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Coregulation of Respiratory Sinus Arrhythmia between Parents and Preschoolers: Differences by Children's Externalizing Problems

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Abstract

The coordination of physiological processes between parents and infants is thought to support behaviors critical for infant adaptation, but we know little about parent-child physiological coregulation during the preschool years. The present study examined whether time-varying changes in parent and child respiratory sinus arrhythmia (RSA) exhibited coregulation (across-person dynamics) accounting for individual differences in parent and child RSA, and whether there were differences in these parasympathetic processes by children's externalizing problems. Mother-child dyads (N=47; Child age M=3½ years) engaged in three laboratory tasks (free play, clean up, puzzle task) for 18 min, during which RSA data were collected. Multilevel coupled autoregressive models revealed that mothers and preschoolers showed positive coregulation of RSA such that changes in mother RSA predicted changes in the same direction in child RSA and vice versa, controlling for the stability of within-person RSA over time and individual differences in overall mean RSA. However, when children's externalizing behaviors were higher, coregulation was negative such that changes in real-time mother and child RSA showed divergence rather than positive concordance. Results suggest that mothers and preschoolers do coregulate RSA during real-time interactions, but that children's higher externalizing behavior problems are related to disruptions in these processes.

Keywords

parent-child interaction; coregulation; self-regulation; externalizing behavior problems; respiratory sinus arrhythmia; parasympathetic processes

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INTRODUCTION

Early caregiving is characterized by physiological coordination between parent and infant to support behaviors critical for infant adaptation (Feldman, 2012). Through this coordination, parents help organize the infant's biological, behavioral, and affective systems and provide the neural inputs to lay the foundation for the child's stress regulation system (Champagne, 2008; Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011). In this stress regulation system, the parasympathetic nervous system is important because it helps maintain biological homeostasis when the body is at rest (Porges, Doussard-Roosevelt, & Maiti, 1994). Parasympathetic processes can be measured using respiratory sinus arrhythmia (RSA), an index of cardiac vagal tone (Porges, 2007). Vagal tone during periods of low stress is thought to reflect the ability to maintain homeostasis and the capacity to react to stress (Beauchaine, 2001); it is reflected in higher resting vagal tone or RSA. During stress, however, RSA is suppressed in order to mobilize the body's fight or flight responses to meet environmental demands. These processes are evident in the individual reactivity of mothers and infants during stressful dyadic interactions in the laboratory (Conradt & Ablow, 2010). For example, mothers show RSA suppression in response to infant distress during the Strange Situation (Hill-Soderlund et al., 2008) and the Still Face task (Oppenheimer, Measelle, Laurent, & Ablow, 2013). Also, infants who do not show RSA suppression during the Still Face have lower levels of affective synchrony with their mothers (Moore & Calkins, 2004).

Though empirical evidence is limited, mothers and infants have also shown dyadic coordination of RSA and other cardiac measures. Mothers and infants show coordination of heart rhythms within a lag of less than one second, and show greater concordance during times of interpersonal behavioral synchrony (Feldman et al., 2011). Others have found a marginal positive correlation in RSA suppression between mothers and their two month-olds in response to changes from baseline to a laboratory assessment (Bornstein & Suess, 2000). Moore and colleagues found that in the context of stress (the Still Face), infants showed RSA suppression while parents showed RSA augmentation during the disrupted interaction condition (Moore et al., 2009). This divergent responding may reflect disrupted coregulation due to stress; however, it may also reflect the goals of the Still Face, in which infants are thwarted in their interaction attempts whereas mothers are asked not to engage or soothe the infant. In sum, there is evidence that mothers and infants coregulate parasympathetic processes, but whether this coregulation is positive or negative may depend upon the goal of the interaction.

It is less clear whether parents and children coordinate parasympathetic processes after infancy. The preschool years are important for the development of self-regulation because children experience rapid growth in the emotional, cognitive, and behavioral skills that underlie self-regulation and are actively internalizing the capacity to self-regulate from parents and teachers (Calkins, 2007). Parasympathetic processes are considered the physiological substrates of these emotional and behavioral self-regulatory processes throughout development (Bornstein & Suess, 2000). Thus, parent-child coregulation of parasympathetic processes during preschool may be important in laying the physiological foundations for how successfully children internalize regulatory abilities during this period.

