Developmental Psychology

ISSN: 0012-1649

2022, Vol. 58, No. 2, 286–296

Dynamic Fluctuations in Maternal Cardiac Vagal Tone Moderate Moment-to-Moment Associations Between Children's Negative Behavior and Maternal Emotional Support

Niyantri Ravindran[1], Nancy L. McElwain[2, 3], Daniel Berry[4], and Laurie Kramer[2, 5]

[1] Department of Human Development and Family Sciences, Texas Tech University
[2] Department of Human Development and Family Studies, University of Illinois at Urbana-Champaign
[3] The Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign
[4] Institute of Child Development, University of Minnesota
[5] Department of Applied Psychology, Northeastern University

Our primary objective was to examine the extent to which moment-to-moment associations between preschool-aged children's behavior and maternal emotional support differed for mothers showing different levels of parasympathetic engagement. We used behavioral observations of maternal and child behavior and maternal changes in cardiac vagal tone assessed via respiratory sinus arrhythmia in 15-s intervals during a 5-min challenging puzzle task (N = 121 dyads; 65 girls, M_{age} = 4.42 years). Results from multilevel models showed that increases in children's defeat (e.g., frustration, task withdrawal) coupled with maternal vagal augmentation (an index of social engagement) in a given 15-s interval predicted increases in maternal support in the next interval, whereas increases in children's defeat coupled with maternal vagal withdrawal (an index of physiological arousal) in a given 15-s interval did not predict increases in maternal support. Findings suggest that vagal augmentation in mothers may operate together with fluctuations in children's negative behaviors to predict supportive parenting in real time.

Keywords: respiratory sinus arrhythmia, emotional support, parent-child interaction, within-person analyses

In early childhood, the ability to focus and persist with a task, remember and follow directions, inhibit impulses, and manage negative emotions are central markers of effective self-regulation ( ). As primary agents of socialization, parents contribute to children's development of self-regulation as they guide and respond to children's ongoing behavior and emotional displays ( ). These processes may be most apparent during exchanges in which parents and children work together to solve problems or master a challenging task. In these contexts, parents work to facilitate children's effective management of negative emotions, development of competence and mastery, and advancement of cognitive skills. Indeed, maternal emotional support (e.g., responding to children's needs in a positive manner, supporting children's autonomy) during problem-solving situations plays a unique role in predicting children's cognitive skills, over and above other parenting behaviors such as cognitive support (;). Maternal emotional support also predicts children's physiological regulation and fewer externalizing symptoms longitudinally ( ). It is important to understand factors that contribute to parents' emotional support during problem-solving interactions, particularly in response to children's expressions of failure and success.

Determinants of parenting behavior involve dynamic changes in both interindividual processes (e.g., behavior of the child toward the parent) and intraindividual processes (e.g., the parent's own physiology;), yet inter- and intraindividual factors have rarely been considered together. Increases or decreases in children's positive or negative behavior may place unique demands on parents, requiring physiological resources to mobilize parents to engage in an appropriate response that is receptive to children's needs in the moment. Thus, the core aim of the present

This article was published Online First January 6, 2022.

Niyantri Ravindran

This study was supported by funding from the United States Department of Agriculture (USDA) National Institute of Food and Agriculture (ILLU-793-362) and the National Science Foundation (SMA-1416971) to Nancy L. McElwain and Daniel Berry. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA, the National Science Foundation, or the academic institutions that the authors are affiliated with. We are grateful to the families who participated in this research. We also thank Andrea Sinele and Jordan Bodway who each played a key role in coordinating and supervising the laboratory visits, Helen Emery and the undergraduate research assistants who assisted with observational coding, and Keri Heilman, Maria Davila, and Xi Chen who assisted with preparing and editing the cardiac data. This study was not preregistered. Data, study materials, and analysis code are available upon request. Preliminary findings from this report were presented at the Society for Research in Child Development in March 2019.

Correspondence concerning this article should be addressed to Niyantri Ravindran, Department of Human Development and Family Sciences, Texas Tech University, 1301 Akron Avenue, Lubbock, TX 9409, United States. Email:

study is to test the extent to which "real-time" associations between child behavior and maternal emotional support varies as a function of maternal parasympathetic engagement. With respect to children's behaviors, we focused on child defeat (e.g., children's expressions of frustration, disappointment, and withdrawal) and agency (e.g., children's expressions of engagement, enthusiasm, and confidence).

Maternal Emotional Support and Respiratory Sinus Arrhythmia

Emotionally supportive parenting requires parents to interpret and respond to children's needs, and likely varies as a function of the way parents experience children's behaviors. Specifically, parental regulation of emotions, attention, and physiology can operate as proximal mechanisms that determine emotional support in the moment (;). A particular physiological response that has been frequently examined in relation to parenting is parasympathetic engagement. The parasympathetic nervous system is responsible for rest and digest functions, but also plays a vital role in affective arousal and social engagement ( ). Cardiac vagal tone is considered an important and well-established biological indicator of parasympathetic regulation and is thought to be indexed by respiratory sinus arrhythmia (RSA)—heart-rate variability occurring at the frequency of spontaneous respiration.

