the table. SE=standard error, CI=confidence interval. 1295 observations nested within 71 dyads for mothers' model, 1315 observations nested within 72 dyads for children's model.

*** p<.001

** p<.01

* p<.05

[†]p<.1. For parameter nomenclature see also equations 1.1 – 2.2. Average resting RSA (a)=child RSA, average resting RSA (b)=mother RSA.

**Table 4**

Father-Child Models

| | (a) Child RSA Predicting Paternal RSA | | | (b) Paternal RSA Predicting Child RSA | | |
|---|---|---|---|---|---|---|
| **Parameter** | **Estimate (SE)** | **95% CI** | **p-value** | **Estimate (SE)** | **95% CI** | **p-value** |
| ***Fixed effects*** **(Intercept)** | 5.601 (0.098) | [5.419, 5.784] | <0.001 *** | 4.799 (0.108) | [4.598, 4.999] | <0.001 *** |
| **Time** $_{\gamma 20}$ | 0.014 (0.005) | [0.005, 0.023] | 0.003 ** | −0.001 (0.004) | [−0.010, 0.007] | 0.752 |
| **Resting RSA** $_{\gamma 01}$ | 0.725 (0.060) | [0.615, 0.615] | <0.001 *** | 0.700 (0.087) | [0.539, 0.861] | <0.001 *** |
| **Dyadic Positive Affect** $_{\gamma 02}$ | −0.001 (0.002) | [−0.004, 0.002] | 0.514 | 0.002 (0.002) | [−0.002, 0.006] | 0.361 |
| **History of Childhood Maltreatment** $_{\gamma 03}$ | 0.000 (0.008) | [−0.015, 0.015] | 0.984 | −0.002 (0.010) | [−0.021, 0.016] | 0.801 |
| **Parent Psychological Distress** $_{\gamma 04}$ | −0.326 (0.358) | [−0.987, 0.334] | 0.368 | −0.353 (0.442) | [−1.167, 0.462] | 0.430 |
| **Average RSA** $_{\gamma 05}$ | 0.025 (0.082) | [−0.126, 0.178] | 0.758 | −0.066 (0.089) | [−0.231, 0.098] | 0.462 |
| **State RSA** $_{\gamma 06.1}$ | −0.013 (0.043) | [−0.098, 0.072] | 0.764 | −0.007 (0.032) | [−0.070, 0.056] | 0.828 |
| **State RSA2** $_{\gamma 06.2}$ | −0.008 (0.041) | [−0.088, 0.073] | 0.852 | 0.026 (0.029) | [−0.032, 0.082] | 0.378 |
| **Average RSA * Psych. Distress** $_{\gamma 07}$ | 0.667 (0.320) | [0.075, 1.257] | 0.043 * | −0.281 (0.330) | [−0.889, 0.327] | 0.399 |
| **Average RSA * State RSA** $_{\gamma 06.11}$ | 0.041 (0.042) | [−0.040, 0.123] | 0.327 | −0.008 (0.027) | [−0.060, 0.044] | 0.766 |
| **Average RSA * State RSA**$^{2}$ $_{\gamma 06.21}$ | 0.028 (0.042) | [−0.054, 0.108] | 0.506 | 0.027 (0.024) | [−0.020, 0.074] | 0.260 |
| **State RSA * Psych. Distress** $_{\gamma 06.12}$ | −0.207 (0.168) | [−0.536, 0.120] | 0.218 | −0.262 (0.121) | [−0.499, −0.025] | 0.031 * |
| **State RSA**$^{2}$ ***Psych. Distress** $_{\gamma 06.22}$ | −0.111 (0.171) | [−0.444, 0.222] | 0.518 | 0.218 (0.103) | [0.018, 0.421] | 0.035 * |
| **State RSA * Psych. Distress * Average RSA** $_{\gamma 06.13}$ | −0.063 (0.180) | [−0.413, 0.288] | 0.726 | −0.126 (0.086) | [−0.294, 0.043] | 0.145 |
| **State RSA**$^{2}$ *** Psych. Distress * Average RSA** $_{\gamma 06.23}$ | −0.126 (0.151) | [−0.419, 0.169] | 0.405 | 0.179 (0.072) | [0.038, 0.320] | 0.013 * |
| ***Random effects*** | | | | | | |
| **Intercept** $_{\mu 0j}$ | 0.251 (0.501) | [0.361, 0.583] | <0.001 *** | 0.379 (0.616) | [0.454, 0.712] | <0.001 *** |

*Note.* Unstandardized beta estimates for mother-child models are represented in the table. SE=standard error, CI=confidence interval. 884 observations nested within 47 dyads for fathers’ model, 850 observations nested within 45 dyads for children’s model.

*** p<.001

** p<.01

* p<.05

† p<.1. For parameter nomenclature see also equations 1.1 – 2.2. Average resting RSA (a)=child RSA, average resting RSA (b)=father RSA.