However, we lack empirical studies on these processes in early childhood. Related research has demonstrated that parents and preschoolers reflected one another's stress reactivity through correlated adrenocortical responses during stressful tasks, though this concordance was only found in dyads of highly sensitive mothers (Sethre-Hofstad, Stansbury, & Rice, 2002). With respect to parasympathetic processes specifically, one study on children in kindergarten found dynamic positive concordance between mother and child heart rate as well as concordance between mother heart rate and child RSA across a 5-min resting condition (Creaven, Skowron, Hughes, Howard, & Loken, 2014). However, they found no direct concordance between mother and child RSA. Accordingly, we have much more to learn about whether and how parasympathetic processes are coregulated between parents and their preschoolers.

Physiological coregulation may also be an important biomarker of risk (Hibel, Granger, Blair, & Cox, 2009). Parent-child behavioral coregulation, or the processes by which parent and child regulate one another's affect and behavior, can be compromised by risk factors in the dyad (Lunkenheimer, Albrecht, & Kemp, 2013; Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011). Poor coregulation may reflect difficulties in the "fit" between child temperament and parenting behaviors, which is also often compromised by early familial risk (e.g., Martorell & Bugental, 2006). In preschool, children's externalizing problems are the most common risk factor, which also reflect the child's behavioral dysregulation (Olson, Sameroff, Kerr, Lopez, & Wellman, 2005). Research has shown differences in parasympathetic arousal such that lower levels of resting RSA and greater RSA augmentation (as opposed to suppression) during stress have been associated with children's higher externalizing problems (Calkins, Graziano, & Keane, 2007; Hastings et al., 2008; Hinnant & El-Sheikh, 2009). Accordingly, children's externalizing problems may be particularly likely to be related to the coordination of RSA between parents and preschoolers. For example, the child's dysregulated behavior or atypical RSA responding to moments of stress during parent-child interaction could disrupt the coregulation of RSA between parent and child; alternatively, disrupted parent-child RSA coregulation could create corresponding challenges for the child in regulating his or her physiology or behavior.

PRESENT STUDY

The present study examined whether parents and preschoolers showed positive coregulation of RSA as measured across three different laboratory tasks (free play, a clean up task, a puzzle task) that lasted 18 min. Thus, we did not examine physiological reactivity to stress, but rather average RSA across 30-s intervals during parent-child interactions. We used a multilevel coupled autoregressive modeling approach to examine whether parent-child coregulation of RSA predicted each individual's current RSA above and beyond intraindividual variability in RSA, measured at 30-, 60-, and 90-s lags. This novel approach allowed us to examine dynamic relations between changes in parent and child RSA across time. Specific research questions included: 1) Do patterns of time-varying changes in parent and child RSA exhibit coregulation (i.e., across-person dynamics) accounting for individual differences in mean level RSA and intraindividual variability in RSA across time? 2) Are individual differences in externalizing problems related to these coregulatory dynamics? We hypothesized that parents and children would show positive coregulation of RSA given prior evidence in parent-child dyads of positive concordance in physiological measures (Bornstein & Suess, 2000; Creaven et al., 2014; Feldman et al., 2011). We also hypothesized that higher levels of child externalizing problems would be associated with disrupted coregulation, but did not specify the direction or nature of that disruption.

METHOD

Participants

Participants were 47 mother-child dyads who were part of a larger study (*N*=100) on parent-child coregulation. These participants were selected because they had complete RSA data for mother and child across all laboratory tasks. Participants identified as 86% White, 8% Biracial, 3% Asian, and 3% "other" race, and 10% Hispanic or Latino ethnicity. Children (54% female) were 41 months old on average (*SD*=3 months). Median annual family income was $65,000 and parental education was high on average (college graduate). Marital status was 79% married, 7% cohabiting, 7% single, 5% separated or divorced, and 1% remarried. Participants were recruited via flyers in preschools and businesses and through email listserves of agencies serving families with young children. Families were excluded if children had a pervasive developmental disorder, if parents could not speak and read in English, or if participants had a health condition that interfered with cardiac data collection.

