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DYADIC FLEXIBILITY MEDIATES THE RELATION BETWEEN PARENT CONFLICT AND INFANT VAGAL REGULATION

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ABSTRACT

Parent conflict is associated with behavior problems and atypical physiological regulation during childhood. Recent research has found that parent conflict is also related to atypical physiological regulation in infants, suggesting that potential effects of parent conflict on immature regulatory systems during infancy may explain childhood outcomes. Because infants rely on their caregivers for external regulation during the first year of life, one way conflict could affect infant regulation is through effects on parent-infant dyadic regulation. In a sample of 6-month-old infants and their mothers (N = 52), this study investigated dyadic flexibility, a novel measure of dyadic regulation, as a mediator of the relation between parent conflict and infant vagal regulation during a mild social stressor (the Face-to-Face Still Face). Dyads with mothers reporting higher conflict were less flexible in the reunion episode of the FFSF, and infants of these dyads exhibited less vagal reactivity in the reunion episode, suggesting less effective recovery and greater need to engage in physiological self-regulation. A test of mediation found that conflict was related to infant vagal reactivity through an indirect effect on dyadic flexibility during the reunion episode. Flexibility may uniquely illustrate the process of dyadic regulation and may be one mechanism by which conflict is related to infant self-regulation.

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ANS: Autonomic nervous system
FFSF: Face-to-Face Still Face
HP: Heart period
IBI: Interbeat interval
PNS: Parasympathetic nervous system
REML: Restricted maximum likelihood
RSA: Respiratory sinus arrhythmia
SNS: Sympathetic nervous system
SSG: State Space Grid

Parent conflict is associated with negative outcomes in middle childhood, including greater physiological arousal, atypical physiological regulation (over- and under-reactivity), slower recovery from stress (e.g., El-Sheikh, 2005), and higher rates of behavior problems (e.g., Davies & Cummings, 1994; El-Sheikh, Keiley, Erath, & Dyer, 2013). Recent research has found that parent conflict is also related to atypical physiological regulation in infants (Moore, 2010; Porter, Wouden-Miller, Silva, & Porter, 2003), suggesting that the impact of parent conflict on rapidly developing regulatory systems during infancy may explain, in part, maladaptive outcomes later in life. However, little is known about *how* conflict may get under the skin to shape infants' regulatory functioning. One possible mechanism is through parent-infant dyadic regulation, which may be influenced by conflict-related stress on both mothers and infants (e.g. Davies, Sturge-Apple, Woitach, & Cummings, 2009).

The goal of infant-caregiver interactions is to achieve calm, positive states through an exchange of behavior and affect between infant and caregiver (Cohn & Tronick, 1988; Tronick, 2007). It is thought to be through this process of dyadic regulation that children gradually gain the ability to independently regulate their behavior and physiology (Calkins & Hill, 2007; Tronick & Cohn, 1989). Consistent with theoretical work that suggests that dyadic regulation is largely parent-driven in the first months of life (Kopp, 1982; Calkins & Hill, 2007) individual differences in dyadic regulation during infancy have been found as a function of parental factors, including parental stress and psychopathology (Coburn, Crnic, & Ross, 2015; Feldman, 2007; Feldman & Eidelman, 2009). Although research has found that parent conflict is related to more negative parenting behaviors during infancy (McElwain & Volling, 1999) and childhood (Shelton & Harold, 2008), studies have yet to examine whether parent conflict is related to individual differences dyadic regulation, the context in which much of parenting takes place during the first year of life.

Physiological systems may be particularly sensitive to environmental influences as they develop rapidly during the first year of life (Bar-Haim, Marshall, & Fox, 2000), and individual differences in physiological regulation are associated with differences in behavior regulation (Geisler, Kubiak, Siewert, & Weber, 2013). Examining relations among parent conflict, parent-infant dyadic regulation, and infant physiological regulation is likely to lend insight to the developmental trajectories by which parent conflict influences child adjustment. Therefore, the current study investigated whether dyadic regulation is a pathway by which parent conflict is related to infant physiological regulation.

Parent Conflict and Infant Physiological Regulation

Recent research, using measures of Respiratory Sinus Arrythmia (RSA; an index of parasympathetic nervous system [PNS] control of cardiac function), has found that parent conflict is associated with infant physiological functioning. Infants in families where mothers reported higher levels of conflict exhibited lower baseline RSA (Porter et al , 2003), suggesting a lesser capacity for physiological regulation, compared with infants in families with lower levels of conflict. Consistent with this, other work using the same sample that was used in the current study found that higher parent conflict was associated with lower infant RSA at baseline and across all episodes of the Face-to-Face Still Face (FFSF; Tronick, Als, Adamson, Wise, & Brazelton, 1978), a mild social stressor. Conflict was also related to lesser RSA reactivity (change in RSA) over the course of the FFSF (Moore, 2010), which is thought to reflect less effective regulation or recovery in response to stress. This initial evidence suggests that parent conflict is associated with less effective vagal regulation in infants, which may reflect the sensitivity of rapidly-developing physiological systems to environmental input during the first year of life.

Infant vagal functioning. The PNS, through the action of the myelinated vagus, dynamically modulates autonomic arousal in response to environmental demands. PNS control of cardiac functioning is reflected in RSA, an index of vagal tone. Changes in vagal tone are typically conceptualized as withdrawal or augmentation, referring to inhibition or action of the PNS, respectively (Beauchaine, 2001; Beauchaine, Gatzke-Kopp, & Mead, 2007). Vagal withdrawal allows an increase in cardiac output without the activation of the metabolically costly sympathetic nervous system, in turn supporting individuals' abilities to engage with their environments (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). In this way, vagal functioning plays a central role in the regulation of behavior, emotions, and attention (Berntson, Cacioppo, Quigley, & Fabro, 1994; Porges, 2001). Vagal withdrawal in response to stress during infancy is related to greater soothability (Huffman et al., 1998; Stifter & Corey, 2001), more effective emotion regulation (Calkins, Dedmon, Gill, Lomax, & Johnson, 2002; Calkins, 1997; Porges, Doussard-Roosevelt, Lourdes Portales, & Suess, 1994), and better attentional control (Huffman et al., 1998; Suess, Porges, & Plude, 1994).

Development of vagal regulation. As the last component of the autonomic nervous system (ANS) to emerge in the human fetus, the myelinated vagus develops rapidly during the third trimester of pregnancy. Vagal tone can be measured as early as 30-32 weeks gestational age (Porges, 1995) and continues to develop during the first few months of infancy (Bar-Haim et al., 2000). This ongoing development of the vagal system manifests in an increase in baseline vagal tone across the first years of life (Bar-Haim et al., 2000; Patriquin, Lorenzi, Scarpa, & Bell, 2014) continuing until at least 5 years of age (Bornstein & Suess, 2000). These changes purportedly indicate greater capacity for neurophysiological regulation, and correspond to increased ability for social engagement and more dynamic response to social stress (Geisler et al., 2013; Patriquin et al., 2014).

