Published in final edited form as:

Child Maltreat. 2018 August ; 23(3): 211–220. doi:10.1177/1077559517751672.

Mother-Child Coregulation of Parasympathetic Processes Differs by Child Maltreatment Severity and Subtype

Erika Lunkenheimer¹, Alex Busuito¹, Kayla M. Brown¹, and Elizabeth A. Skowron²

¹Pennsylvania State University

²University of Oregon

Abstract

Parasympathetic processes appear to underlie maladaptive parent-child interactions in maltreating families, but it is unknown whether parent-child coregulation of respiratory sinus arrhythmia (RSA) differs by child maltreatment severity and subtype. RSA coregulation in maltreating and non-maltreating mother-child dyads ($N=146$; Age 3-5 years) during two dyadic tasks was analyzed using dynamic time series modeling. Non-maltreating dyads showed positive RSA concordance but maltreating dyads (when examined as one group) did not. However, when examined separately by subtype, physically abusive dyads showed positive concordance, and neglectful dyads no concordance, in dyadic RSA. Patterns were further modified by maltreatment severity, which predicted discordant RSA (one partner's RSA predicting decreases in the other's) in both groups. Specifically, higher physical abuse severity predicted lower resting child RSA, declining mother RSA over time, and mother RSA predicting declines in child RSA over time, suggesting a mother-driven dyadic stress response. Higher neglect severity predicted increasing child RSA over time and child RSA predicting declines in mother RSA over time, suggesting a child-driven maternal stress response. These findings show there are distinct patterns of RSA coregulation in non-maltreating, physically abusive, and neglectful mother-child dyads, which may inform etiology and intervention with respect to stress regulation in maltreating families.

Keywords

physical abuse; neglect; parent-child relationships; physiological processes

Theorists argue that early physiological coregulation between parent and child supports behaviors critical for the child's developing biobehavioral regulatory systems (Champagne, 2008; Feldman, 2012). In typical families, this coregulation manifests as concordance (also termed "synchrony") in regulatory biomarkers between parent and child such as heart rate, respiratory sinus arrhythmia, or adrenocortical responses (Lunkenheimer, Tiberio, Buss, Boker, & Timpe, 2015; Sethre-Hofstad, Stansbury, & Rice, 2002). This physiological concordance is associated with positive behaviors, such as maternal sensitivity to child cues and shared positive affect (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011). However, these processes appear to be disrupted in maltreating families such that maltreating parents and children show no concordance in heart rate or RSA during face-to-face interactions (Creaven, Skowron, Hughes, Howard, & Loken, 2014). Maltreating dyads also show corresponding behavioral disruptions, such as greater interactive mismatch and

poorer maternal responding to children's positive bids (Skowron et al., 2011). These disruptions may have important implications for the longer-term development of physiological and behavioral regulatory systems in maltreated children.

Research has emphasized global differences in regulatory processes between non-maltreating families and maltreating families in which children experience parent-perpetrated physical, emotional, or sexual maltreatment or neglect. But maltreating families are characterized by phenotypic heterogeneity, and dimensions such as severity and subtype (e.g., physical abuse, neglect) differ considerably across maltreating families (Manly, Kim, Rogosch, & Cicchetti, 2001). Some research suggests there are differences in individual parent and child regulatory behavior and physiology by subtype (Skowron, Cipriano-Essel, Benjamin, Pincus, & van Ryzin, 2013) and severity (Manly et al., 2001), but more evidence is needed to understand how these factors influence dynamic and dyadic regulatory processes. We argue that maltreatment severity may be particularly likely to influence regulatory processes because higher severity implies greater dysfunction of self-regulation in the parent and greater regulatory resources required on the part of the child. Therefore, we used advanced methodological approaches to tease apart the influences of maltreatment subtype and severity on the moment-to-moment coregulation of parasympathetic processes between mother and child.

Parent-Child Parasympathetic Coregulation

Polyvagal theory (Porges, 2007) designates the parasympathetic nervous system (PNS) as an important physiological substrate of emotional and behavioral self-regulation. Respiratory sinus arrhythmia (RSA), or the amount of variability in heart rate associated with the respiration rate, is a common index of parasympathetic processes. RSA is determined by output from the vagal nerve, which connects the central nervous system to the heart, producing an inhibitory feedback loop that slows heart rate during periods of rest (Berntson, Cacioppo, & Quigley, 1993). Higher levels of resting RSA in the absence of stress, and moderate to high RSA withdrawal (i.e., decrease in RSA) during stress, is argued to reflect better emotional and behavioral self-regulation, which in turn supports more optimal social engagement (Thayer & Lane, 2000). In contrast, lower resting RSA or RSA augmentation (i.e., increase in RSA) in the context of stress are thought to reflect poorer parasympathetic inhibitory control and are associated with insufficient response to social demands (Thayer & Lane, 2000).

Emotional and behavioral regulatory skills begin to internalize and stabilize as children approach kindergarten. Prior to this point in development, parents play a major role as external regulators of children's needs. The coordination of parasympathetic physiology between parent and child may be a crucial way in which early interactions with parents support children's developing stress regulation systems (Champagne, 2008). For example, mothers and infants show increases in heart rate concordance (i.e., positive covariation over time) during positive, synchronous behavior (Feldman et al., 2011). Mothers and preschoolers show RSA concordance over time within task (Lunkenheimer et al., 2015) and reductions in RSA concordance moving from less to more challenging tasks (Lunkenheimer, Tiberio, Skoranski, Buss, & Cole, 2018).

This parasympathetic concordance appears to be altered in maltreating families. Creaven et al. (2014) found that non-maltreating mothers and children showed concordance in heart rate over time, but maltreating dyads showed no concordance in heart rate or RSA. However, higher resting heart rate in maltreating mothers was associated with lower resting RSA in children (Creaven et al., 2014), implying parasympathetic discordance. Skowron et al. (2013) showed that when maltreating mothers displayed physiological arousal via RSA withdrawal, they were more likely to use hostile control immediately following this arousal. Together, these findings imply that maltreating mothers' physiological stress responses may underlie the disruption of parent-child physiological coregulation, which could in turn portend difficulties for the child's developing regulatory skills. However, it should be noted that children's behavior problems have also been associated with discordant RSA between mother and child (Lunkenheimer et al., 2015), suggesting that parasympathetic discordance may be driven by child risk as well as parental risk. Thus, in the present study, we examined RSA coregulation bidirectionally from mother to child and from child to mother to explore differences in the drivers of these effects.