Procedure

A 2½-h laboratory visit began with an orientation and the application of electrodes and a respiration strap to mothers and their children (see below). During the session, mothers filled out questionnaires including a measure of children's externalizing problems. Mothers and children also completed three dyadic tasks. The free play task involved asking mothers and children to "play as they normally would" with a variety of toys (7 min). The clean up task involved asking mothers to help guide children to put away the toys in a bin using only their words (i.e., mothers were asked not to physically help the children) (5 min). The puzzle task was a semi-structured task in which mothers were asked to guide children to complete three successive 3D wooden puzzles based on designs from a guidebook; once again, mothers were asked to use only their words to guide children (6 min). Families were compensated $50 for laboratory sessions and mother questionnaires. Please see Lunkenheimer et al. (2013) for more information about the larger study.

Measures

Respiratory Sinus Arrhythmia (RSA)—Physiological data for mother and child was acquired simultaneously via the Mindware 3000A Wireless System (Mindware Technologies, Gahanna, OH). Disposable electrocardiogram (ECG) electrodes were placed over the mother or child's right clavicle and the left side below the ribcage (the recording electrodes), and on the right side below the ribcage (the grounding electrode). A crystal respiratory effort belt was placed below the diaphragm to monitor respiration. Both were connected to handheld computers placed in backpacks worn by each participant that communicated wirelessly with a desktop computer in the adjacent observation suite, which was monitored by a research assistant.

ECG data were processed offline using Mindware Heart Rate Variability 3.0.13 software (Mindware Technologies). Interbeat interval data was edited by trained research assistants for artifacts resulting from mother and child movement or software misidentification. Misidentified or missing heartbeats were manually deleted or inserted as needed. Epochs requiring more than 10% editing were dropped from analysis; across all participants, 4.9% of the total epochs were dropped due to movement (166 out of 3384 epochs). Once these epochs were removed, five dyads showed more than 10% missing data within-dyad; however, these dyads did not significantly differ from other dyads in levels of child externalizing problems, $t=-.77$, $df=45$, n.s. RSA magnitude was calculated as the natural logarithm of the variance of heart period within the frequency bandpass related to respiration (0.24–1.04 Hz for children and 0.12–0.40 for adults) (Fracasso, Porges, Lamb, & Rosenberg, 1994) using Biolab 2.5 software (Mindware Technologies). Mean RSA magnitude was calculated for each 30-s interval and statistical outliers of the resulting RSA values were dropped from analysis (16 epochs).

There were wireless interference problems in the laboratory space such that the wireless connection was difficult to establish, or if the connection was broken (e.g., when children needed to use the bathroom midtask), it was difficult to re-establish. Accordingly, only 47 families out of 100 in the larger study had complete and valid RSA data for all three tasks. On average, families with intact RSA data differed such that they had higher annual income, $t=2.32$, $p<.05$, their children were older, $t=2.80$, $p<.01$, and these children were rated lower on average on externalizing problems by mothers, $t=-2.16$, $p<.05$.

$$\begin{aligned} pRSA_{i,t} &= \mu_{Pi} + \beta,_{P,IIV1} pRSA_{i,t-1} + \beta,_{P,IIV2} pRSA_{i,t-2} + \beta,_{P,IIV3} pRSA_{i,t-3} + \beta,_{P,CO} cRSA_{i,t} + \epsilon_{P_{i,t}} \\ cRSA_{i,t} &= \mu_{Ci} + \beta,_{C,IIV1} cRSA_{i,t-1} + \beta,_{C,IIV2} cRSA_{i,t-2} + \beta,_{C,IIV3} cRSA_{i,t-3} + \beta,_{C,CO} pRSA_{i,t} + \epsilon_{C_{i,t}} \end{aligned} \quad (1)$$

Externalizing Problems—Mothers reported on child externalizing problems via the Child Behavior Checklist (1.5–5; Achenbach & Rescorla, 2000). This scale reflects impulsivity, poor attentional control, and aggressive behavior. Convergent validity has been established with other measures of behavioral dysregulation (Olson et al., 2005). Cronbach's alpha was .89. Three children met criteria for clinical levels of externalizing problems (T≥64), and three children met criteria for borderline clinical levels (60≤T≤63) of externalizing problems.