Infants have been found to exhibit vagal responses to the FFSF as early as 3 months postnatal (Moore & Calkins, 2004). In 6-month-old infants, vagal tone consistently shows a normative increase during the normal play and reunion episodes, reflecting a calm, regulated state, and a decrease during the still-face episode, indicating an active regulation of distress (Bazhenova, Plonskaia, & Porges, 2001; Conradt & Ablow, 2010; Moore & Calkins, 2004; Weinberg & Tronick, 1996). On average, vagal tone increases between the still-face and the reunion episodes, but does not return to levels seen during normal play (Bazhenova et et al., 2001; Conradt & Ablow, 2010; Moore & Calkins, 2004), similar to the patterns of behavioral distress, suggesting a continuing need to regulate.

***Individual differences in vagal regulation*.** Theoretical work on the development of self-regulation (e.g., DiCorcia, Sravish, & Tronick, 2013; Tronick, 2007), proposes that infants' development of internal regulatory capacities is contingent upon engagement with their environment and with external regulatory resources. Consistent with this, research on infant vagal regulation suggests that the first months of life may be a period during which the vagal system is particularly sensitive to distal and proximal environmental influences such as socio-economic status, parental psychopathology (Feldman & Eidelman, 2009), and parenting behavior (Moore et al., 2009).

Empirical work has also investigated associations between parent-infant dyadic regulation and infant physiological functioning more directly. Infants of mothers who were highly contingently responsive to infant vocalizations or facial expressions during the normal play and the first reunion episode of a modified FFSF exhibited lower heart rate, indicating less arousal, during the second reunion episode (Haley & Stansbury, 2003). Infants of dyads that were less synchronous during the normal play episode of the FFSF showed higher heart rate and did not show the expected RSA withdrawal to the still-face, suggesting that the quality of dyadic regulation has consequences for infant self-regulation when the child is subsequently stressed. In contrast, infants of dyads that exhibited less matched affect during the reunion episode showed greater RSA withdrawal during the reunion episode, suggesting that those dyads may have been actively engaged, but less successful in recovering from the arousal and dyadic mismatch generated by the still-face episode (Moore & Calkins, 2004). Finally, infants of dyads that were more synchronous showed higher overall RSA across the FFSF (Feldman, Singer, & Zagoory, 2010), suggesting better regulation.

Because infants require external support (dyadic regulation) to engage with their environments and this regulatory support is theorized to contribute to vagal development, individual differences in infant vagal regulation may reflect sensitivity to environmental factors that influence dyads' ability to engage in adaptive regulatory strategies. Infants who lack sufficient external support for regulation may then need to initially over-rely on immature self-regulatory strategies. Parent conflict maybe one environmental factor that affects the availability and quality of external regulatory support during infancy.

Parent Conflict and Dyadic Regulation

Research on parent conflict suggests that conflict may introduce stress to the family environment that could affect infants directly or indirectly through effects on parents (i.e., spillover; Cummings & Davies, 2002). For example, infants exposed to anger prior to the FFSF exhibited greater vagal withdrawal during the still-face compared with infants who were exposed to neutral or excited affect (Moore, 2009), suggesting a greater need to regulate in response to anger than to neutral or positive affect. Over time, with repeated exposure to conflict, over-reliance on immature physiological systems may lead to regulatory “burnout” or less effective regulation of future stress (Muraven & Baumeister, 2000). This is consistent with the recent findings from the sample used in the current study that infants in families with higher conflict showed diminished RSA reactivity (i.e., less change in RSA) across the FFSF (Moore, 2010). Thus, infants exposed to conflict may require greater support for physiological regulation and be less able to optimally contribute to dyadic regulation.

During infancy, parenting occurs largely in the context of face-to-face interaction. Therefore, indirect effects of conflict on infant regulation may be most evident through effects on dyadic regulation, which is thought to be largely parent-led during the first year of life (Kopp, 1982). Therefore, to the extent that conflict influences mothers’ abilities to regulate, it may also affect the quality of dyadic regulation. The heightened physiological response to anger or conflict exhibited by mothers (Moore, 2009; Sturge-Apple, Davies, Cicchetti, & Cummings, 2009) may reflect diminished ability to provide support for dyadic regulation which could, in turn, influence infants’ abilities to modulate their own arousal.

In sum, parent conflict is related to atypical infant physiological regulation, including attenuated vagal response to social stress. Parent conflict may also influence mother and infant contributions to dyadic regulation; thus, effects of parent conflict on infant physiological regulation may be due to impairment of mothers’ and infants’ abilities to engage in effective dyadic regulation. When external regulatory support (dyadic regulation) is unavailable or diminished, infants may over-rely on internal resources. However, no studies have tested this directly.

Measuring Dyadic Regulation

To date, only one study of which we are aware (Moore, 2010) has examined the association between parent conflict and dyadic regulation and found no relation between conflict and dyadic synchrony. Together, other work (Kim & Kochanska, 2012; Moore et al., 2009; Moore, 2010; Pratt, Singer, Kanat-Maymon & Feldman, 2015) has found inconsistent evidence that dyadic synchrony is related to infant vagal regulation. There are likely methodological reasons for inconsistent findings that revolve around issues of measurement of dyadic indices (Harrist & Waugh, 2002); for example, these measures of synchrony typically describe interactions in terms of the correlation between the behavior or affect of mothers and infants (Moore et al., 2013; Feldman, 2003, 2007)**,** and may not capture all aspects of dyadic processes thought to support the development of self-regulatory capacities, including the range of emotions experienced by dyads or how dyads move among affective states. Indeed, researchers have speculated that parent-infant interactions, or dyadic regulation, in which infants experience a range of emotions- and, therefore, have the opportunity to practice and internalize the ability to move among affective states- may optimally support the development of effective self-regulation (Cassidy, 1994).

Dyadic flexibility. Over the first year of life dyadic interactions become more coordinated, synchronous, and predictable (Evans & Porter, 2009); however, states of synchrony or matching are more the exception than the rule. Dyads spend most of their time (80%) in mismatched states (Tronick & Cohn, 1988), during which the infant may be stressed and experience increased arousal or negative affect. The dyads address dysregulation through dyadic regulation, which, if successful, serves to decrease arousal and negative affect. It is thought to be through the successful and repeated reparation of dysregulated states that infants internalize regulatory strategies and learn to independently regulate their behavior and physiology (DiCorcia et al., 2013).

Dyadic flexibility, a comparatively unstudied measure of dyadic regulation that describes movement among and variability in dyadic states, may illustrate these aspects of dyadic regulation not captured by more commonly used measures (Hollenstein, Granic, Stoolmiller, & Snyder, 2004). Using the State Space Grid method (SSG; Hollenstein, 2013), a recent technique that was developed within a dynamic systems framework, dyadic flexibility has been quantified as the range of dyadic states experienced relative to the total range of possible dyadic states (Hollenstein et al., 2004; Lunkenheimer, Olson, Hollenstein, Sameroff, & Winter, 2011). SSG techniques graphically represent the intersection of affective states of both members of a dyad on two separate axis, resulting in a grid that illustrates all possible dyadic states, as depicted in Figure 1 (Granic & Lamey, 2002; Hollenstein, 2007).