Child Maltreatment Severity and Subtype

Some research suggests that parent-child coregulation may be modified by maltreatment subtype. For example, during challenging tasks, abusive mothers exhibit RSA augmentation while their abused children exhibit RSA withdrawal (Skowron et al., 2011). In contrast, neglectful mothers exhibit RSA withdrawal while their neglected children show RSA augmentation (Skowron et al., 2011). Thus, abused children and neglectful mothers, respectively, show greater physiological regulation in challenging parent-child interactions. Additionally, abusive mothers show RSA withdrawal concurrent with positive parenting, a coupling that is followed by hostile control (Skowron et al., 2013); this pattern implies that abusive mothers' physiological regulation plays a role in driving abusive parenting in real time. Conversely, in neglectful mothers, hostile and positive parenting behaviors precede RSA withdrawal and augmentation, respectively (Skowron et al., 2013), suggesting that parenting behaviors drive physiological reactions in neglectful mothers. Thus, physically abusive and neglectful mother-child dyads manifest distinct patterns of physiological and behavioral self-regulation, which may have differential implications for children's developing self-regulation.

Few studies have examined the relations between parent and child regulatory processes and maltreatment severity. Parent factors related to self-regulation such as harsh discipline, poorer emotional functioning, and higher stress predict greater maltreatment severity (Sprang, Clark, & Bass, 2005). Additionally, higher severity of physical abuse (Manly et al., 2001) and neglect (Manly, Lynch, Oshri, Herzog & Wortel, 2013) predict greater emotional and behavioral regulatory difficulties in preschool-aged children. But we do not know whether maltreatment severity impacts dynamic regulatory processes in parent-child interactions. If parasympathetic functioning supports the modulation of behavior and emotion during social interactions (Beauchaine, Gatzke-Kopp, & Mead, 2007), higher levels of maltreatment severity may be reflected in more extreme disruptions to mother-child RSA coregulation.

Researchers have argued that examining maltreatment severity while accounting for subtype may be the most optimal approach to measure maltreatment severity (Litrownik et al., 2005). For example, Manly et al. (2001) showed that higher neglect severity was linked with children's internalizing problems, whereas higher emotional maltreatment severity was linked with externalizing problems, thus reflecting distinct effects of severity by subtype interactions. Other studies have shown maltreatment severity, accounting for subtype, predicts children's adaptive and externalizing behaviors (Jackson, Gabrielli, Fleming, Tunno, & Makanui, 2014; Litrownik et al., 2005). Thus, we examined the effects of maltreatment severity on mother-child parasympathetic coregulation within subtype, namely physical abuse and neglect.

Present Study

We examined the coregulation of RSA between maltreating and non-maltreating mothers and children during 10 minutes of dyadic problem-solving tasks in the laboratory, accounting for resting RSA and the self-regulation of RSA (i.e., intraindividual variability in within-person RSA over time). First, we examined global differences in RSA coregulation between non-maltreating and maltreating dyads to replicate existing findings on overall differences between these two groups. Second, we examined whether RSA coregulation patterns differed between physically abusive and neglectful dyads when analysis was conducted separately by maltreatment subtype. Third, we examined whether higher levels of maltreatment severity influenced RSA coregulation patterns within subtype, and whether there were differences in the direction of these effects (from mother to child or from child to mother). We used a multilevel coupled autoregressive modeling approach, which involved examining resting RSA and self-regulation and coregulation of RSA at the within-person level and child maltreatment severity at the between-person level, performing models separately by maltreatment subtype.

In the present study, we operationalized coregulation as the level of concordance in mother and child RSA. Concordance was defined as the dynamic, positive prediction of child RSA by mother RSA and vice versa across time (i.e., mother and child RSA both increasing or decreasing) and discordance was defined as the dynamic, negative prediction of one partner's RSA by the other's over time (i.e., one partner's RSA increasing while the other's is decreasing). We expected to find RSA concordance in non-maltreating families (Lunkenheimer et al., 2015). However, given prior mixed findings in maltreating families, with evidence for individual differences in RSA by subtype (Skowron et al., 2011) yet no evidence of RSA concordance in maltreating mother-child dyads (Creaven et al., 2014), we made no specific hypotheses about differences in mother-child parasympathetic concordance by maltreatment severity and subtype.

Method

Participants

Participants were 146 mothers and children ($M_{age} = 3.78$ yrs, $SD_{age} = 0.73$ yrs, Range = 3-5 yrs), a subsample of a larger study recruited through caseworkers at public welfare offices. Mothers were 18 years or older, spoke fluent English, and currently living with their

preschooler; parents and children with severe physical health problems or disabilities were excluded. Maltreating families had a recent report of maltreatment with Child Protective Services (CPS) that could be coded with the Maltreatment Classification System (see Measures; Barnett et al., 1993). Non-maltreating families were recruited from a birth database, were matched with maltreating families on socioeconomic status, and excluded if they had a prior record with CPS.

For maltreating families, ethnicity was 94.9% Non-Hispanic White, 3.4% Hispanic, and 1.7% Multi-ethnic. Mothers were married (37.3%) or cohabiting (23.7%), 20.4% separated or divorced, 16.9% single, and 1.7% widowed. Annual income range was \$10,000 to \$30,000. Mothers' education included 20.3% completing some high school, 74.6% with high school degrees, 1.7% completing some college, and 3.4% with college degrees. For non-maltreating families, ethnicity was 93.5% Non-Hispanic White, 2.6% African American, 2.6% Hispanic, and 1.3% Multi-ethnic. Mothers were married (59.7%) or cohabiting (19.5%), 15.6% separated or divorced, and 5.2% single. Annual income range was \$30,000 to \$50,000. Mothers' education levels included some high school (5.2%), high school degree (42.9%), some college (14.3%), college degree (27.3%), graduate level degree (9.1%), and 1.3% did not report.