Analytic Approach

To examine the dynamics of mother-child RSA, multilevel coupled autoregressive models were fitted in Mplus version 7.2 (Muthen & Muthen, 1998–2012). Two models were run to account for potential differences in the direction and magnitude of the effects of intraindividual variability in RSA and RSA coregulation between mothers and preschoolers: one model predicting current parent RSA and one model predicting current child RSA. Overall parent and child mean RSA levels were included in these models to account for the effects that individual differences in mean RSA might have on intraindividual variability in RSA, coregulation of RSA, and moderation by child externalizing problems. Coupled autoregressive analyses were applied to 30-s epochs of RSA data for 47 mothers and 47 children on a total of 18 min of data.

Within-Dyad Model—The within-dyad associations across the epochs of RSA time series data were modeled using the Level 1 equations above.

Level 1 (Within-dyad, across time): (1)

In these equations, $pRSA_{i,t}$ and $cRSA_{i,t}$ denote the *i*th parent and ith child's RSA values, respectively, at time *t*. These Level 1 equations involved consideration of the number of time lags necessary to capture the dynamics of intraindividual variability (IIV) and coregulation in parent-child RSA. We expected stability in intraindividual RSA (Porges et al., 1994), so accordingly, three time-lagged RSA values measured 30, 60 and 90 s prior to the current RSA value (denoted by t - 1, t-2 and t-3 in Equation 1) were included to capture the expected dynamics of IIV in RSA. The average effects of IIV in RSA over three 30-s time lags were denoted by $\beta_{,P,IIV1}$,$\beta_{,P,IIV2}$ and $\beta_{,P,IIV3}$ for parents and $\beta_{,C,IIV1}$, $\beta_{,C,IIV2}$ and $\beta_{,C,IIV3}$ for children. With respect to coregulation, average effects of concurrent coregulation (CO) in parent and child RSA were modeled via $\beta_{,P,CO}$ and $\beta_{,C,CO}$. We considered adding lagged coregulation to the model to determine whether prior maternal RSA predicted current child RSA and vice versa. However, 30-s-lag coregulation parameters were non-significant for both parents, b=−0.03, p=.14, and children, b=−0.06, p=.12, and so lagged coregulation effects were not included in the model. Next, we determined whether our sample exhibited significant heterogeneity in each of the IIV and coregulation parameters and mean RSA values using model fit comparisons evaluated via the Wald statistic. As shown in Table 1, none of the IIV and coregulation variance components reached significance. However, our sample did exhibit significant heterogeneity in parents' mean RSA values and marginally significant heterogeneity in children's mean RSA values. Despite this marginal significance for child RSA heterogeneity, we fitted random intercept only models for both parents and children in order to make direct comparisons between the parent and child models. Specifically, parent and child RSA intercepts at epoch *t* were modeled as a function of μ_{Pi} and μ_{Ci}, respectively (where the *i* subscripts denote that random effects were included). Note that none of the regression coefficients for the IIV and coregulation parameters contain *i* subscripts and were thus modeled as fixed effects only.

Between-Dyad Model—Next, we examined whether differences among parents' and children's mean RSA values, IIV in RSA, and RSA coregulation parameters were moderated by differences in children's externalizing behaviors using the Level 2 equations below. Note that the fixed effects denoted as $\beta_{,P/C}$ in the Level 1 Equations are represented as $\gamma_{P/C}$ in the Level 2 Equations.