A flexible interaction (see left grid in Figure 1) is one in which dyads transition frequently among a wide number of dyadic states without getting “stuck” in a single state. In an inflexible interaction (see right grid in Figure 1), dyads experience a limited range of dyadic states, do not frequently move between different dyadic states, or spend most time in only one or two dyadic states. Dyads that exhibit greater flexibility may be more actively engaged in the mismatch-repair process that characterizes effective dyadic regulation (Tronick, 2005) and may use a wider range of dyadic regulatory strategies than dyads that are less flexible; thus, greater dyadic flexibility may represent more effective dyadic regulation.

Research on dyadic flexibility has largely been focused on middle childhood and found that greater flexibility is related to positive emotional and behavioral outcomes (Hollenstein et al., 2004; Lunkenheimer, Albrecht, & Kemp, 2013; Lunkenheimer, Hollenstein, Wang, &

Shields, 2012; Lunkenheimer et al., 2011). However, research on flexibility during the first year of life is limited. Infants of dyads that were more flexible at 6 months of age were more likely to be classified as securely attached at 15 months of age (Cerezo, Trenado, & Pons-Salvador, 2012). To our knowledge, only two studies have examined dyadic flexibility during the FFSF, and both found that flexibility increases between normal play and reunion episodes (Provenzi, Borgatti, Menozzi, & Montirosso, 2015; Sravish, Tronick, Hollenstein, & Beeghly, 2013). The disruption introduced by the still-face episode requires dyads to work together to regulate infants' arousal and repair the mismatch in their interaction, and this adaptation may be illustrated by an increase in flexibility across the FFSF. By measuring the movement among and range of dyadic states, particularly in the context of a task that disrupts an interaction (e.g., FFSF), dyadic flexibility may illustrate the way in which dyads adapt and re-organize in response to stress. In doing so, flexibility may uniquely quantify aspects of dyadic regulation through which infants internalize the ability to regulate their physiology (Tronick, 2005).

The Current Study

Existing work suggests that parent conflict may influence infant physiological self-regulation through disruptions in dyadic regulatory processes. The overall goal of the current study was to examine whether a novel measure of dyadic regulation, flexibility, would mediate the relation between parent conflict and attenuated infant vagal reactivity to a mild social stressor found in prior research. With the sample used in the current study (Moore, 2010), prior work found that infants in higher conflict families showed attenuated RSA reactivity, i.e., change in RSA during episodes of the FFSF, suggesting they were not physiologically responsive to the change in social conditions. To test whether dyadic flexibility mediated the relation between parent conflict and lesser RSA reactivity, the current study examined: 1) associations between parent conflict and dyadic flexibility; 2) associations between dyadic flexibility and infant RSA reactivity, assessed as RSA in episodes of the FFSF compared with baseline RSA (Perry, Calkins, & Bell, 2015; Stifter & Corey, 2001); and 3) the indirect effect of parent conflict on infant RSA reactivity through dyadic flexibility.

H1. Based on theories that parent conflict may affect the quality of dyadic regulation (Cummings & Davis, 2002), higher levels of parent conflict were expected to be associated with lower flexibility in normal play (H1a) and in reunion (H1b) episodes of the FFSF.

H2. Dyadic regulation is thought to provide support for infant physiological regulation during social interaction and carry-over to conditions in which infants need to engage in self-regulation (Feldman, 2007; Moore & Calkins, 2004). This is reflected in the normative FFSF response, which is RSA augmentation during the normal play and reunion episodes. Therefore, lower levels of flexibility during the normal play episode of the FFSF were expected to be related to lesser RSA reactivity (change in RSA from baseline) in both the normal play and still-face episodes of the FFSF (H2a). Flexibility during the reunion episode likely reflects dyadic regulatory support for infants' recovery from any distress and for repairing the interaction after disruption of the still-face. Therefore, lower levels of flexibility during the reunion episode were expected to be related to lesser RSA reactivity in the reunion only (H2b).

H3. Dyadic flexibility during the normal play episode was expected to mediate the relation between parent conflict and lesser RSA reactivity in the normal place and still-face episodes of the FFSF (H3a). Dyadic flexibility during the reunion episode was expected to mediate the relation between parent conflict and lesser RSA reactivity in the reunion episode (H3b).

Method

Participants

The current study used the sample studied in Moore (2010). Participants (N = 75) were recruited from urban and rural areas in the southeast United States using birth records and flyers at public birth and parenting classes. To participate, mothers must have been married, cohabitating, or had weekly contact with the infants' fathers. The study was approved by the Institutional Review Board at Duke University and informed consent was obtained from all mothers.

The current study used data from 52 mothers and their infants who had valid physiological data for at least one episode of the FFSF (baseline, normal play, still-face, or reunion). A full description of missing physiological data is included below. These 52 infants ranged in age from 6 to 8.5 months (M = 6.8, SD = .67), 39% were female, and 54% were European American. Maternal age (M = 27.87, SD = 5.69) ranged from 21 to 37 years. Thirty-one percent of mothers reported a family income below the poverty line, and of these, 36% were European American and 50% were non-cohabitating. The subsample with complete data did not differ significantly from the complete sample on any demographic variables.

Measures

Parent conflict. Conflict between parents was assessed using Braiker and Kelley's (1979) relationship questionnaire, which mothers completed during the laboratory visit. This measure assesses the overall quality of partner relationships over the past 2 months, and includes Love, Ambivalence, Maintenance, and Conflict subscales. The current study utilized only the 5-item Conflict subscale, which assesses communication of negativity or hostility and overt behavioral conflict. Items included "To what extent did you communicate negative feelings toward your partner (e.g., anger, dissatisfaction, frustration, etc.)?" and "When you and your partner argued, how serious were the problems or arguments?". Possible total scores range from 5 to 45, with individual items scored on a scale of 1 (Not at all) to 9 (Very much).

The validity of this instrument is demonstrated by sensitivity to change in relationship quality across the transition to parenthood and by correlations between husbands' and wives' reports, which ranged from .24 to .62 across all subscales (Belsky, Lang, & Rovine, 1985). Internal consistency in existing research in conflict between parents ranged from .61 to .92 and test-retest reliability of .51 to .81 over a 12 month-period (Belsky & Hsieh, 1998; Belsky et al., 1985). In the current study, the Conflict subscale showed good internal consistency ($\alpha = .76$). Mild to moderate levels of conflict were reported in this sample, with total scores ranging from 5 to 24 (M =15.75, SD = 6.89). The mean and range in the current study is comparable to that found in an independent study using the same measure (Porter et al. 2003).