Procedure

Two home sessions and one lab session occurred over 2-3 weeks; the final 2.5-hour lab visit was assessed presently. Mothers and children engaged in a resting baseline period and two dyadic puzzle tasks, during which RSA data was collected. These puzzle tasks were selected to prompt regulatory processes: mothers needed to scaffold the child's task-oriented behavior and children needed to follow the mother's instructions and complete the task. Such goal-oriented tasks have been shown to evoke changes in parent and child RSA in prior research (Skowron et al., 2011; Lunkenheimer et al., 2018; Suveg, Shaffer, & Davis, 2016). In the Train Task, mother and child were given a two-dimensional puzzle depicting a train with nine pieces. The child was asked to assemble the puzzle and mother was asked to only use verbal guidance. In the Duplo Puzzle task (Hoffman, Crnic, & Baker, 2006), dyads were provided a 3-dimensional figure made of Duplo blocks. The child was asked to build an exact replica of the model using blocks provided. Mothers were asked to help using only their words and not touch the pieces. Each task terminated after 3 minutes if successfully completed and lasted a maximum of 5 minutes. Families were compensated \$150, provided transportation, and children were given a small toy. The study and all procedures were approved by the university's institutional review board.

Measures

Respiratory sinus arrhythmia (RSA)—RSA was collected with the Mindware wireless ambulatory electrocardiograph (ECG) MW1000A. Three disposable pregelled Ag/AgCl electrodes were placed in a modified Lead II placement on the right clavicle, lower left rib cage chest, and lower abdomen. Heart rate was quantified by taking ECG signals and passing them through an A/D converter sampled at a rate of 500ms. ECG data was processed offline using Mindware Heart Rate Variability 3.0. Data was parsed into 30s epochs across the 10 minutes of tasks (Calkins & Keane, 2004; Lunkenheimer et al., 2015) and trained

research assistants manually corrected missing or erroneous heartbeats. RSA was measured as the natural logarithm of the variance of heart period within the frequency band related to respiration (0.12-0.40 for parents and .24-1.04 for children; Fracasso, Lamb, Porges, & Rosenberg, 1994). A fast-Fourier transformation was used on the interbeat interval time series and power in the respiratory frequency band was derived from the spectral density function (Berntson et al., 1993).

Maltreatment subtype—Subtype was coded from CPS records using the Maltreatment Classification System (MCS; Barnett et al., 1993). *Physical abuse* reflected a non-accidental physical injury of a child perpetrated by a caregiver. *Neglect* reflected failing to meet the child's minimum needs in terms of failure to provide or a lack of child supervision. *Emotional maltreatment* reflected failing to meet children's emotional needs in terms of psychological safety and security, self-esteem, and autonomy. Sexual abuse was not analyzed given qualitative differences in relationship processes related to sexual abuse (Trickett & McBride-Chang, 1995).

As in prior work, subtypes were classified hierarchically such that physical abuse was ranked first, followed by neglect, followed by emotional maltreatment (Pollak, Cicchetti, Hornung, & Reed, 2000). Thus, if a child had a physical abuse record, even if the child also had records of neglect or emotional maltreatment, they were classified as physically abused. If a child was neglected but had no physical abuse, even if the child had also experienced emotional maltreatment, the child was categorized classified as neglected. For emotional maltreatment, children had a record of emotional maltreatment but no physical abuse or neglect. Roughly half of maltreated children (51.2%) experienced more than one subtype, consistent with the literature (Belsky, 1993); given the hierarchical ranking, more children in the physical abuse group experienced multiple forms of maltreatment as compared to the neglect group.

Maltreatment severity—Severity was coded from CPS records using the MCS (Barnett et al., 1993) only for children with documented maltreatment. *Physical abuse severity* ranged from 1 (dangerous act but did not leave marks) to 5 (permanent disability, scarring, disfigurement, or fatality) in categories such as hitting, kicking, pushing, shoving, or throwing. The maximum score across these categories was the physical abuse severity score. *Neglect severity* was scored in two domains. *Neglect - Failure to Provide* ranged from 1 (not providing adequate or regular food, medical care, shelter, or clothing) to 5 (not providing food, medical care, shelter, or clothing such that the child experiences failure to thrive, is born addicted to substances, or experiences permanent consequences). *Neglect - Lack of Supervision* ranged from 1 (inadequate supervision such as a preschooler playing outside unsupervised) to 5 (placing the child in a life threatening situation). The maximum score across these two categories was used as the neglect severity score. Severity was scored within subtype classification, therefore if a child was classified as physically abused, the severity score referred to the severity of physical abuse, regardless if they had also experienced neglect and/or emotional maltreatment.

Analytic Plan

First, global differences in self-regulation and coregulation of mother and child RSA were examined in maltreating and non-maltreating families via coupled autoregressive models in Mplus 7.3 (Muthen & Muthen, 1998-2012). Models were applied to 30-s epochs of RSA data on 10 minutes of dyadic tasks in the laboratory. Mother and child resting RSA was included in these models to account for the effects that individual differences in resting RSA might have on RSA self-regulation and coregulation. This initial set of models was tested to replicate prior findings in the literature suggesting that dynamic, positive RSA concordance is normative, and to establish patterns for non-maltreating families with which to compare to maltreating families.

Second, multilevel coupled autoregressive models examined differences in mother-child RSA coregulation by severity and subtype, which varied as function of time (RSA; Level 1) and person (severity; Level 2). Models specified how maltreatment severity predicted mother and child resting RSA, self-regulation of RSA (SR; i.e., prediction of one's current RSA from one's previous RSA at 30-s and 60-s lags), and coregulation of RSA (CO; i.e., prediction of one's current RSA from partner's concurrent RSA). Models were performed separately by subtype. Models accounted for potential differences in the direction of self-regulation and coregulation effects by modeling the effects of mother on child and of child on mother separately. Thus, four models were run to compare global differences in maltreating and non-maltreating families, and four models were run to examine differences in physically abusive and neglectful dyads.