According to polyvagal theory, individuals engage in a process that termed "neuroception" ( ), in which they unconsciously monitor and evaluate environmental challenges and affordances in real time. Based on these evaluations, the myelinated vagus—the Xth cranial nerve—dynamically modulates parasympathetic activity as a means of supporting real-time adaptation to situational demands. In the context of challenge or threat, relaxation of parasympathetic control (i.e., vagal withdrawal) speeds the heart and facilitates sympathetic adjustments necessary for negotiating the challenge. In contrast, in the context of relaxed engagement, polyvagal theory posits that increased parasympathetic activity facilitates flexible attention and positive social affiliative behaviors. With respect to parenting, when a parent perceives their child's behavior to be safe or nonchallenging, the myelinated vagus nerve may increase vagal influence on the parent's heart to slow down cardiac output, which can promote eye contact, listening, social gesture and orientation behaviors, vocalizations, and calming behaviors that promote social engagement and communication (indexed by increases in RSA and referred to as vagal augmentation;). When a parent perceives their child's behavior to be challenging or threatening, the vagus nerve may decrease influence on the parent's heart to increase cardiac output, which is considered an indicator of emotional arousal and mobilization behaviors toward the stressor (indexed by decreases in RSA and referred to as vagal withdrawal;). As such, dynamic changes in RSA can reflect a parent's real-time physiological adaptation to changing demands during parent–child interaction.

Consistent with polyvagal theory, studies examining RSA in adults show that vagal augmentation (i.e., increases in RSA relative to baseline) are associated with greater compassion and the use of cognitive reappraisal (an adaptive emotion regulation strategy) when faced with another's distress (;) and more emotional support when discussing a problem with a romantic partner ( ). Evidence also suggests that vagal augmentation is associated with greater parental support (or less nonsupport) during parent–child interactions. For instance, mothers who displayed vagal augmentation relative to baseline during moderately challenging tasks with their toddler- and preschool-aged children were rated higher on warm, positive parenting behaviors and coordination with their children, and lower on harsh discipline practices during the interaction (; ; ;). Other work has illustrated that mothers tend to show vagal augmentation while watching positively or negatively evocative film clips with their children, yet less so when watching similar clips alone. These augmentation effects were particularly strong when the child showed an indication being upset ( ). In summary, maternal vagal augmentation has been associated with supportive parenting in the context of moderate parenting challenges, particularly with toddler- and preschool-aged children. As such, augmentation has seen as a potential indicator of parents' ability to stay calm in the face of challenging child behaviors and respond in supportive ways that may help counterbalance the child's overarousal.

On the other hand, vagal withdrawal might also play a role in parenting as it may be indicative of parents' ability to regulate arousal that arises during parenting challenges. Studies show that vagal withdrawal during stressful situations or when faced with heightened infant distress (e.g., the still-face paradigm, separations from the child, and audio recordings of infant cries) is associated with more sensitive parenting either in the same or different context (; ; ; ;). Thus, vagal withdrawal appears to be associated with more sensitive parenting in more stressful contexts, although levels of infant distress was not explicitly assessed in these studies. Specifically, these studies examined RSA reactivity and parenting in tasks that elicit high levels of infant distress, which may be distinct from momentary increases in negative behaviors among older children. Parents may perceive infant distress as particularly stressful, and vagal withdrawal may reflect parents' arousal and readiness to respond to the stressor.

Although prior studies have highlighted associations between RSA reactivity and parenting, both maternal RSA and parenting are typically averaged across an interaction task or a series of tasks. Dynamic fluctuations in maternal RSA from moment to moment may reflect physiological flexibility in accord with changing contextual demands. To our knowledge, only one prior study, to date, has investigated associations between dynamic fluctuations in maternal RSA reactivity and parenting in real time with preschool-aged children. Skowron and her colleagues ( ) demonstrated that during a moderately challenging joint puzzle task, greater maternal vagal withdrawal during a given 30-s interval (relative to the mother's average level of RSA across the task) predicted increases in positive parenting toward their preschool-aged children and decreases in negative control in the *next* 30-s interval. This important finding suggests temporal alignment between maternal RSA and maternal behavior. However, these authors did not model temporal relations between maternal and child behavior or the extent to which maternal behavior was contingent on mothers' real-time physiological responses. Momentary increases in children's negative or positive behaviors may require increased physiological engagement or regulation for mothers to respond in a supportive manner. For instance, increases in child defeat may prompt mothers to respond empathically or encourage the child to reengage with the task. Increases in child agency, on the other hand, may prompt mothers to sustain their enthusiasm for the task by reaffirming the child's positive evaluations or responding positively to the child's bids for help. Maternal physiological responses may help them to show increased emotional support on these occasions. Drawing from ,) concept of neuroception, mothers who perceive increases in young children's defeat as challenging may display vagal withdrawal, which may help them regulate their emotional arousal and subsequently respond with increases in emotional support. Alternatively, mothers who perceive child defeat as nonthreatening and stay calm in those moments may show vagal augmentation, which may help them be more attuned to the child's needs and respond supportively. Prior research has shown that vagal withdrawal was associated with more sensitive parenting in distressing contexts, but it remains to be seen whether that would be the case in the context of momentary increases in children's negative behaviors during a moderate challenge, or if vagal augmentation would be more beneficial. With respect to momentary increases in children's positive behaviors, mothers who perceive children's agency as safe or nonthreatening may display vagal augmentation, which may support mothers' ability to engage with children, orient to children's cues, and respond supportively in those moments. Thus, changes in mothers' emotional support following children's momentary increases in negative or positive behaviors may differ as a function of mothers' physiological responses in those moments.