Level 2 (Between-dyad): (2)

These equations model the main effects of mean RSA (γ_P), moderation of parents' IIV in RSA and RSA coregulation by child externalizing problems (α_P), and random intercepts (u_{Pi}):

$$\begin{aligned}\mu_{Pi} &= U_{Pi} + \gamma_P + \alpha_{P,Mean} ChildExt \\ \beta,_{P,IIV1} &= \gamma_{P,IIV1} + \alpha_{P,IIV1} ChildExt \\ \beta,_{P,IIV2} &= \gamma_{P,IIV2} + \alpha_{P,IIV2} ChildExt \\ \beta,_{P,IIV3} &= \gamma_{P,IIV3} + \alpha_{P,IIV3} ChildExt \\ \beta,_{P,CO} &= \gamma_{P,CO} + \alpha_{P,CO} ChildExt\end{aligned} \quad (2)$$

These equations model the main effects of mean RSA (γ_C), moderation of children's IIV in RSA and RSA coregulation by child externalizing problems (a_C), and random intercepts (u_{Ci}):

$$\begin{aligned}\mu_{Ci} &= u_{Ci} + \gamma_C + \alpha_{C,Mean} ChildExt \\ \beta,_{C,IIV1} &= \gamma_{C,IIV1} + \alpha_{C,IIV1} ChildExt \\ \beta,_{C,IIV2} &= \gamma_{C,IIV2} + \alpha_{C,IIV2} ChildExt \\ \beta,_{C,IIV3} &= \gamma_{C,IIV3} + \alpha_{C,IIV3} ChildExt \\ \beta,_{C,CO} &= \gamma_{C,CO} + \alpha_{C,CO} ChildExt\end{aligned} \quad (2)$$

RESULTS

Preliminary Analyses

Potential differences by socio-demographic factors were examined. Average mother and child RSA and externalizing problems were not related to SES, maternal education, child sex, or child age, and thus these controls were not included in analyses. The variables of average mother RSA, *D*(47) ¼.56, n.s., average child RSA, *D*(47)=.73, n.s., and child externalizing problems, *D*(47)=1.17, n.s., were normally distributed. Descriptive statistics and bivariate correlations are shown in Table 2. Lower average child RSA was correlated with higher externalizing problems, in line with prior research (Hinnant & El-Sheikh, 2009), whereas average mother RSA was not. Repeated measures ANOVA revealed that mother RSA, Wilks' Lambda=.751, *df*=43, *p*<.05, and child RSA, Wilks' Lambda=.659,*df*=43, *p*<. 01, were higher during the Free Play task than during the Cleanup or Problem-Solving tasks, which did not differ from one another.

Primary Analyses

Results for the multilevel coupled autoregressive models are in Table 3 (mother model) and Table 4 (child model). These models explained 37.55% of variance in mothers' RSA and 30.17% of variance in children's RSA, respectively. As shown, all intercepts ($\gamma_{P/C}$), including the effects of overall mean RSA, intraindividual variability in RSA at all three lags, and coregulation of RSA, were significant in predicting current RSA for both mother and child. Thus, mothers and children exhibited both within-person stability in RSA and coregulation of RSA such that their current RSA was positively predicted by their own prior RSA at 30-, 60-, and 90-s intervals and positively predicted by their partner's concurrent RSA. Findings indicated that, on average, both mothers and children exhibited significant time-varying dependence with their partner in changes in their RSA over the course of their interaction.

With respect to the effects of externalizing problems in the child model, children with higher externalizing problems showed lower overall mean RSA levels, whereas externalizing problems was not related to intraindividual variability in children's RSA. However, when children's externalizing problems were higher, the effect of mothers' concurrent coregulation on current child RSA was negative (despite that the overall effect of coregulation was positive). With respect to the parent model, higher externalizing problems were associated with higher overall mean mother RSA levels, but were not significantly related to mothers' intraindividual variability in RSA. Also, once again, when children's externalizing problems were higher, the effect of coregulation was negative such that children's concurrent coregulation was negatively associated with mother RSA. Thus, with respect to directions of influence from both mother to child and child to mother, the coregulation of RSA was negatively coupled when children had higher levels of externalizing problems. These effects of child externalizing problems on coregulation held even after accounting for the individual differences in mother and child mean RSA that might be directly associated with children's externalizing problems.