Overall, there were 77 non-maltreating and 69 maltreating dyads with complete mother and child RSA data. In analyzing global differences between maltreating and non-maltreating dyads, we made use of all maltreating dyads, including families classified by physical abuse, neglect, or emotional maltreatment. In analyzing differences by maltreatment severity, we separated dyads by subtype. Unfortunately, the emotional maltreatment group was too small to analyze in a group comparison ($n = 9$) and were thus dropped from further analysis. Thus, there were 22 physically abusive dyads and 38 neglectful dyads with complete RSA data for mother and child that served as the subtypes under investigation. Statistical power is a function of both sample size and the number of repeated measures per person (Guo, Logan, Glueck, & Muller, 2013); accordingly, these analyses still offered 440 person-by-time observations for physically abusive dyads and 760 person-by-time observations for neglectful dyads.

Within-dyad RSA: Level 1 model—The SR and CO of RSA within dyad were modeled using the equations below, in which $mRSA_{ijt}$ and $CRSA_{ijt}$ denote the i^{th} mother and child's RSA values, respectively, during the j^{th} task at time t . The effects of SR at 30-s and 60-s lags are denoted by $\beta_{M,SRj}$ for mothers and $\beta_{C,SRj}$ for children. The effects of CO are denoted by $\beta_{M,COj}$ for mothers and $\beta_{C,COj}$ for children. Mother and child RSA intercepts at epoch t were modeled as a function of μ_{Mi} and μ_{Ci} (where i indicates that random effects were included). Previously, within-person RSA has been examined at up to three lags (30-, 60-, and 90-s) to account for intraindividual variability over time (Lunkenheimer et al, 2015).

Though we expected within-person stability (Porges, Doussard-Roosevelt, & Maiti, 1994), 90-s lagged RSA did not predict current RSA across families, and thus was dropped from Level 1 equations for parsimony.

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

$$mRSA_{i,t} = \mu_{Mi} + \beta_{M,SR1} mRSA_{i,t-1} + \beta_{M,SR2} mRSA_{i,t-2} + \beta_{M,CO} CRSA_{i,t} + \varepsilon_{Mi,t}$$

$$CRSA_{i,t} = \mu_{Ci} + \beta_{C,SR1} CRSA_{i,t-1} + \beta_{C,SR2} mRSA_{i,t-2} + \beta_{C,CO} mRSA_{i,t} + \varepsilon_{Ci,t}$$

Between-dyad differences by maltreatment severity: Level 2 model—We then examined whether maltreatment severity predicted mother and child resting RSA and SR and CO of RSA using the Level 2 equations below. Note that the fixed effects denoted as $\beta_{M/C}$ in the Level 1 equations are represented as $\gamma_{M/C}$ in the Level 2 equations.

Level 2 (Between-dyad): (2)

These equations model the prediction of mothers' resting RSA (γ_M), SR of RSA, and RSA coregulation by child maltreatment severity (α_M), including random intercepts (u_{Mi}):

$$\mu_{Mi} = u_{Mi} + \gamma_M + \alpha_{M,Mean} Severity$$

$$\beta_{M,SR1} = \gamma_{M,SR1} + \alpha_{M,SR1} Severity$$

$$\beta_{M,SR2} = \gamma_{M,SR2} + \alpha_{M,SR2} Severity$$

$$\beta_{M,CO} = \gamma_{M,CO} + \alpha_{M,CO} Severity$$

These equations model the prediction of children's resting RSA (γ_C), SR of RSA, and RSA coregulation by child maltreatment severity (α_C), including random intercepts (u_{Ci}):

$$\mu_{Ci} = u_{Ci} + \gamma_C + \alpha_{C,Mean} Severity$$

$$\beta_{C,SR1} = \gamma_{C,SR1} + \alpha_{C,SR1} Severity$$

$$\beta_{C,SR2} = \gamma_{C,SR2} + \alpha_{C,SR2} Severity$$

$$\beta_{C,CO} = \gamma_{C,CO} + \alpha_{C,CO}^{Severity}$$

Results

Preliminary Analyses

For families with documented maltreatment, severity ranged from 1 to 5 with 5 the most severe ($M = 3.12$, $SD = 1.07$). Mothers' resting RSA was 5.95 ($SD = 1.30$, Range = 6.75) and child's resting RSA was 5.48 ($SD = 1.17$, Range = 7.62). There were no differences in primary variables by child sex or family income. Child age showed a marginal negative relation with maternal resting RSA ($r = -0.14$, $p < .10$) and maternal education showed a negative correlation with child resting RSA ($r = -0.15$, $p < .05$); however, these relations became non-significant when tested separately by maltreatment status and thus were not included as control variables.

Differences between Maltreating and Non-Maltreating Dyads

First, analyses were conducted to replicate prior findings of positive RSA concordance in typical families and no RSA concordance in maltreating families (Table 1). For non-maltreating families, all intercepts ($\gamma_{M/C}$), including the effects of resting RSA, SR of RSA at 30- and 60-s time lags, and CO of RSA, were significant in predicting current RSA for children. Non-maltreated children predicted increases in their own RSA over time and mothers' RSA positively predicted children's RSA over time. Non-maltreating mothers' resting RSA was significant, and their SR at a 30-s lag (positively predicting their own RSA) and CO (children positively predicting mother RSA) were trending in the expected direction. Thus, findings generally replicated prior work showing positive RSA concordance between typical mothers and preschoolers (Lunkenheimer et al., 2015), though some effects were trending.

For maltreating families, intercepts for resting RSA were significant in predicting current RSA for mothers and children, and SR of RSA at a 30-s lag was significant for mothers and trending for children in predicting current RSA. However, CO intercepts were not significant for either mothers or children. Thus, in line with prior literature (Creaven et al., 2014), dynamic concordance in RSA was not found when examining all maltreating families as one group.

Differences by Maltreatment Severity and Subtype

Second, we examined whether maltreatment severity predicted mother and child resting RSA, SR, and CO of RSA separately by subtype using multilevel coupled autoregressive models. Results are presented for physical abuse first, followed by neglect (Table 2). In physically abusive dyads, as indicated by model intercepts, there was positive concordance of RSA from both mother to child and child to mother. Thus, although RSA was not concordant in a global analysis of all maltreating dyads, it was significant and positive in physically abusive dyads when examined by subtype. Physically abused children also

showed positive effects of resting RSA and SR of RSA on current RSA, similar to non-maltreated children.