Procedures

Mothers and their infants came into the laboratory as part of a study on dyadic interactions. Experimenters attached heart rate monitoring equipment (described below) on infants prior to the baseline assessment. Mothers then placed infants in an infant seat and sat in a chair directly in front of the infant seat. Mothers were then given verbal instructions for the FFSF and then asked to sit and review the instructions in written form for 3 minutes while infants' baseline cardiac data were collected.

Face to Face Still-Face. The FFSF (Tronick et al., 1978) was used to elicit infant's physiological and behavioral responses to social engagement and unexpected disengagement. Following a 3-minute baseline episode, mothers were instructed to play with their babies as they normally would (without toys). After the normal play episode, mothers were told to face away from their infants for 15 seconds, and then return back and maintain a neutral expression for the 2-minute still-face episode. Mothers were asked to refrain from responding to their infants in any way during this episode, including vocalization or facial expression. They were assured that the experimenter would discontinue the interaction if the infant became too distressed. Mothers were then instructed to turn away from their infants again for 15 seconds and return to interact with them in whatever manner they chose during the reunion episode without taking infants out of the infant seat. The baseline episode and each episode of the FFSF were video recorded using a split-screen procedure, with one camera recording the mother and one recording the infant.

Mother and infant affective behaviors. Mothers' and infants' behaviors during the FFSF were coded by trained research assistants who were naïve to the hypotheses of the current study. Separate coders were assigned to code mothers' and infants' behaviors. Facial affect was coded as positive, negative, or neutral in 1-second intervals. If mothers' or infants' faces were obscured (e.g., infant turned away, mothers face turned towards the ground), affect was coded as missing. Gaze was coded as away or toward partner in 1-second intervals. Coders were trained to reliability using a large pool of videotaped FFSF interactions from a separate study. A subset of interactions from the current study (15% of full sample) was randomly selected for double coding. Inter-coder reliability between coders was defined as coders observing the same behavior within one second of each other and was quantified using kappa to correct for chance agreement ($\kappa = .89$ for infants, .83 for mothers).

Following prior research (Cohn & Tronick, 1988; Moore et al., 2013) affect and gaze codes were combined to calculate a 6-point social engagement score for mothers and for infants separately at each second of the interaction. A value of 1 was assigned if the individual displayed negative affect and gaze away from partner, 2 if negative affect was displayed and gaze towards partner, 3 if neutral affect and gaze away, 4 if neutral affect and gaze toward, 5 if positive affect and gaze away, and 6 if positive affect and gaze toward. Thus, a social engagement score of 1 indicated the individual was negative and disengaged and a score of 6 indicated the individual was positively engaged at that second. These scaled social engagement scores were used to generate the dyadic states grid because the scaled scores provided a wider range of variability and more information than the affect scores (positive, neutral, negative) alone.

Dyadic flexibility. Consistent with prior research (Hollenstein & Lewis, 2006; Sravish et al., 2013), dispersion, a measure of flexibility, was computed using Gridware software version 1.15 (Lamey, Hollenstein, Lewis, & Granic, 2004). Because we expected flexibility to vary between interactive episodes of the FFSF due the different demands of each episode, separate flexibility variables were created for the normal play and reunion episodes. Gridware employs a graphical approach that uses time series of two observational variables to define a state space for a system (such as a mother-child dyad). Using infants' and parents' social engagement scores (described earlier as ranging from 1 to 6), Gridware was used to generate a 6 x 6 state space matrix for each dyad to represent the intersection of mother and infant social engagement states. Each matrix (see example in Figure 1) was composed of 36 cells with each cell representing a possible dyadic state (e.g., infant=1, mother=1; infant=1, mother=2; infant=1, mother=3, etc.). Following prior work (Hollenstein & Lewis, 2006; Sravish et al., 2013), flexibility was quantified using the measure of dispersion, which was calculated as the squared proportional duration of time spent in all cells, adjusted for the total number of cells and then inverted. Dispersion is a measure of how equally the dyads spent time in all possible states, and has a possible range of 0 (dyad remained in a single cell for the duration of the interaction) to 1 (dyad spent an equal amount of time in each of the 36 cells). Thus, higher dispersion is indicative of higher dyadic flexibility.

Infant cardiac vagal tone. Prior to the baseline episode, the experimenter placed two disposable pediatric electrodes on the infant's chest while the infant was in the seat next to the mother. The electrodes were connected to a preamplifier, which transmitted output to a monitor that collected cardiac interbeat intervals (IBIs; Mini Logger 2000; Mini-Mitter Corp., Bend, OR). A data file containing IBIs for the entire collection period was transferred to a laptop for editing and analysis. Editing was conducted using MXedit software (Delta Biometrics, Inc., Bethesda, MD), and consisted of examining each data file for artifacts (e.g., from infant movement). When outlier points relative to surrounding data were found, they were replaced by dividing or summing them so they were consistent with the adjacent data. Data files that required editing of more than 2% (e.g., 12 outliers in a 5-minute period) were not included in analyses. RSA was calculated using Porges' (1985) method, which applies an algorithm to the IBI data that consists of a moving 21-point polynomial, which detrends periodicities in heart period (HP) slower than RSA. A band-pass filter then extracts the variance of HP within the frequency band of spontaneous respiration in young children (.24 - 1.04). Research with young children has consistently used this frequency band and found associations with child functioning (Moore & Calkins, 2004; (Moore, 2010; Porges et al., 1996; Stifter & Fox, 1990). The final estimate of RSA was computed by taking the natural log of this variance and is reported in units of 1n $(\text{msec})^2$.

RSA was calculated in 30-second epochs for the 3-minute baseline episode and in 15-second epochs for each 2-minute episode of the FFSF. These epoch lengths are typical and valid for parent-infant paradigms of this duration (Bar-Haim et al., 2000). The mean of RSA epochs within each episode (baseline, normal play, still-face, reunion) was calculated and was used for analyses in the current study. Larger values of RSA indicated greater vagal tone.

Missing RSA data. RSA data were available for 52 infants in the baseline condition, 50 in the normal play episode, 51 in the still-face episode, and 48 in the reunion episode. Data were missing due to technical problems, including electrodes falling off ($N = 4$), infants becoming too distressed to complete the FFSF ($N = 6$), or data artifacts that required editing in more than 2% of the episode or were invalid indicated by a standard deviation of greater than 1.00 across epochs, likely due to excessive infant movement ($N = 17$). This amount of missing data is typical of studies with infants (e.g., Calkins, 1997).

Results

Preliminary Analyses

Relations among demographic and study variables. Preliminary analyses were conducted to examine associations among study variables using IBM SPSS for Windows, Version 22.0 (SPSS Inc., 2013). Marital status, years of education completed by the mother, family income, mother age and parity, and infant age, sex, and race were all unrelated to parent conflict and to flexibility during the normal play and reunion episodes. Male infants had higher RSA at baseline, $F(1, 48) = 4.42$, $p < .05$. Infant race and age and mother's age, parity, marital status, income, and level of education were unrelated to infant RSA.