Findings for the effects of externalizing problems on mother and child mean RSA and RSA coregulation are illustrated in Figure 1a and b, respectively. Figure 1a demonstrates that, on average, mother mean RSA was higher and child mean RSA was lower for dyads with above average child externalizing problems. With respect to the coregulation of RSA, Figure 1b depicts differences in the ratios of mother to child concurrent predicted RSA over time given average or above average child externalizing problems (where a positive or negative slope suggests more disrupted coregulation). When children had higher (versus lower) externalizing problems, these mother-child dyads exhibited a more divergent pattern in predicted RSA values over the course of the interaction, such that the differences in mother and child RSA became more divergent in real time.

DISCUSSION

In infancy, toddlerhood, and early childhood, self-regulation is largely a dyadic process in which care-giver and child regulate, and are regulated by, one another's affect and behavior (Lunkenheimer et al., 2013; Moore et al., 2013). Emerging theory and research suggest that the direct, dyadic coordination of physiological regulatory processes between parent and child may also be important (Feldman, 2012). The present study expanded on this work and our findings converged with related studies (Bornstein & Suess, 2000; Creaven et al., 2014) in showing evidence of positive concordance in physiological processes between mothers and their children. We believe this to be the first study to demonstrate that preschoolers and their mothers show concordance in average RSA across time during parent-child interactions. These findings were robust in that the effects from both parent to child and child to parent were significant, over and above the effects of individual differences in mean RSA and within-person stability of RSA over time. These findings suggest that positive concordance in RSA may be normative in early childhood and an indicator of adaptive coregulation in mother-preschooler interactions.

Theorists argue that parent-child physiological coregulation lays the groundwork for the child's developing self-regulatory abilities and corresponding difficulties (Calkins, 2011), and therefore may be an important biomarker of risk. Given that children with externalizing problems manifest dysregulated physiology in the form of poor vagal regulation (Calkins et al., 2007), we hypothesized that when children had higher levels of externalizing problems, parent-child coregulation of RSA could be disrupted. We found that it was disrupted, and in particular, that mother-child dyads diverged in real-time changes in RSA over time when children had greater externalizing problems. This finding was robust in that it was found in both directions of influence (parent-to-child and child-to-parent) and accounting for the individual differences in mean child RSA shown to be associated with children's externalizing problems (Calkins et al., 2007). These results suggest that positive concordance in parasympathetic processes between mother and child can be disrupted when children have higher levels of externalizing problems in early childhood, though the direction of causality is not yet clear. Given the importance of parent-child affective coregulation in preschool for children's later behavior problems (Lunkenheimer et al., 2011), future longitudinal research could consider the role of parent-child physiological coregulation in the etiology and prevention of children's behavior problems.

Research suggests that parent-child physiological concordance may depend upon the context of the interaction, as well as moderators such as maternal sensitivity or familial risk (Atkinson et al., 2013; Barbara et al., 2013; Ebisch et al., 2012; Van Bakel & Riksen-Walraven, 2008). We found positive concordance in overall mother-child RSA, but divergence when a risk factor (externalizing problems) was considered. Previous research has shown divergent patterning such that maternal RSA increased while infant RSA decreased in response to the Still Face paradigm (Moore et al., 2009). This pattern was explained in terms of Porges' (2007) polyvagal theory of social interaction such that when mothers disengaged from interaction with their infants, their RSA increased. When applied to the present findings, this theory could imply that a) when dysregulated children attempted to elicit social interaction, mothers were more likely to disengage from them, or that b) mothers who viewed their children as challenging may have been less likely to engage with them. An alternative explanation might be c) that because children with higher externalizing problems have shown atypical augmentation of RSA in prior research (Calkins et al., 2007), the divergent pattern may reflect that when these children were disengaged, it required more active engagement and regulation from mothers to orient them to the task at hand. However, our findings (as depicted in Fig. 1) lend support to interpretations (a) or (b), given that externalizing problems were associated with higher average RSA for mothers and lower average RSA for children (as opposed to the reverse pattern) and this difference increased in magnitude over the course of the interaction.