However, at higher levels of physical abuse severity, a different pattern emerged. Higher physical abuse severity was associated with mothers' negative SR of RSA (predicting declines in their own RSA over the course of the interaction). It was also associated with children's lower resting RSA levels and discordant RSA with mothers. At a one-unit increase in physical abuse severity, the parameter for mother-to-child RSA CO was adjusted by $b = -.091$, going from positive ($b = .086$) to negative ($b = -.005$). Accordingly, higher levels of severity led to discordant RSA in physically abusive dyads such that mothers' RSA was actively driving declines in children's RSA across the interaction. In sum, physically abusive dyads were characterized by lower resting child RSA, mothers' declining RSA over time, and mothers predicting declines in child RSA over time at higher levels of severity. See Figure 1 for an illustration of the effects of physical abuse severity on model-predicted mother and child RSA.

In neglectful dyads, intercepts were similar to the global maltreating group analysis: resting RSA predicted current RSA for mothers and children and SR of RSA at a 30-s lag predicted current RSA for children. Another similarity was that RSA CO intercepts were not significant for mothers or children. Thus, there were no time-dependent relations between mother and child RSA in neglectful dyads overall. But once again, when maltreatment severity was higher, unique patterns emerged. At higher levels of neglect severity, the effect of child-to-mother RSA CO became negative. At a one-unit increase in neglect severity, coregulation became discordant such that child RSA was driving declines in mother RSA over time. Also, children's SR of RSA was positive, indicating the prediction of increases in their own RSA over time. In sum, neglectful dyads were characterized by children's increasing RSA over time and child RSA predicting declines in mother RSA over time at higher levels of severity. See Figure 2 for an illustration of the effects of neglect severity on model-predicted mother and child RSA.

Discussion

If early parent-child physiological coregulation is an essential support to children's developing biobehavioral regulatory systems (Feldman, 2012), and typical mother-child dyads show dyadic concordance in the parasympathetic processes that underlie emotional and behavioral self-regulation (Lunkenheimer et al., 2015), then disruptions to this concordance could portend challenges for children's developing regulatory skills. However, we do not yet know whether concordant physiological coregulation signifies adaptation or discordant or absent physiological coregulation signifies maladaptation, particularly given that effects may differ based on familial risk. Prior research suggested these dyadic relations were absent in maltreating families (Creaven et al., 2014), but other work on maltreating mothers and their children indicated there might be differences in parasympathetic processes by maltreatment subtype (Skowron et al., 2011). Through the use of dynamic statistical methods to capture physiological responding in real time, and by examining differences by maltreatment subtype and severity within subtype, we expanded this area of the literature

through the discovery of distinct patterns of RSA coregulation in physically abusive, neglectful, and non-maltreating mother-child dyads.

Consistent with prior research (Creaven et al., 2014), maltreating dyads showed no RSA concordance when examined as an integrated group. But when examined separately by subtype, physically abusive and neglectful dyads showed unique patterns of dyadic RSA: physically abusive dyads demonstrated positive concordance, whereas neglectful dyads—like the maltreating group as a whole—showed no concordance. Thus, the absence of RSA concordance found in prior studies was likely driven by the fact that neglect is a more common form of maltreatment than physical abuse, and thus neglectful dyads made up a greater proportion of dyads when all maltreating families were aggregated into one analysis.

These novel findings have implications for the meaning of parasympathetic coordination between parent and child. Feldman (2012) suggested that physiological concordance reflects behavioral synchrony. So the RSA concordance shown in non-maltreating dyads in the context of a dyadic task may reflect this behavioral synchrony, such as the dyad's joint attention and coordinated effort towards their shared goal. For example, when reuniting after a stressful separation, more-sensitive mothers and their infants show similar patterns of RSA (lower RSA relative to baseline), whereas less-sensitive mothers and their infants show opposite patterns of RSA (Moore et al., 2009). But then what exactly does positive RSA concordance signify in the context of higher risk, as in physically abusive families, and what does the absence of RSA concordance signify, as in neglectful families?

Though theory suggests physiological concordance has a positive influence (Feldman, 2012), this may not be the case for all children. Some studies have shown stronger physiological concordance in highly negative dyads (Papp, Pendry, & Adam, 2009) or between insecure-resistant children and their mothers (Smith et al., 2015). Since physically abusive mothers often express more negative behavior than non-maltreating or neglectful mothers (Skowron et al., 2011), RSA concordance in physically abusive dyads may reflect synchrony around negative behavior and may perpetuate coercive cycles that impair children's self-regulatory development. In fact, in higher risk families, parent-child behavioral coregulation and child self-regulation have been shown to be greater when physiological concordance is low (Suveg et al., 2016). This suggests we should include behavioral measures in studies of physiological coregulation to distinguish adaptation from maladaptation, and take developmental status and task context into account when interpreting findings (Lunkenheimer et al., 2018).

Research on physiological coregulation through breastfeeding (Quigley, Moore, Propper, Goldman, & Cox, 2016), maternal holding (Neu, Laudenslager, & Robinson, 2009), and parasympathetic processes (Moore et al., 2009) confirms the importance of caregiving for the development of children's regulatory systems. Neglectful parents' failures to provide appropriate and consistent caregiving may prevent physiological concordance from developing, in turn interfering with the process by which children's biobehavioral regulation is conditioned upon social interactions (Shipman, Edwards, Brown, Swisher, & Jennings, 2005). The absence of RSA concordance could suggest that neglectful dyads have not developed the ability to coordinate parasympathetic processes with which to navigate dyadic

social challenges. It should be noted that some interventions have been effective in helping neglected children catch up in regulatory skills when implemented early (Bernard, Dozier, Bick, & Gordon, 2015).