Infant RSA and FFSF behavior. Means and standard deviations for infants' RSA and behavior are reported in Table 1 and associations among infants' RSA and behavior are presented in Table 2. Infant RSA showed moderate to high stability, and infant affect showed low to moderate stability across the FFSF. Infant RSA and behavior were uncorrelated within FFSF episodes.

On average, infants showed the expected behavioral and physiological responses to the FFSF (Table 1). Behavioral and physiological responses followed similar patterns, indicating increased arousal and need to regulate during the still-face episode and recovery in the reunion episode.

Relations among flexibility, infant RSA, and mothers' and infants' FFSF behavior. Consistent with prior research (Provenzi et al., 2015; Sravish et al., 2013), flexibility increased significantly from the normal play to reunion episodes (Table 1), and was only modestly correlated between episodes (Table 2). Dyadic flexibility during the normal play episode was significantly related to baseline infant RSA and RSA in each episode of the FFSF. Flexibility during the reunion was unrelated to infant RSA (Table 2).

To determine the relative contributions of mothers' and infants' affect to the measure of dyadic flexibility, mother and infant positive and negative affect during the normal play and reunion episodes of the FFSF were used to predict dyadic flexibility in the corresponding episode. During the normal play episode, higher infant negative, $\beta = .32$, $p < .01$, and positive affect, $\beta = .33$, $p < .01$, and lower mother positive affect, $\beta = -.35$, $p < .01$ were significantly related to higher flexibility. In the reunion episode, higher infant positive affect, $\beta = .29$, $p < .05$, and lower mother positive affect, $\beta = -.53$, $p < .001$, were significantly related to higher flexibility.

Demographic covariates. Because male infants had greater RSA at baseline, infant sex was added to analyses. Although there were no differences in flexibility or in infant RSA as a function of infant age, prior research (Bar-Haim et al., 2000) has found that older infants have higher baseline RSA than younger infants; therefore, infant age was added to the analyses as a covariate.

Mediation Analyses

H1: Effects of parent conflict on dyadic flexibility. Higher levels of parent conflict were expected to predict lower flexibility during the interactive episodes (normal play and reunion) of the FFSF. Separate linear regression models were conducted in SAS software Version 9.4 of the SAS System for Windows (SAS Institute Inc., 2012) to predict flexibility in the normal play and flexibility in the reunion episode from parent conflict, controlling for infant sex and age. Parent conflict was unrelated to dyadic flexibility during the normal play episode of the FFSF, $\beta = -.01$, $F(2, 278) = .04$, Adj. $R^2 = -.003$. Higher conflict was significantly related lower flexibility during the reunion episode, $\beta = -.12$, $F(2, 260) = 2.85$, Adj. $R^2 = .02$, $p < .05$ (Figure 2).

H2: Effects of dyadic flexibility on infant RSA. Lower levels of flexibility during the normal play episode were expected to be related to lesser RSA reactivity in the normal play and still-face episodes of the FFSF (H2a). Lower levels of flexibility during the reunion episode were expected to be related to lesser RSA reactivity in the reunion only (H2b). Following guidelines for testing multilevel mediation effects (Krull & MacKinnon, 2001), multilevel models were estimated using the PROC MIXED procedure in SAS. The PROC MIXED analytic method is appropriate for repeated measures designs (Little & Rubin, 1989), dealing with missing data, and for small sample sizes (Schafer & Graham, 2002), as it uses all available data. Restricted maximum likelihood (REML) was used in estimating and reporting model parameters. Sex was effect coded as -1 (female) and 1 (male). Because RSA reactivity was the outcome of interest and is typically assessed as level of RSA compared to baseline level (e.g., Perry, Calkins, & Bell, 2015; Stifter & Corey, 2001), reference cell coding was employed such that values for FFSF episodes represented change from baseline. Interaction terms between flexibility and FFSF episode, therefore, tested whether RSA in each episode differed from baseline as a function of flexibility.

The models included the intercept (baseline), FFSF episode (normal play, still-face, reunion), parent conflict, dyadic flexibility during the normal play or reunion episode (separate models), the interactions of FFSF episodes by flexibility, and infant age and sex as covariates. Normal play flexibility was unrelated to infant RSA reactivity. Consistent with prior research (Moore, 2010; Porter et al., 2003), there was a main effect of conflict on RSA, such that higher conflict was related to lower RSA in all episodes of the FFSF. Controlling for covariates and parent conflict, there was a significant interaction between reunion flexibility and reunion episode of the FFSF, $\beta = .22$, $p < .05$ (Table 3), indicating, as expected, that lower flexibility in the reunion episode was related to lesser RSA reactivity; that is, infants of dyads lower in flexibility did not exhibit the expected RSA augmentation in the reunion (Figure 3).

H3: Indirect effects of parent conflict on infant RSA. Because parent conflict was not related to flexibility in the normal play episode, the mediation model was tested only for flexibility during the reunion episode (H3b). Dyadic flexibility during the reunion episode was expected to mediate the relation between higher parent conflict and lesser RSA reactivity in the reunion episode. Although Baron and Kenny's (1986) guidelines have typically been used for testing mediation, recent work has delineated more reliable tests of mediation with multilevel data, particularly with small samples (Bauer, Preacher, & Gil, 2006; Hayes, 2009). Following guidelines for testing mediation with a multilevel outcome variable (Dearing & Hamilton, 2006), the indirect effect of conflict on RSA reactivity was calculated as the product of the parameter estimates of the association between conflict and dyadic flexibility in the reunion (H1b) and between dyadic flexibility and infant RSA reactivity in the reunion (H2b). To test significance of this indirect effect, a Monte Carlo confidence interval was computed using parameter estimates and asymptotic sampling variance (the squared standard errors) from H1b and H2b (Selig & Preacher, 2008). As hypothesized, parent conflict had a significant indirect effect on infant RSA reactivity through its effect on flexibility during reunion, $\mu = .03$, $p < .05$, 95% CI [-.07, -.001].

Discussion

Although recent research (Moore, 2010; Porter et al., 2003) has identified associations between parent conflict and infant vagal functioning, much remains to be known about *how* parent conflict may get under the skin to affect infant vagal regulation. Existing work on parent conflict and adjustment in older children (Cummings & Davies, 2002; Gerard, Krishnakumar, & Buehler, 2006) has adopted a spillover framework in which parent conflict is related to child adjustment through parenting behavior, which may be negatively influenced by conflict-related stress. During infancy, parenting largely takes place in the context of face-to-face dyadic interactions to which both parents and infants contribute, although parent contributions may be necessarily greater during the first year of life (Tronick, 2007). Thus, because stress from parent conflict may be related to the quality of parent-infant interactions, dyadic regulation may be one mechanism by which conflict is related to infant vagal functioning. However, little work has examined associations between parent conflict and dyadic regulation. The current study aimed to examine a novel measure of dyadic regulation, flexibility, in a sample with previously established associations between parent conflict and infant vagal regulation (Moore, 2010).