The Current Study

In this study, we examined the extent to which dynamic fluctuations in children's behavior (i.e., defeat and agency) and maternal cardiac vagal tone made interactive contributions to maternal emotional support. Specifically, we examined the moderating role of maternal RSA in real-time associations between child behavior (i.e., defeat and agency) and maternal emotional support. To address these aims, we assessed both maternal RSA and maternal and child behavior as children worked on a challenging puzzle in which mothers could only provide verbal assistance to their child. The task was intended to be frustrating for preschool-aged children but create opportunities for mothers to play a facilitative role. Thus, in addition to providing cognitive instruction to the child, mothers also had to manage the relational and emotional aspects of the situation (e.g., responding to children's negative and positive behaviors), making this an optimal task to examine maternal emotional support. We examined within-person associations (i.e., fluctuations in maternal RSA and maternal/child behavior in a 15-s interval relative to each mother's/child's own mean), which control for all time-invariant factors (e.g., genes, sex, and socioeconomic status;). To assess temporal ordering of child and parent behavior, we examined time-lagged effects (i.e., interaction between child behavior and maternal RSA in the prior 15-s interval as a predictor of maternal emotional support in the subsequent interval).

Given mixed findings on whether vagal augmentation or withdrawal is associated with more supportive parenting during chal-), we had competing hypotheses for child defeat. On the one hand, vagal augmentation in moments when children display increases in defeat may indicate mothers' ability to become engaged, focus on the affective and social demands of the situation, and respond in an emotionally supportive manner. On the other hand, vagal withdrawal may indicate mothers' efforts to regulate their own arousal and frustration in the face of child defeat, resulting in increases in emotional support. Thus, either maternal vagal augmentation or withdrawal may predict increases in maternal emotional support following children's increased defeat. For child agency, we hypothesized that the combination of maternal vagal augmentation and increases in child agency in a given 15-s interval of the challenging puzzle task would predict increases in maternal emotional support in the next interval, as vagal augmentation may promote attunement and orientation to children's positive cues in low-stress contexts, increasing supportive behavior.

Method

Participants

Families were recruited through flyers distributed at local childcare centers and community organizations (e.g., public libraries). Participants were 130 mothers and their preschool-aged children (65 girls) who averaged 4.42 years of age (*SD* = .67 years, range = 3.08–5.83 years). Of the 96 children who had siblings in the home, 77 were first-born, 29 were second-born, and 15 were third- or later-born. Mothers were 91% European American, 2.3% Asian, 1.6% African- American, .8% Native American, and 3.9% identified as other. Eighty-six percent of mothers were married or had partners and 73% of mothers worked outside the home. Three percent of mothers were high school graduates, 14.6% had some college degree, 32.3% had a bachelor's degree, and 42% had an advanced degree. The average household income was between $61,000–$70,000. The study was approved by the Institutional Review Board at the University of Illinois (*Mother-Child Relationships Project*, IRB Protocol#14288). This study was not preregistered.

Of the 130 mother–child dyads who participated in the study, four dyads were missing behavioral data because of missing audio due to technical problems (n = 1) or because the child was off-task for most of the session (n = 3). Additionally, physiological data for five cases were missing due to synchronization issues, frequent loss of signal, an arrhythmia in maternal heart rhythm, outlier values, and/or more than 5% of the data points requiring editing. These dyads were excluded from analyses, resulting in a final sample size of 121 dyads.

Procedure

Time-synced physiological and behavioral data for mothers and children were collected during real-time mother–child interactions during a 90-min laboratory visit. After a brief warm-up period, physiological sensors were attached to mothers and children. Mothers and children completed a 5-min baseline physiological assessment, in which they watched an unstimulating video (i.e., "Spot goes to the farm"). Mother–child dyads also completed a series of interaction tasks, including two 5-min puzzle tasks. Mothdrawal is associated with more supportive parenting during challenging situations (e.g., ;

ries of interaction tasks, including two 5-min puzzle tasks. Mothers and children were presented with two 14-piece Tangram

puzzles (i.e., a dog and a lion; order was counterbalanced across participants) where the level of challenge was beyond what a preschooler was capable of completing independently. Mothers and children were seated across from each other at a child-sized table, with a barrier positioned in the middle of the table. During one puzzle task, the barrier was set low so that the mother could see her child but not the puzzle board or pieces; during the other puzzle task, the barrier was set high so that the mother could not see either her child or the puzzle. The order of the low versus high barrier was counterbalanced across participants. The child was given the puzzle board and pieces, and the mother was given the solution to the puzzle. The mother and child were instructed to try and complete the puzzle in 5 min and to communicate only using words. A large countdown timer was visible to both the mother and the child and signaled the end of the task.