Maltreatment severity modified RSA coregulation such that at higher severity, both abusive and neglectful dyads showed discordant coregulation (i.e., higher RSA in one member predicting lower RSA in the other). These findings echo work suggesting that discordant parasympathetic coregulation is a risk marker (Creaven et al., 2014; Lunkenheimer et al., 2015; Lunkenheimer et al., 2018). We proposed that higher severity would reflect parents' greater difficulty regulating themselves, which would prompt greater disruption in coregulation. These disruptions were demonstrated via the move from positive or no concordance in RSA at mean level severity to RSA discordance at higher levels of severity. Discordance may indicate that one partner is not engaging to meet social demands, reflected in RSA augmentation, which could result in a more physiologically stressful experience for the other partner, reflected in excessive RSA withdrawal. It should be considered, however, that discordance may be adaptive under some circumstances. For example, if children cannot rely on their parents it may be more adaptive not to engage, which seems to be indicated by the fact that neglected children showed augmented RSA while interacting with mothers. It should also be noted that in prior research, discordant mother-infant RSA in response to stress has been interpreted as adaptive in terms of mothers becoming more physiologically aroused to support caregiving (Ostlund, Measelle, Laurent, Conradt, & Ablow, 2017). Thus, as noted, the meaning of discordant parasympathetic regulation must be interpreted in light of developmental status and the interaction context.

By analyzing the directionality of mother-to-child and child-to-mother effects, we were also able to identify specific drivers of discordant coregulation by maltreatment subtype: physically abusive mothers' RSA predicted decreases in child RSA over time, whereas neglected children's RSA predicted decreases in maternal RSA over time at higher levels of maltreatment severity. These patterns mirror those shown in prior research at the individual level (Skowron et al., 2011), but illustrate how each partner drove the respective effect. Physically abusive mothers may have been less engaged in helping children complete the task, forcing children to rely more heavily on their own self-regulation (reflected in RSA withdrawal). In contrast, neglectful dyads showed *child*-driven declines in mother RSA over the course of the task. Supporting children in a difficult task may be especially challenging for neglectful mothers and may require greater physiological activation (Skowron et al., 2013), which may be exacerbated when children do not engage. Together, our findings suggest that both maltreatment subtype and severity within subtype predict meaningful differences in the underlying parasympathetic processes that are thought to calibrate children's developing self-regulatory systems (Beauchaine et al., 2007).

Limitations and Future Directions

The maltreated subgroups were small in size and limited to low-income families. Thus, our results may not generalize to other groups and should be replicated in larger and more diverse samples. We were unable to examine emotional and sexual maltreatment, so future work could address parasympathetic processes related to these subtypes. Although greater

use of continuous dimensions of maltreatment such as severity is needed, they are not without confounds. For example, severity indices for some subtypes (i.e., lasting physical damage) may be easier to document than for other types, such as neglect (Trocmé et al., 2003). This should be considered when interpreting the meaning of the effects of maltreatment severity within subtype.

Given the greater power afforded to parents relative to their children, self-regulation in maltreating parents is a particularly important target of future work. Higher maternal heart rate has been linked to maltreatment risk (Creaven et al., 2014) but because heart rate reflects dual innervation by the PNS and SNS (Berntson et al., 1993), it is unclear whether higher heart rate reflects higher sympathetic tone, lower parasympathetic tone, or both. Further, we did not control for individual differences in breathing rate nor for physical touch between parent and child, which could influence RSA. If PNS functioning underlies parents' abilities to engage with children, it will be important to pursue more specific and comprehensive measurement of parental PNS and SNS functioning in studying how it is involved in physiological coregulation (Skoranski, Lunkenheimer, & Lucas-Thompson, 2018).

Conclusion

Finding that RSA coregulation differs as a function of maltreatment subtype and severity suggests that early biobehavioral regulatory processes between mother and child may be uniquely disrupted by physical abuse and neglect. In cases of severe abuse, children may need to rely on their own regulatory resources as a result of maternal disengagement, leading to the taxation of immature physiology. With severe neglect, children may disengage due to mothers' unavailability and mothers may find interaction with their children demanding, diminishing their already limited regulatory resources. Because the PNS is thought to support the regulation of behaviors necessary for social interaction (Porges, 2007), the patterns of RSA discordance identified in this study could reflect disruptions to behavioral coregulation. Identifying the dyadic behaviors (Woltering et al., 2015) and child self-regulatory outcomes associated with these patterns are the next steps towards understanding how children's developing regulatory systems are dynamically calibrated in the context of different forms and degrees of maltreatment.

Acknowledgments

Research reported in this publication was supported by the National Institute of Child Health and Human Development of the National Institutes of Health, grant number K01HD068170. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References

- Barnett D, Manly JT, Cicchetti D. Defining child maltreatment: The interface between policy and research. *Child Abuse, Child Development, and Social Policy*. 1993; 8:7–73.
- Beauchaine TP, Gatzke-Kopp L, Mead HK. Polyvagal theory and developmental psychopathology: Emotion dysregulation and conduct problems from preschool to adolescence. *Biological Psychology*. 2007; 74(2):174–184. DOI: 10.1016/j.biopsycho.2005.08.008 [PubMed: 17045726]