There were certain limitations of this study. It is standard to control for resting RSA in analyses of RSA change in real time (Graziano & Derefinko, 2013); however, a measure of resting RSA was not available and so we employed overall mean RSA as an index of individual differences. Mean RSA might have been lower on average than resting RSA given that two of the tasks required actions of the dyad that may have been challenging, which could have impacted analyses. Although children's externalizing problems were normally distributed, few children showed clinical levels. Therefore, more research is needed to determine generalizability to clinical populations. We also have more to learn about how the measurement of RSA in 30-s epochs interfaces with dynamic time series analysis. For example, in our examination of coregulation, it is unclear why the partner's concurrent RSA was influential, but the partner's previous (lagged) RSA was not. This finding may reflect a 'true' absence of lagged effects, or could reflect that lagged effects occurred in less than 30 s (Feldman et al., 2011), which would have been obscured by the standard approach to calculating RSA. RSA coregulation could also vary by interaction context, including the demands placed upon the dyad (Bornstein & Suess, 2000) and the dynamic, time-varying behaviors of the parent and child during the task. For example, positive coregulation may be more likely when parent and child are asked to perform similar tasks, or less likely when the task is stressful and they respond to stress in different ways. Externalizing behavior ratings are rated in reference to the child's behavior over months, but knowing whether dynamic measures of parent and child affect and goal-directed behavior during the task vary in relation to physiological coregulation would be especially informative. We plan to explore these dynamic and contextual dimensions in future work.

More research will be needed to begin to establish norms pertaining to physiological coregulation between parents and children, where those norms are possible. Related research has shown positive cortisol coregulation in parent-infant (Atkinson et al., 2013; Van Bakel & Riksen-Walraven, 2008) and parent-preschooler dyads (Sethre-Hofstad et al., 2002), as well as coordination of thermal indices of autonomic responding in mothers and children (Barbara et al., 2013; Ebisch et al., 2012). We only addressed one physiological system, but given convergent evidence, the examination of multiple systems could be more informative (Dennis, Buss, & Hastings, 2012). Our multilevel, coupled autoregressive analytic approach was advantageous in allowing for the study of coordination in time-varying changes in RSA over time. Researchers have offered other new methods of note for measuring RSA (Brooker & Buss, 2010; Burt & Obradovi,c, 2013) and analyzing physiological coregulation in dyadic interactions (Ferrer & Helm, 2013; McAssey, Helm, Hsieh, Sbarra, & Ferrer, 2013; Saxbe & Repetti, 2010). Considering the established importance of parent-child coregulation of emotion and behavior and its effects on child development (e.g., Cole, Teti, & Zahn-Waxler, 2003), a better understanding of parent-child physiological coregulation can offer new insights into the biological underpinnings of children's self-regulatory development and new biological markers and mechanisms to explore in delineating trajectories of developmental psychopathology.

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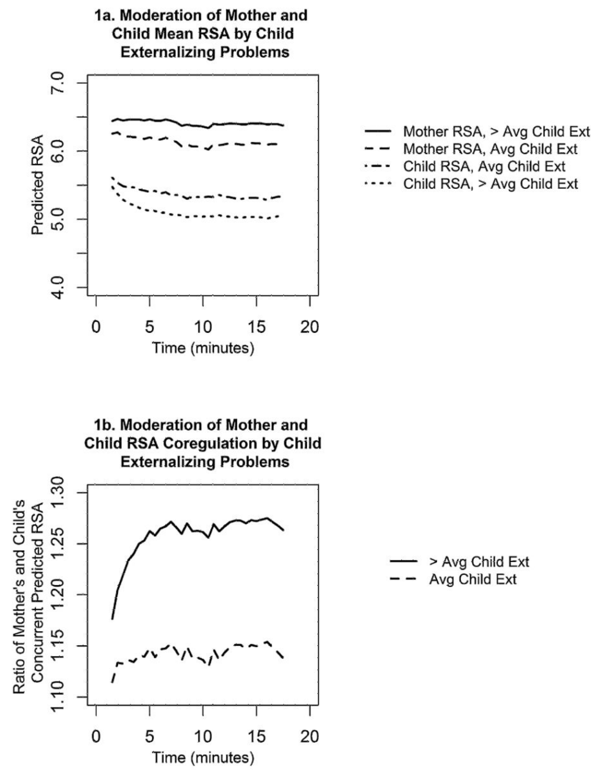

FIGURE 1.