The puzzle tasks were designed specifically to address an objective of the larger study on maternal speech prosody and children's behavioral and physiological regulation. Because our hypotheses focused on maternal responses to children's affective cues, we examined data from the low barrier condition only for the purposes of this report, and we excluded examination of the high barrier condition, in which the mother's view of her child's face and gestures were blocked.

Measures

Maternal Cardiac Vagal Tone

Maternal cardiac data was collected with a wireless three-lead electrocardiogram (ECG) using the Biopac MP150 system (Biopac Systems, Santa Barbara, CA). Interbeat interval (IBI) data were examined for artifacts and outliers using the CardioEdit program) developed by Porges (Brain-Body Center, University of Illinois at Chicago [UIC]). Research staff who edited data were trained by Dr. Keri Heilman (UIC Brain-Body Center) to be reliable in both the number and type of edits made to the IBI data. Forty percent of the maternal IBI data were double-edited and RSA values were computed for each set of edits, with the acceptable standard for inclusion in the analyses being that the absolute difference in the RSA values between the two edited files was $\leq .05$. In cases where the difference between the two edited files was greater than .05 ($n = 4$), a consensus file was created by both editors editing the case together. RSA scores were computed from the IBI data using the Porges-Bohrer algorithm ( ), using a 250 ms sampling rate (respiratory frequency band = .12–.40 Hz). Within the puzzle task with the low barrier, RSA data were segmented into 15-s intervals and calculated for each interval. Fifteen-second epochs have been used and validated by prior research to calculate RSA in adults using the Porges-Bohrer algorithm during brief duration tasks (e.g., ;).

Observed Mother and Child Behavior

From digital video recordings of the puzzle task, independent teams of trained and reliable coders assessed maternal and child behaviors. For the purpose this report, we examined maternal emo-) into a microcoding system for shorter intervals of time. Behaviors were rated in 15-s intervals because such intervals were long enough to rate on a continuum the quality of maternal or child behavior yet brief enough to capture relatively rapid moment-to-moment change in behavior as it unfolded across real time. Coders were blind to all other study data. Intervals were synchronized in time across mother and child behaviors using Datavyu ( ), a computerized video coding tool.

Following previous research that has rated maternal support during a challenging puzzle task with preschool-aged children (e.g., ;), our maternal emotional support code consisted of several discrete parenting behaviors that have each been associated with positive child outcomes. We elected to do this because we were interested in capturing mothers' tendency to be supportive toward the child in general, following increases in both negative and positive child behaviors, and because each discrete behavior was occurred too infrequently to be examined separately. Examples of the maternal emotional support code include praising or encouraging the child's efforts, responding positively to the child's bids, validating the child's affect, supporting the child's autonomy, or engaging the child in the task. Coders rated maternal emotional support on a 4-point rating scale for each 15-s interval, ranging from 0 (*not at all characteristic*) to 3 (*very characteristic*). Single-measure intraclass correlations (ICCs), utilized to assess interobserver agreement and calculated on 22% of the protocols by two independent raters, was .65. ICC values above .60 are considered adequate (see).

A separate team of coders rated child negative affect (e.g., frowning, whining, and frustrated tones), child defeat (e.g., statements or facial expressions indicating uncertainty or lack of confidence in one's ability to do the task, physical or verbal withdrawal from the task), and child agency (e.g., expressing confidence in one's ability to do the task or enthusiasm for the task, desire for autonomy, requesting the mother's help with the task) on 4-point scales for each 15-s interval, ranging from 0 (*not at all characteristic*) to 3 (*very characteristic*). Twenty-two percent of the protocols were double-coded, and the scales showed good interobserver reliability (Single-measure ICCs = .71, .76, and .71 for child negative affect, defeat, and agency, respectively). Child negative affect and defeat were positively correlated both within intervals ($r = .42$, $p < .001$) and on average ($r = .81$, $p < .001$). Because the two constructs are conceptually similar (i.e., affective or behavioral indicators of frustration or withdrawal), ratings of child negative affect and defeat were summed within each 15-s interval, with higher scores indicating more defeat (possible range = 0 to 6).

Data Analytic Strategy

To address the moderating role of maternal RSA in moment-to-moment associations between children's behavior and maternal emotional support, two multilevel models (one model examining child defeat and one model examining child agency) were tested using M*plus* Version 8.1 ( ). Because maternal emotional support was rated as discrete, rather than continuous, values (0, 1, 2, or 3), it was treated as an ordinal tional support and child defeat and agency. These codes were adapted from a global rating system developed for the NICHD study of Early Child Care and Youth Development to assess mother–child interactions during the preschool period (

outcome in both models. Specific intervals (ranging from 1–8) for eight dyads were excluded from analyses because of an interruption (e.g., bathroom break; $n = 1$), because the child was off-task ($n = 4$), or because the child completed the puzzle before the timer

went off ($n = 3$). In the case of interruptions due to a bathroom break, behavioral and physiological data following the interruption were coded as missing. The total number of intervals in the main models was 2217. Child defeat was negatively skewed, and we used a robust full-information maximum likelihood (FIML) estimator to account for both missing data and nonnormality. FIML utilizes all data available and, given the assumption that missing data are conditionally random after accounting for the other variables included in the observed variance matrix (i.e., Missing at Random, MAR), provides estimates unbiased by missingness (see ;).