- Bernard K, Dozier M, Bick J, Gordon MK. Intervening to enhance cortisol regulation among children at risk for neglect: Results of a clinical trial. *Development and Psychopathology*. 2015; 27(3):829–841. DOI: 10.1017/S095457941400073X [PubMed: 25156798]
- Berntson GG, Cacioppo JT, Quigley KS. Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*. 1993; 30(2): 183–196. [PubMed: 8434081]
- Calkins SD, Keane SP. Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology*. 2004; 45(3):101–112. [PubMed: 15505799]
- Champagne FA. Epigenetic mechanisms and the transgenerational effects of maternal care. *Frontiers in Neuroendocrinology*. 2008; 29(3):386–397. DOI: 10.1016/j.yfrne.2008.03.003 [PubMed: 18462782]
- Creaven AM, Skowron EA, Hughes BM, Howard S, Loken E. Dyadic concordance in mother and preschooler resting cardiovascular function varies by risk status. *Developmental Psychobiology*. 2014; 56(1):142–152. DOI: 10.1002/dev.21098 [PubMed: 24022469]
- Feldman R. Biobehavioral synchrony: A model for integrating biological and micro-social processes in the study of parenting. *Parenting: Science and Practice*. 2012; 12:154–164.
- Feldman R, Magori-Cohen R, Galili G, Singer M, Louzoun Y. Mother and infant coordinate heart rhythms through episodes of interaction synchrony. *Infant Behavior & Development*. 2011; 34(4): 569–577. DOI: 10.1016/j.infbeh.2011.06.008 [PubMed: 21767879]
- Fracasso MP, Porges SW, Lamb ME, Rosenberg AA. Cardiac activity in infancy: Reliability and stability of individual differences. *Infant Behavior & Development*. 1994; 17(3):277–284. DOI: 10.1016/0163-6383(94)90006-X
- Guo Y, Logan HL, Glueck DH, Muller KE. Selecting a sample size for studies with repeated measures. *BMC medical research methodology*. 2013; 13(1):100. [PubMed: 23902644]
- Hoffman C, Crnic KA, Baker JK. Maternal depression and parenting: Implications for children's emergent emotion regulation and behavioral functioning. *Parenting: Science and Practice*. 2006; 6(4):271–295. DOI: 10.1207/s15327922par0604_1
- Jackson Y, Gabrielli J, Fleming K, Tunno AM, Makanui PK. Untangling the relative contribution of maltreatment severity and frequency to type of behavioral outcome in foster youth. *Child Abuse & Neglect*. 2014; 38:1147–1159. DOI: 10.1016/j.chiabu.2014.01.008 [PubMed: 24612908]
- Litrownik AJ, Lau A, English DJ, Briggs E, Newton RR, Romney S, Dubowitz H. Measuring the severity of child maltreatment. *Child Abuse & Neglect*. 2005; 29:553–573. [PubMed: 15970325]
- Lunkenheimer E, Tiberio SS, Buss KA, Lucas-Thompson RG, Boker SM, Timpe ZC. Coregulation of respiratory sinus arrhythmia between parents and preschoolers: Differences by children's externalizing problems. *Developmental Psychobiology*. 2015; 57(8):994–1003. DOI: 10.1002/dev.21323 [PubMed: 25976070]
- Lunkenheimer E, Tiberio SS, Skoranski AM, Buss KA, Cole PM. Parent-child coregulation of parasympathetic processes varies by social context and risk for psychopathology. *Psychophysiology*. 2018; Advance online publication. doi: 10.1111/psyp.12985
- Manly JT, Kim JE, Rogosch FA, Cicchetti D. Dimensions of child maltreatment and children's adjustment: Contributions of developmental timing and subtype. *Development and Psychopathology*. 2001; 13(4):759–782. [PubMed: 11771907]
- Manly JT, Lynch M, Oshri A, Herzog M, Wortel SN. The impact of neglect on initial adaptation to school. *Child Maltreatment*. 2013; 18(3):155–170. DOI: 10.1177/1077559513496144 [PubMed: 23843472]
- Moore GA, Hill-Soderlund AL, Propper CB, Calkins SD, Mills-Koonce W, Cox MJ. Mother-infant vagal regulation in the face-to-face still-face paradigm is moderated by maternal sensitivity. *Child Development*. 2009; 80(1):209–223. DOI: 10.1111/j.1467-8624.2008.01255.x [PubMed: 19236402]
- Muthén, LK., Muthén, BO. *Mplus User's Guide* Los Angeles, CA: Muthén; 1998–2012
- Neu M, Laudenslager ML, Robinson J. Coregulation in salivary cortisol during maternal holding of premature infants. *Biological Research for Nursing*. 2009; 10(3):226–240. DOI: 10.1177/1099800408327789 [PubMed: 19028768]

- Ostlund BD, Measelle JR, Laurent HK, Conradt E, Ablow JC. Shaping emotion regulation: Attunement, symptomatology, and stress recovery within mother–infant dyads. *Developmental Psychobiology*. 2017; 59(1):15–25. DOI: 10.1002/dev.21448 [PubMed: 27481553]
- Papp LM, Pendry P, Adam EK. Mother-adolescent physiological synchrony in naturalistic settings: Within-family cortisol associations and moderators. *Journal of Family Psychology*. 2009; 23(6): 882–894. DOI: 10.1037/a0017147 [PubMed: 20001147]
- Pollak SD, Cicchetti D, Hornung K, Reed A. Recognizing emotion in faces: Developmental effects of child abuse and neglect. *Developmental Psychology*. 2000; 36(5):679–688. DOI: 10.1037/0012-1649.36.5.679 [PubMed: 10976606]
- Porges SW. The polyvagal perspective. *Biological Psychology*. 2007; 74(2):116–143. DOI: 10.1016/j.biopsycho.2006.06.009 [PubMed: 17049418]
- Porges SW, Doussard-Roosevelt JA, Maiti AK. Vagal tone and the physiological regulation of emotion. *Monographs of the Society for Research in Child Development*. 1994; 59(2-3):167–186. DOI: 10.2307/1166144 [PubMed: 7984159]
- Quigley KM, Moore GA, Propper CB, Goldman BD, Cox MJ. Vagal regulation in breastfeeding infants and their mothers. *Child Development*. 2016; Advance online publication. doi: 10.1111/cdev.12641
- Sethre-Hofstad L, Stansbury K, Rice MA. Attunement of maternal and child adrenocortical response to child challenge. *Psychoneuroendocrinology*. 2002; 27(6):731–747. DOI: 10.1016/S0306-4530(01)00077-4 [PubMed: 12084665]
- Shipman K, Edwards A, Brown A, Swisher L, Jennings E. Managing emotion in a maltreating context: A pilot study examining child neglect. *Child Abuse & Neglect*. 2005; 29(9):1015–1029. DOI: 10.1016/j.chiabu.2005.01.006 [PubMed: 16159666]
- Skoranski AM, Lunkenheimer E, Lucas-Thompson RG. The effects of maternal respiratory sinus arrhythmia and behavioral engagement on mother-child physiological coregulation. *Developmental Psychobiology*. 2018; doi: 10.1002/dev.21543
- Skowron EA, Cipriano-Essel E, Benjamin LS, Pincus AL, Van Ryzin MJ. Cardiac vagal tone and quality of parenting show concurrent and time-ordered associations that diverge in abusive, neglectful, and non-maltreating mothers. *Couple & Family Psychology*. 2013; 2(2):95–115. DOI: 10.1037/cfp0000005 [PubMed: 24729945]
- Skowron EA, Loken E, Gatzke-Kopp LM, Cipriano-Essel EA, Woehrle PL, Van Epps JJ, Ammerman RT. Mapping cardiac physiology and parenting processes in maltreating mother–child dyads. *Journal of Family Psychology*. 2011; 25(5):663–674. DOI: 10.1037/a0024528 [PubMed: 21842991]
- Smith JD, Woodhouse SS, Clark CA, Skowron EA. Attachment status and mother–preschooler parasympathetic response to the strange situation procedure. *Biological Psychology*. 2016; 114:39–48. DOI: 10.1016/j.biopsycho.2015.12.008 [PubMed: 26738633]
- Sprang G, Clark JJ, Bass S. Factors that contribute to child maltreatment severity: A multi-method and multidimensional investigation. *Child Abuse & Neglect*. 2005; 29(4):335–350. DOI: 10.1016/j.chiabu.2004.08.008 [PubMed: 15917076]
- Suveg C, Shaffer A, Davis M. Family stress moderates relations between physiological and behavioral synchrony and child self-regulation in mother–preschooler dyads. *Developmental Psychobiology*. 2016; 58(1):83–97. DOI: 10.1002/dev.21358 [PubMed: 26376933]
- Thayer JF, Lane RD. A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*. 2000; 61(3):201–216. DOI: 10.1016/S0165-0327(00)00338-4 [PubMed: 11163422]
- Trickett PK, McBride-Chang C. The developmental impact of different forms of child abuse and neglect. *Developmental Review*. 1995; 15:311–337. DOI: 10.1006/drev.1995.1012
- Trocmé N, MacMillan H, Fallon B, De Marco R. Nature and severity of physical harm caused by child abuse and neglect: Results from the Canadian Incidence Study. *Canadian Medical Association Journal*. 2003; 169(9):911–915. [PubMed: 14581308]
- Woltering S, Lishak V, Elliott B, Ferraro L, Granic I. Dyadic attunement and physiological synchrony during mother-child interactions: An exploratory study in children with and without externalizing