Note: “Avg Child Ext” denotes child externalizing problems equal to the sample mean (8.98) and “> Avg Child Ext” denotes child externalizing problems one standard deviation above the sample mean (15.21). The observed sample means of mothers’ and children’s RSA values at each 30-s epoch were used to estimate coregulation effects, and the means for the first three 30-s epochs were used as the initial conditions for the effects of intraindividual variability.

Table 1

Tests of Random Variance Components

	Wald Statistics	*df*	*p-value*
Child			
Multivariate test	13.06	5	.023
Univariate tests*:			
Overall Mean RSA	3.42	1	.064
IIV (30-s lag)	1.57	1	.210
IIV (60-s lag)	3.50	1	.062
IIV (90-s lag)	.62	1	.433
Coregulation (concurrent)	1.16	1	.282
Parent			
Multivariate test	21.05	5	<.001
Univariate tests*:			
Overall Mean RSA	14.42	1	<.001
IIV (30-s lag)	.06	1	.813
IIV (60-s lag)	1.65	1	.199
IIV (90-s lag)	.92	1	.340
Coregulation (concurrent)	3.23	1	.072

Note: IIV=Intraindividual variability, s=second.

* Univariate tests were performed by comparing an alternate model with all five random effects to a null model where the effect specified above was constrained to zero.

Table 2

Descriptive Data

	1	2	3	4	5	6	7	8	9	*M*	*SD*
1. Parent RSA Overall Mean	—									6.11	.80
2. Parent RSA Free Play	.91***	—								6.25	.84
3. Parent RSA Cleanup	.89***	.85***	—							6.03	.90
4. Parent RSA Problem-Solving	.97***	.81***	.78***	—						6.09	.85
5. Child RSA Overall Mean	.18	.11	.18	.21	—					5.30	.96
6. Child RSA Free Play	.21	.23	.29†	.19	.75***	—				5.62	.93
7. Child RSA Cleanup	.23	.11	.30*	.24	.87***	.70***	—			5.09	1.07
8. Child RSA Problem-Solving	.15	.08	.11	.17	.96***	.57***	.73***	—		5.23	1.08
9. Child Externalizing	.18	.17	.25	.13	−.30*	−.26†	−.25†	−.28†	—	8.98	6.23

** $p < .01$,

† $p < .10$,

* $p < .05$,

*** $p < .001$.

Table 3

Coupled Multilevel Autoregressive Models Predicting Current RSA for Parents

Parent RSA Model	Estimate	SE
Fixed Effects:		
Parent Overall Mean RSA	6.128***	.001
Parent IIV (30-s lag)	.095***	.028
Parent IIV (60-s lag)	.140***	.032
Parent IIV (90-s lag)	.073*	.032
Child Concurrent Coregulation	.159***	.028
Externalizing × Parent Mean RSA	.032**	.010
Externalizing × IIV (30-s lag)	.006	.004
Externalizing × IIV (60-slag)	−.008†	.004
Externalizing × IIV (90-s lag)	.001	.005
Externalizing × Child Coregulation	−.007*	.003
Random Variance Components:		
Level 1 Residual	.582***	.030
Parent Mean RSA	.207***	.046

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$.

Table 4

Coupled Multilevel Autoregressive Models Predicting Current RSA for Children

Child RSA Model	Estimate	SE
Fixed Effects:		
Child Overall Mean RSA	5.317***	.067
Child IIV (30-s lag)	.205***	.040
Child IIV (60-s lag)	.219***	.048
Child IIV (90-s lag)	.094**	.035
Parent Concurrent Coregulation	.184***	.036
Externalizing × Child Mean RSA	−.021*	.010
Externalizing × IIV (30-s lag)	.002	.004
Externalizing × IIV (60-s lag)	.003	.006
Externalizing × IIV (90-s lag)	.000	.004
Externalizing × Parent Coregulation	−.011*	.005
Random Variance Components:		
Level 1 Residual	.799***	.062
Child Mean RSA	.159*	.077