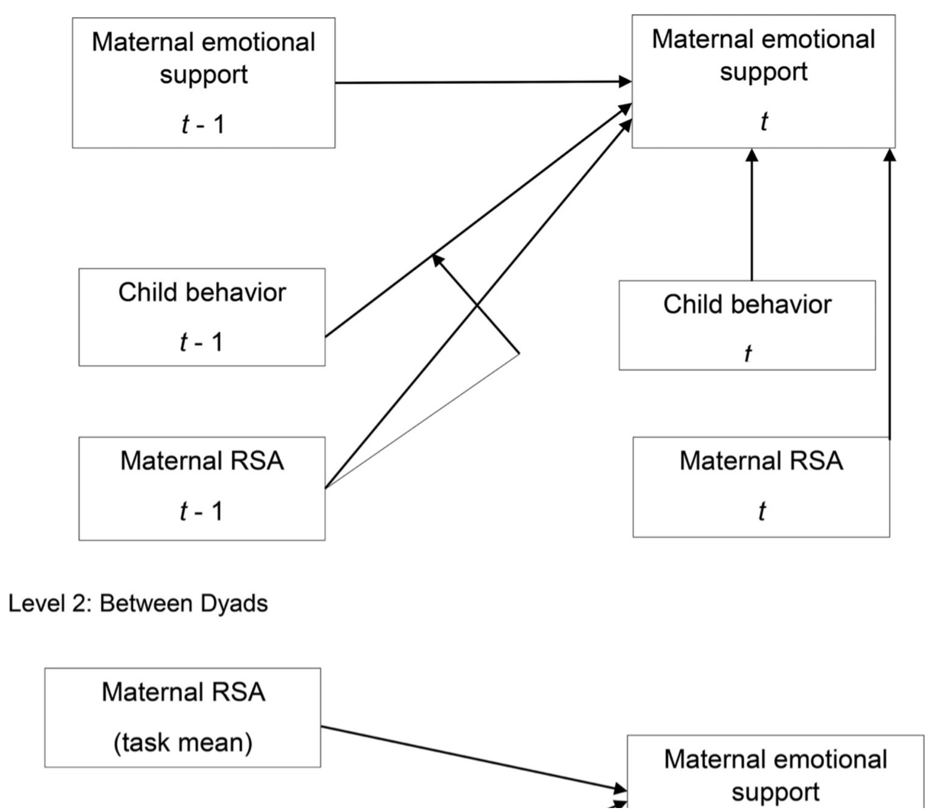
The Level 1 (within-person) equation of our model is as follows (see for an exemplar model):

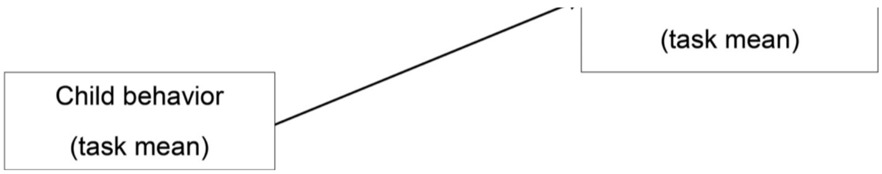
$$\text{Maternal emotional support}_{it} =$$

$$\beta_{0i} + \beta_{1i}(\text{WP maternal emotional support}_{t-1}) + \beta_{2i}(\text{WP child behavior}_{t}) + \beta_{3i}(\text{WP maternal RSA}_{t})$$
$$+ \beta_{4i}(\text{WP child behavior}_{t-1}) + \beta_{5i}(\text{WP maternal RSA}_{t-1}) + \beta_{6i}(\text{WP child behavior}_{t-1} \text{ x WP maternal RSA}_{t-1}) + e_{it}$$

Here, our primary interests concern the lagged regression parameters, β_{4i} *child behavior*$_{t-1}$, β_{5i} *maternal RSA*$_{t-1}$, and β_{6i} *Child Behavior*$_{t-1}$ × *Maternal RSA*$_{t-1}$, where the interaction term represents the extent to which the lagged relation between children's behavior and their mothers' subsequent emotional support varies as a function of lagged maternal RSA. The e_{it} parameter represents time-specific within-person variation unaccounted for by the model. Statistically significant interaction terms were probed using tests of model constraints. Additionally, to provide a clearer picture of the actual data underlying the interaction, we plotted associations between child behavior and maternal emotional support at conditional values of maternal RSA (i.e., ± at least one within-person *SD* above and below the mean). All time-varying predictors were person-mean centered to disaggregate within-individual variation from between-person variation.