Consistent with previous research (Moore, 2010; Porter et al., 2003), greater conflict was related to lower RSA across the FFSF, suggesting that these infants had a lesser capacity for self-regulation, independent of the effects of dyadic flexibility. The theory that flexibility would mediate the association between parent conflict and infant RSA reactivity was confirmed, but only for flexibility and RSA reactivity in the reunion episode. Dyads with mothers who reported higher conflict were less flexible during the reunion episode of the FFSF than other dyads, and infants of these dyads showed lesser vagal reactivity in the reunion episode, suggesting that dyadic flexibility may be one mechanism by which parent conflict is related to infant vagal reactivity.

Parent Conflict and Dyadic Regulation

The current study provides initial evidence that parent conflict is related to dyadic regulation. This association may be due, in part, to effects of conflict-related stress on mothers' ability to effectively support dyadic regulation with their infants. Consistent with this theory, parent conflict is related to heightened physiological arousal and regulation (Moore, 2009; Sturge-Apple et al., 2009) and higher mother-reported stress during pregnancy has been associated with less flexible parent-infant interactions (Coburn et al., 2015). Although independent measures of mothers' stress or regulation were not assessed in this study, an examination of mothers' contribution to dyadic flexibility, independent of infant contributions, indicates that the magnitude of mother's support of regulation was greater than infants, specifically during reunion episode. This is consistent with the finding that parent conflict was related to dyadic flexibility during the reunion but not the normal play episode in the current study, which suggests that apparent effects of conflict-related stress may be more likely to spill over during higher-demand, compared with lower-demand, contexts. Mothers' contributions to flexible dyadic regulation may be especially salient in the context of the increased demands of the reunion episode, during which dyadic are tasked with recovering from social stress that may be beyond infants' capacity to navigate independently. To do this, it is often necessary for dyads to make numerous attempts before distress and arousal are attenuated.

Perhaps reflecting this increased demand to adapt, and consistent with recent work (Provenzi et al., 2015; Sravish et al., 2013), the current study found that, on average, flexibility increased from the normal play to reunion episodes. Mothers who require more effort to regulate their own emotions (e.g., those who report high parent conflict) may experience "regulatory burnout" (Muraven & Baumeister, 2000) during the reunion episode which may lead to diminished resources to support infant regulation (Skowron, Cipriano-Essel, Benjamin, Pincus, & Van Ryzin, 2013). Therefore, mothers who experience conflict may have sufficient regulatory resources to support flexible dyadic interaction initially during normal play, but lack additional regulatory resources necessary to respond to increased demands for flexible dyadic regulation during the reunion, during which their contributions may be more important for infant regulation.

Dyadic Flexibility and Infant Vagal Regulation

Dyadic regulation, often indexed as greater synchrony, has been linked to infant behavioral and physiological regulation (e.g., Feldman, 2003; Pratt et al., 2015), although some work has found no relation between dyadic synchrony and vagal regulation (Moore, 2010), or found relations only for infants high in negative emotionality (Kim & Kochanska, 2012; Pratt et al., 2015). Inconsistent findings from research examining links between dyadic regulation and infant vagal functioning may be, in part, due to lack of consistency in measures of dyadic regulation or to using measures of dyadic regulation that do not adequately assess relevant qualities of the interaction. Infants may need to experience a range of emotions and frequent and successful transitions among affective states in order to learn social contingencies and internalize effective regulatory strategies (Cassidy, 1994; Tronick, 2007).

Therefore, the current study examined flexibility, a novel measure of dyadic regulation that illustrates dynamic nonlinear movement among dyadic states and may provide unique information about the dyadic regulatory processes that support infant self-regulation.

As expected, flexibility during the reunion episode predicted infant vagal reactivity in the reunion. While infants in less flexible dyads showed little difference in level of vagal tone compared with baseline, infants in more flexible dyads exhibited significant vagal augmentation during the reunion (Figure 3), suggesting that flexibility is related to more effective vagal regulation in response to social stress. This is consistent with emerging work finding that more frequent reparation, or the rate of movement between matched and mismatched states, during the normal play episode of the FFSF is related to vagal withdrawal during the still-face episode (e.g., Provenzi et al., 2015). Infants typically show vagal augmentation during the reunion episode of the FFSF (Bazhenova et al., 2001; Moore, 2009) suggesting that the resumption of social interaction may help to regulate arousal; thus, the lesser vagal reactivity (less augmentation) exhibited by infants in less flexible dyads may reflect a greater reliance on immature self-regulatory capacities relative to infants in more flexible dyads who, presumably, received greater external support and exhibited the expected vagal augmentation.

Contrary to study hypotheses and to recent work on dyadic reparation (Provenzi et al., 2015), flexibility during the normal play episode of the FFSF was unrelated to infant vagal reactivity in the current study. Greater dyadic flexibility may not be necessary to regulate arousal when dyads are mutually positive, as they typically are during the normal play, consistent with findings that more sensitive interaction may be necessary to achieve infant regulation during distress but not during periods of calm (Conradt & Ablow, 2010; Leerkes, Blankson, & O’Brien, 2009; McElwain & Booth-LaForce, 2006). Thus, during the reunion episode, when infants exhibit greater distress, greater flexibility may be required to adapt, re-organize, and regulate arousal following the disruption presented by the still-face.

In the current study, lower mother positive affect was related to higher dyadic flexibility during the reunion episode, consistent with recent work finding that lower mother positive affect was related to higher mother-infant synchrony (Moore, Quigley, Voegtline, & DiPietro, 2016). Excessive maternal positivity, particularly in the context of infant distress, may impede sensitive responding. Instead, a range of affective responses may be necessary to help infants achieve regulated states. Greater flexibility may indicate ideal levels of sensitivity and attunement (DiCorcia et al., 2013), which may optimally support infant regulation in the context of increased negative affect and arousal. In light of findings suggesting that conflict-related stress may affect mothers' ability to engage in flexible dyadic regulation during challenging interactions (e.g., the reunion episode of the FFSF) more so than during relaxed interactions (e.g., the normal play episode), infants in families with higher parent conflict may face a compounded challenge during the reunion episode: they are tasked with restoring a calm, regulated state but may have to do so with less external regulatory support.

The current study provides initial evidence that greater movement among dyadic states during reunion is related to more effective vagal regulation, reflected in greater vagal augmentation during reunion. Future research should examine movement among matched and mismatched dyadic states across the reunion and relations with infant regulation; this may provide insight into whether more movement among dyadic states in general, as is quantified in the current measure of flexibility, is associated with better outcomes, or whether movement among specific dyadic states best supports infant regulation.