behavior problems. *Journal of Psychopathology and Behavioral Assessment*. 2015; 37(4):624–633.
DOI: 10.1007/s10862-015-9480-3

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1.

Differences in RSA coregulation as a function of maltreatment severity in mother-child dyads characterized by physical abuse. Note: HIGHER PA SEV and LOWER PA SEV refer to values plus one and minus one standard deviation, respectively, of the maltreatment severity of physical abuse.

Figure 2.

Differences in RSA coregulation as a function of maltreatment severity in mother-child dyads characterized by neglect. Note: HIGHER NEG SEV and LOWER NEG SEV refer to values plus and minus one standard deviation, respectively, of the maltreatment severity of neglect.

Table 1

Coupled Autoregressive Models: Global Differences between Non-Maltreating and Maltreating Dyads

Effect	Non-Mal Mother Model (<i>N</i> = 77)	Non-Mal Child Model (<i>N</i> = 75)	Maltreating Mother Model (<i>N</i> = 68)	Maltreating Child Model (<i>N</i> = 67)
Estimated intercepts:				
Resting RSA	6.064 (.090) ***	5.436 (.041) ***	5.981 (.125) ***	5.628 (.166) ***
RSA Self-regulation 1 lag	.262 (.149) [†]	.414 (.042) ***	.162 (.069) *	.400 (.208) [†]
RSA Self-regulation 2 lags	.113 (.149)	.302 (.048) ***	.033 (.067)	.207 (.191)
RSA Coregulation	.063 (.037) [†]	.079 (.031) **	.025(.042)	.050 (.058)
Estimated variance components:				
Level-1 Residual Variance	.768 (.152) ***	.786 (.067) ***	.509 (.045) ***	.681 (.195) ***
Wald Multivariate Test	.693	.036	2.883 [†]	.042
Intraclass Correlation	.306	.001	.708	.001
Average Cluster Size	8.481	8.680	9.853	9.910
# Clusters	77	75	68	67

Note: Values in table denote $b(SE)$ unless noted otherwise. Non-Mal = Non-maltreating; RSA = respiratory sinus arrhythmia.

[†] $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$

Table 2

Multilevel Coupled Autoregressive Models: Effects of Child Maltreatment Severity by Subtype

	PA Mother Model (<i>N</i> = 21)	PA Child Model (<i>N</i> = 22)	NG Mother Model (<i>N</i> = 38)	NG Child Model (<i>N</i> = 38)
Estimated intercepts:				
Resting RSA	5.878 (.136) ***	5.380 (.048) ***	5.735 (.243) ***	5.585 (.103) ***
RSA Self-regulation 1 lag	.212 (.166)	.469 (.051) ***	.070 (.081)	.318 (.084) ***
RSA Self-regulation 2 lags	.108 (.160)	.247 (.063) ***	.030 (.077)	.114 (.071)
RSA Coregulation	.131 (.066) *	.086 (.043) *	-.020 (.040)	.023 (.060)
Estimated regression coefficients and variance components:				
Level 1 (Time):				
Level-1 Residual Variance	.540 (.052) ***	.653 (.179) ***	.511 (.058) **	.679 (.092) ***
Level 2 (Severity):				
Resting RSA	.026 (.091)	-.209 (.036) ***	-.342 (.209)	-.031 (.098)
RSA Self-regulation 1 lag	-.184 (.081) *	.005 (.041)	.064 (.081)	.144 (.061) *
RSA Self-regulation 2 lags	.031 (.062)	.028 (.057)	.092 (.069)	.016 (.058)
RSA Coregulation	-.089 (.065)	-.091 (.045) *	-.092 (.037) *	-.077 (.058)
Level-2 Residual Variance	.241 (.404)	.000 (.016)	2.110 (.843) *	.283 (.180)
Wald Multivariate Test	.356	.001	6.269 *	2.484
Intraclass Correlation	.528	.025	.780	.129
Average Cluster Size	9.905	9.500	10.211	10.026
# Clusters	21	22	38	38

Note: Values in table denote $b(SE)$ unless noted otherwise. PA = Physical abuse; NG = Neglect; RSA = respiratory sinus arrhythmia.†
 $p < .10$,*
 $p < .05$,**
 $p < .01$,***
 $p < .001$