Figure 1
Exemplar Multilevel Model of Child Behavior and Maternal Respiratory Sinus Arrhythmia (RSA) as Predictors of Maternal Emotional Support





With respect to within-person control covariates, we adjusted for autoregressive effects (i.e., moment-to-moment stability) in maternal emotional support. Contemporaneous levels of maternal RSA (β_{3i}) and child behavior (β_{2i}) were also adjusted, to disaggregate these relations from the lagged relations. We also tested the contemporaneous interaction (i.e., Child Behavior$_t$ × Maternal RSA$_t$ predicting maternal emotional support$_t$) but it was statistically nonsignificant, so we limited our controls to main effects for parsimony. Similarly, because alternative specifications indicated that the within-person relations did not vary randomly across mothers/dyads, they remain fixed in all reported models.

The Level 2 (between-person) equation of our model is specified as:

$$\beta_{0i} = \gamma_{00} + \gamma_{10}\ (\text{BP child behavior}) + \gamma_{20}\ (\text{BP maternal RSA}) + u_{0i}$$

Here, maternal emotional support was regressed on mean levels of child behavior and maternal RSA averaged across the task. The between-person parameter, u_{0i}, allows mothers' intercepts to vary randomly between mothers. Level 2 predictors were centered at the grand mean. The data, study materials, and analysis code are available upon request.

Results

Descriptive statistics and correlations for all variables of interest are reported in . Between-person (mean) scores were used to compute descriptive statistics. We also conducted descriptive statistics by interval for all time-varying variables to evaluate the level of variability across the 20 intervals during the task. Sixty-five percent of children showed close to the full possible range in child defeat across the task (0–5 or 0–6). Seventy percent of children showed the full range (0–3) for child agency across the task, and 100% of mothers displayed the full range (0–3) for maternal emotional support. Thus, both mothers and children showed a good amount of within-person fluctuation in behaviors across the task. As shown in , child defeat and agency were negatively associated both on average and within 15-s intervals, although within-person correlations are weaker because both behaviors rarely occurred within the same 15-s interval. Maternal emotional support and child agency were positively associated within intervals. Maternal emotional support and child defeat were positively associated both on average and within intervals. Higher average levels of child defeat were also associated with higher average levels of maternal RSA across the puzzle task.

Main Model Tests

To assess the moderating role of maternal RSA in the respective associations between child behavior and maternal emotional support, two multilevel models were tested: one model examined child defeat, and the other examined child agency. Parameter estimates are reported in .

Child Defeat

To address our first research question, we tested the within-person interaction between lagged child defeat and maternal RSA on maternal emotional support. This interaction was statistically significant (β_{6i} = 114, *SE* = .06, *p* = .045; see Model 1,). We display this interaction in , where high RSA (i.e., vagal augmentation) and low RSA (i.e., vagal withdrawal) are delineated as intervals in which maternal RSA is ±1 within-person *SD* from mothers' person mean (.63 and −.63, respectively). Additionally, we plotted the relation between lagged child defeat and maternal emotional support at high (.63 or greater) and low (−.63 or lower) values of maternal RSA, to demonstrate the underlying interaction in our data (see).

As indicated by the displayed simple slopes (see) and conditional scatter plots ( ), intervals of heightened child defeat were predictive of increased maternal emotional support in the next interval. However, this was evident only to the extent to which mothers showed moderate (β_{6i} = .106, *SE* = .05, *p* = .049) to high levels (β_{6i} = .177, *SE* = .069, *p* = .01) of vagal augmentation in the context of their child's defeat. In contrast, child defeat in a given interval was unrelated to maternal emotional support in the next interval when mothers displayed vagal withdrawal (i.e., 1 *SD* below one's mean RSA) in the prior interval (β_{6i} = .034, *SE* = .06, *p* = .568; see). We note that, as expected, the coverage of observations at the tails of distributions were less concentrated than their respective means (see

Table 1
Descriptive Statistics and Correlations Among Study Variables (N = 121)

Study variables	1	2	3	4
Maternal emotional support	—	.01	.29***	.08***
Maternal RSA	.02	—	−.03	.03
Child defeat	.45***	.19*	—	−.13***

Child agency	.07	−.11	−.34**	—
M (*SD*)	1.00 (.36)	5.90 (.94)	.43 (.51)	.54 (.28)
Range	.30–2	2.71−8.08	.00−3	.00−1.3
Range of means across intervals	.88–1.16	5.79−6.01	.12–.68	.44–.64
Range of *SD*s across intervals	.74–1.01	.98–1.15	.44–1.22	.59–.81

Note. RSA = respiratory sinus arrhythmia. Between-person correlations are reported below the diagonal, and within-person correlations (i.e., correlations within a given 15-s interval across the 20 intervals) are reported above the diagonal. Within-person correlations were obtained by assessing correlations between person-mean centered variables, and between-person correlations were obtained by assessing correlations between averages across the entire task.
* $p < .05$. ** $p < .01$.