Together, findings that dyadic flexibility mediates previously established associations between parent conflict and infant vagal functioning (Moore, 2010) provides initial evidence that conflict-related stress is related to infant regulatory development through effects on dyadic regulation. Associations between dyadic flexibility and infant vagal reactivity only during the reunion episode highlight the unique information this measure offers regarding co-regulation in the context of increased distress and arousal, which may be particularly salient to the development of self-regulation. Therefore, this study lends new insight into how environmental stressors may influence *external* dyadic regulatory processes that may in turn support infants' *internal* self-regulatory capacities.

Limitations and Future Directions

Due to the cross-sectional nature of the data used in the current study, caution should be used in interpreting the direction of effects. For example, the current study speculated that more flexible dyadic regulation facilitated greater vagal reactivity during the reunion episode of the FFSF. Instead, it may be that infants who exhibit the normative vagal response to the FFSF (greater reactivity) were better able to participate in dyadic regulation following the still-face, facilitating more flexible dyadic regulation during the reunion episode.

Emerging work has found that the association between higher levels of synchrony and greater vagal withdrawal during the still-face episode of the FFSF was stronger for infants higher in negative reactivity (Pratt et al., 2015), suggesting that what constitutes "optimal" dyadic regulation may differ as a function of infant characteristics. The small sample size of the current study precluded the power to examine infant temperament, although dyadic flexibility may be particularly indicative of effective dyadic regulation for dyads with highly reactive infants. Reactive infants may become distressed or excited more easily than less reactive infants, and this may necessitate quicker and more frequent dyadic adaptation in order to regulate infant distress and arousal.

Work on dyadic flexibility with older children has found that greater flexibility is related to adaptive behavioral outcomes only in the context of higher maternal positive affect (Lunkenheimer et al., 2011). Because mothers tend to exhibit only positive or neutral affect during the FFSF, the current study did not allow for the examination of affect-specific effects of flexibility on infant vagal regulation. Future studies should investigate dyadic flexibility in contexts that induce a wider-range of affect for both mothers and infants.

On average, mothers in the current study reported low to moderate levels of parent conflict. Future research should examine relations among more severe parent conflict, dyadic regulation, and infant physiological regulation, as more severe conflict may have direct, as well as indirect, effects on infant regulation. Additionally, particularly because infancy is a sensitive period for the development of physiological systems (Bar-Haim, Marshall, & Fox, 2000), future studies should include measurements of the severity and chronicity of conflict to investigate possible dosage-dependent relationships between conflict, dyadic regulation, and vagal functioning.

Future work should also investigate patterns of sympathetic nervous system (SNS) activation during infancy in relation to later outcomes. Some individuals respond to stress primarily with either the SNS or PNS (SNS or PNS dominant), others respond with coactivation of both the SNS and PNS (Berntson et al., 1994). Work with older children has identified differential behavioral outcomes as a function of activation patterns (Quas et al., 2014), but little research has examined both the SNS and PNS during infancy.

Finally, the theoretical framework guiding this study is that the effects of conflict on later child adjustment may be due to earlier effects of conflict on self-regulatory capacities. Specifically, SNS and PNS functioning during middle childhood may be a vulnerability or protective factor for the development of behavior problems in the context of parent conflict (e.g., El-Sheikh et al., 2013). Future research should examine longitudinal relations between parent conflict during infancy, dyadic regulation, infant regulatory functioning, and child adjustment.

Conclusion

Findings of the current study contribute to existing work on effects of conflict on parent-child interactions and to literature on dyadic regulation. Greater dyadic flexibility during the reunion episode was related to greater vagal augmentation during the reunion episode of the FFSF, relative to baseline levels, suggesting that flexibility is related to more effective regulation during conditions when the dyad is mildly stressed. Future research is now needed to examine whether effects of parent conflict on infant regulatory functioning explain later child adjustment problems.

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Appendix: Tables and Figures

Table 1

Means and Standard Deviations of Infant RSA and Behavior

	Normal Play		Still-Face		Reunion				
Variable	*N*	*M (SD)*	*N*	*M (SD)*	*N*	*M (SD)*	*F*	*df*	η^2
Infant RSA	47	3.61[a] (1.08)	47	3.36[b] (.93)	44	3.59[ab] (1.12)	2.40	2, 42	.15
Infant Positive	69	.25[a] (.21)	68	.05[b] (.05)	67	.24[a] (.18)	38.98**	2, 65	.37
Infant Negative	69	.07[a] (.12)	68	.19[b] (.21)	67	.14[c] (.22)	19.18**	2, 65	.26
Mother Positive	69	.72 (.20)	-	-	67	.66 (.20)	8.55*	1, 66	.12
Mother Negative	69	.00 (.01)	-	-	67	.01 (.03)	11.25*	1, 66	.15
Dyadic Flexibility	70	.77 (.12)	-	-	66	.80 (.08)	5.61*	1, 65	.08

Note. Values with different superscripts within rows differ significantly.
$*p < .01$. $**p < .001$.

Table 2

Correlations among Infant RSA and Behavior

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. BL RSA	-												
2. NP RSA	**.74**	**-**											
3. SF RSA	**.78**	**.76**	**-**										
4. RN RSA	**.68**	**.73**	**.74**	-									
5. % Neg NP	.07	-.04	.30*	.06	-								
6. % Pos NP	.06	.20	-.03	.08	-.16	-							
7. % Neg SF	**.41**	.25	.23	.17	**.55**	.04	-						
8. % Pos SF	-.23	-.10	-.04	-.04	-.05	.10	-.21	-					
9. % Neg RN	.24	.08	.08	-.05	**.46**	.10	**.66**	-.14	-				
10. % Pos RN	-.27	-.26	-.19	-.04	-.07	.14	-.45	-.01	**-.37**	-			
11. Flex NP	**.29**	**.32**	**.49**	**.36**	**.32**	.17	**.30**	-.06	.08	-.17	-		
12. Flex RN	.02	.13	.10	.22	-.07	.10	-.06	-.13	.01	.11	**.29**	-	
13. Conflict	-.19	**-.34**	**-.36**	**-.42**	.04	.10	.10	.09	.13	-.08	-.01	-.16	-

Note. Normal Play = NP; Still-Face = SF; Reunion = RN. Pos = Positive; Neg = Negative.
Bolded values are significant at $p < .05$.