Table 2

Interactive Contributions of Within-Person Fluctuations in Child Defeat or Agency and Maternal RSA to Maternal Emotional Support (N = 121)

	Model 1: Child Defeat		Model 2: Child Agency	
Model paths	Est (*SE*)	*p*	Est (*SE*)	*p*
Within-person (Level 1) paths				
Maternal emotional support $_{t\text{-}1}$ → maternal emotional support$_t$	−.063 (.06)	.251	.003 (.05)	.951
Child behavior$_t$ → maternal emotional support$_t$	.631 (.06)	<.001	.234 (.06)	<.001
Mom RSA$_t$ → maternal emotional support$_t$	.034 (.07)	.626	.011 (.08)	.888
Child behavior$_{t\text{-}1}$ → maternal emotional support$_t$	.106 (.05)	.049	−.003 (06)	.957
Mom RSA$_{t\text{-}1}$ → maternal emotional support$_t$	.065 (.07)	.319	.040 (.06)	.512
Child Behavior$_{t\text{-}1}$ × Mom RSA$_{t\text{-}1}$ → maternal emotional support$_t$	.114 (.06)	.045	−.014 (.10)	.885
Between-person (Level 2) paths				
Child behavior (task mean)	.739 (.18)	<.001	.095 (.29)	.743
Maternal RSA (task mean)	−.055 (.07)	.399	.032 (.07)	.663

Note. RSA = respiratory sinus arrhythmia.

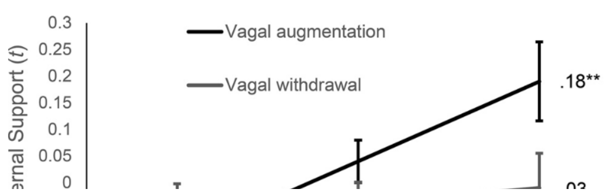
). Although our focus was on the within-person lagged interaction, we also note that higher levels of child defeat (relative to the child's mean) in a given interval were associated with higher levels of maternal emotional support within the same interval (β_{2i} = .631, *SE* = .06, $p < .001$). The autoregressive effect for maternal emotional support as well as concurrent and lagged effects of maternal RSA on maternal emotional support were statistically nonsignificant. At Level 2, paralleling the correlational findings, higher levels of child defeat at Level 2 predicted higher levels of maternal emotional support (γ_{10} = .739, *SE* = .18, $p <$ .001); however, maternal RSA did not predict maternal emotional support.

Child Agency

To address our second research question, we tested the within-person interaction of lagged child agency and maternal RSA on maternal emotional support. This interaction was statistically nonsignificant (see Model 2 in). The main effect of lagged child agency was statistically nonsignificant, as were the concurrent and lagged effects of maternal RSA. However, higher levels of child agency (relative to the child's mean) in a given interval was associated with higher levels of maternal emotional support within the same interval (β_{2i} = .234, *SE* = .06, $p < .001$). Similar to Model 1, the autoregressive effect of maternal emotional support was statistically nonsignificant. At Level 2, child mean agency and maternal mean RSA did not predict maternal emotional support.

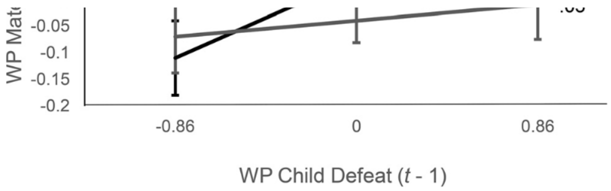
Figure 2

Time-Lagged Associations Between Within-Child Defeat in the Prior Interval and Within-Mother Emotional Support in the Next Interval as a Function of Within-Mother Changes in RSA in the Prior Interval



Discussion

Parental emotional support during problem-solving situations plays an important role in the development of young children's self-regulation, social adjustment, and cognitive abilities (; ; ;). Yet, we have limited knowledge about the factors that predict parents' emotional support in real time. Both contextual processes such as child behavior as well as internal physiological processes may influence parenting in the moment ( ). We examined the extent to which increases in children's defeat and agency predicts momentary fluctuations in mothers' emotional support as a function of dynamic fluctuations in maternal cardiac vagal tone during a problem-solving task. For child defeat, we had two competing hypotheses – that mothers would show increases in emotional support following increases in child defeat if they displayed vagal withdrawal, or if they displayed



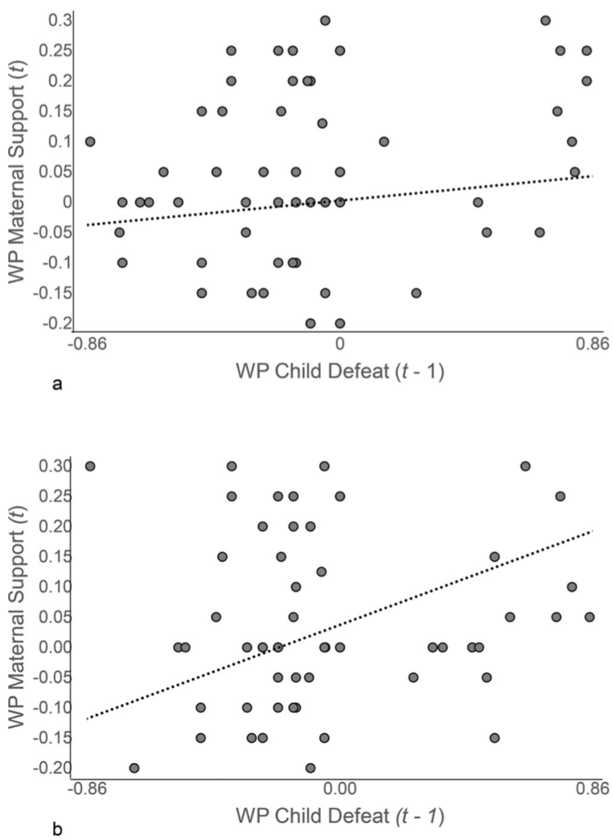
Note. WP = within-person; RSA = respiratory sinus arrhythmia; Vagal augmentation = 1 *SD* above mothers' person mean; vagal withdrawal = 1 *SD* below mothers' person mean. Error bars indicate ±1 *SE* from each point.
** $p < .01$.

vagal augmentation. Our finding supports the latter hypothesis, showing that mothers displayed increases in emotional support following increases in children's defeat if they maintained stability or showed increases in RSA (i.e., vagal augmentation), but not if they displayed decreases in RSA (i.e., vagal withdrawal). For child agency, we hypothesized that mothers would show increases in emotional support following increases in child agency if they displayed vagal augmentation, but this hypothesis was not supported. We first discuss the model examining child defeat, followed by a discussion of the model examining child agency.

Our findings indicate that in moments when children display increases in defeat, mothers who maintained stability in RSA (i.e.,

Figure 3

Relation Between Child Defeat in the Prior Interval (t − 1) and Maternal Emotional Support in the Next Interval (t) When Maternal RSA in Interval t Is (3a) One Within-Person SD (.63) Below the Mean or Lower, and (3b) One Within-Person SD (.63) Above the Mean or Higher



Note. The lines represent the best fit line that expresses this relation in the observed data. Child defeat and maternal emotional support are person-mean centered. WP = within-person; RSA = respiratory sinus arrhythmia.

staying at their mean level) or vagal augmentation showed greater

;), it is possible that in moments when children show increases in defeat, maintaining stability in RSA or increasing RSA indicates that mothers managed their negative emotional arousal (if present) more effectively by reframing the situation as nonthreatening and experienced greater compassion and empathy toward their child. Indeed, experiencing greater empathic emotions and adopting child-centered goals, rather than focusing on modulating one's own distress, are important precursors of emotionally supportive caregiving following children's distress (;).

It is important to note that the puzzle task was designed to elicit moderate levels of negative emotion in children, and this represents a significant difference from stressful tasks that have been used in prior studies (e.g., still-face, separation tasks, and audio recordings of infant cries) that have shown maternal vagal withdrawal to be adaptive for sensitive caregiving (; ; ;). These tasks also do not have a social interaction component, which may place different demands on parents, such as managing their own arousal in observing their children's distress rather than trying to help their children regulate. Additionally, these prior studies focused on mothers of infants. Preschool-aged children likely communicate discontent or defeat verbally (e.g., "I do not want to play this game anymore") and/or exhibit lower levels of distress than infants (e.g., frowning or whining vs. prolonged crying), which may prompt less arousal and require less physiological regulation from parents. Thus, in moments when preschool-aged children show minor increases in frustration or disappointment, maintaining stability in one's RSA or vagal augmentation may help mothers respond with greater emotional support. This interpretation is consistent with studies showing that maternal vagal augmentation is associated with more supportive caregiving behaviors during moderate interactive challenges with toddler- and preschool-aged children (; ; ; but see , for an exception). Notably, by examining within-person associations between these constructs, we extend prior research that has predominantly examined individual differences in maternal parasympathetic physiology. In addition to methodological advantages of maximizing statistical power and treating each dyad as its own control, this places our inferences at the level of analysis in which development is arguably unfolding (i.e., within individuals vs. between individuals; ;).

In contrast to mothers who displayed vagal augmentation, mothmaternal emotional support subsequently. As ,) polyvagal theory suggests, momentary increases in child defeat may present social or interpersonal demands on mothers, requiring greater physiological engagement on those occasions. When children show increases in defeat, maintaining or increasing RSA may indicate that mothers were able to remain calm, counterbalance their child's arousal and orient to their children's affective cues, thereby enabling mothers to increase their level of emotional support. Consistent with this interpretation, mothers showed greater vagal augmentation in a negative emotion-eliciting context if they perceived their children to be experiencing higher anxiety ( ). Given that vagal augmentation has been associated with more adaptive emotion regulation (i.e., reframing the situation) and compassion when faced with another's distress (

In contrast to mothers who displayed vagal augmentation, mothers who showed vagal withdrawal in moments when children displayed increased defeat did not show subsequent increases in maternal emotional support. Based on concept of "neuroception," individuals subconsciously evaluate risk in the environment that determines their physiological response. Mothers who displayed vagal withdrawal may have evaluated children's displays of increased defeat to be challenging or even threatening, and experienced difficulty in managing their own negative emotional arousal in those moments, resulting in a lack of increased emotional support. On the other hand, studies showed that vagal withdrawal was associated with sensitive caregiving in the context of high infant negativity only for insecurely-attached dyads ( ), and that maternal vagal withdrawal in a given 30-s interval of a challenging task was associated with