Table 3

H2 Model: Change in Infant RSA as a Function of the FFSF and Flexibility in the Reunion Episode

	Coefficient	SE	*T*	*df*	*p*
			Fixed Effects		
Intercept	4.59	1.93	2.32	43	**.03**
Infant Age	0.05	0.27	0.17	43	.86
Infant Sex	-0.33	0.26	-1.29	43	.20
Parent Conflict	-0.26	0.10	-2.52	43	**.02**
Normal Play	0.12	0.11	1.15	129	.25
Still-Face	-0.16	0.11	-1.49	129	.13
Reunion	0.07	0.11	0.68	129	.49
Reunion Flexibility	-0.04	0.13	-0.28	43	.77
Reunion Flexibility	0.12	0.10	1.25	129	.21
Reunion Flexibility	0.07	0.10	0.71	129	.48
Reunion Flexibility	0.22	0.10	2.17	129	**.03**
			Random Effects		
	Coefficient	*SE*	*Z*		*p*
Intercept	0.66	0.16	4.18		**.00**

Note. Normal Play= NP; Still-Face= SF; Reunion=RN.
Bolded values are significant at $p < .05$

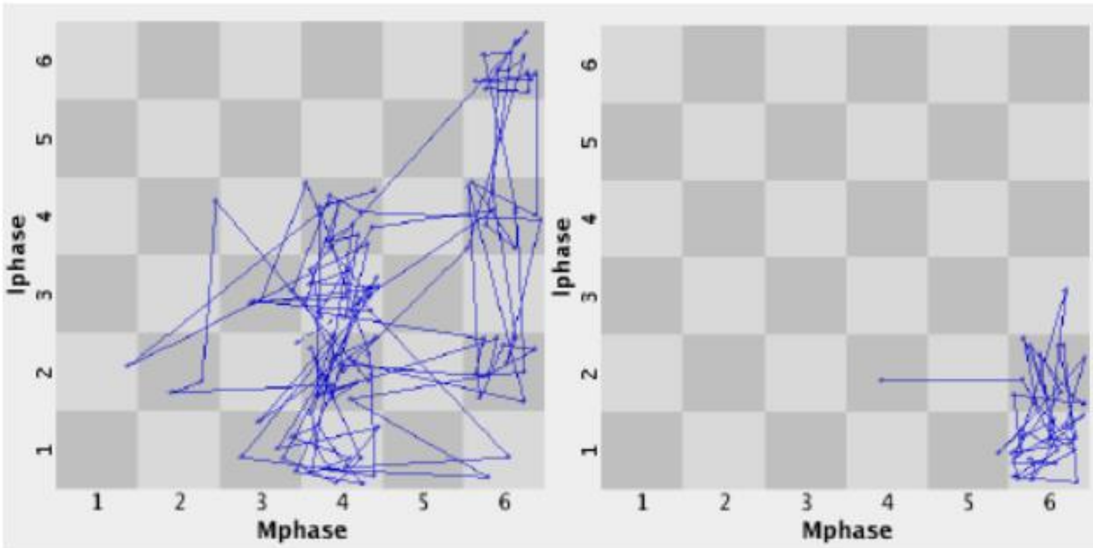

Figure 1. Examples of flexible (left) and rigid (right) interactions on state space grids.

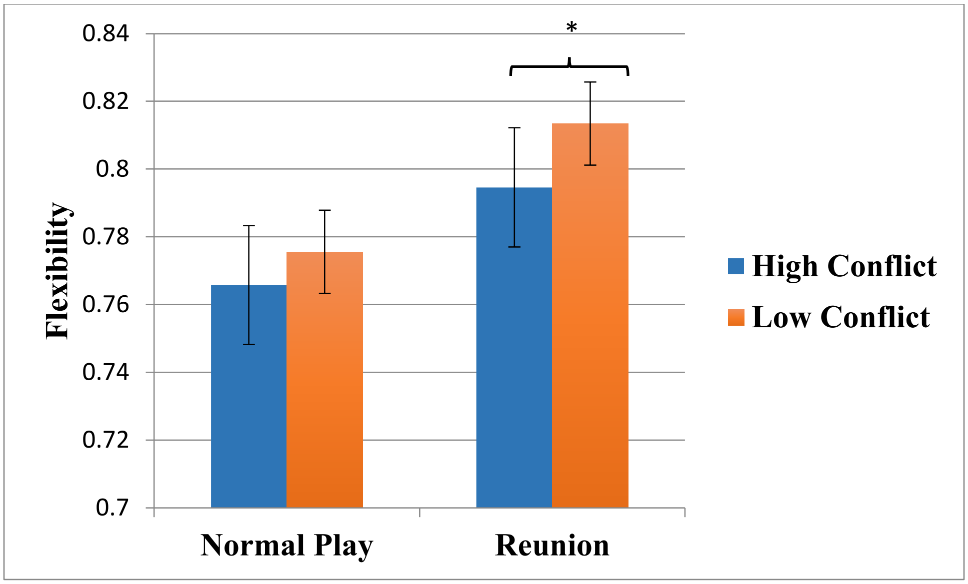

Figure 2. Dyadic flexibility in the normal play and reunion episodes of the FFSF as a function of parent conflict.
* $p < .05$.

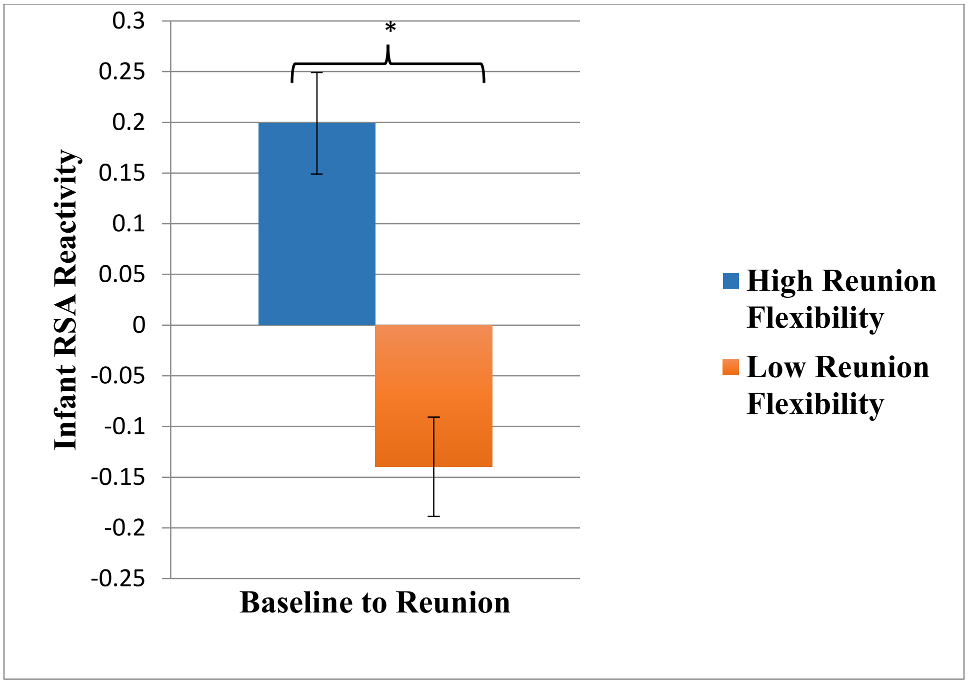

Figure 3. Change in infant RSA from baseline to the reunion episode of the FFSF by dyadic flexibility in the reunion.
* $p < .05$.