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An event-based analysis of maternal physiological reactivity following aversive child behaviors

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Abstract
Research investigating the association between parents' physiological reactivity and their ability to self-regulate in parenting contexts typically examines the average physiological response across the duration of a dyadic task, conflating reactivity across a multitude of parent and child behaviors. The present study utilized a moving-window analytical technique to generate a continuous, second × second time series of mothers' high-frequency heart rate variability (HF-HRV) to conduct an event-based analysis of maternal reactivity in the 10 s following an aversive child event. Analyses examined whether maternal reactivity related to parenting behaviors similarly among maltreating ($n = 48$) and non-maltreating ($n = 29$) mother-preschooler dyads. Results indicate that maternal behavior was not associated with average HF-HRV reactivity, but mothers who demonstrated an increase in HF-HRV immediately following a negative child event were more likely to engage in behaviors to return the dyad to a positive state. Findings were specific to incidents of negative child behavior, and results were not moderated by maltreatment status. These results highlight the value of using an event-based design to isolate reactivity in response to targeted events to understand how physiological reactivity supports parenting.

KEYWORDS
heart rate variability, methods, parenting, self-regulation, respiratory sinus arrhythmia, RSA reactivity

1 | INTRODUCTION

Research has demonstrated that supportive parental interactions are critical in scaffolding children's development of emotion regulation skills (Laible et al., 2015; Maccoby, 2015; Morris et al., 2007), benefiting children's social, academic, and mental health outcomes (Côté-Lecaldare et al., 2016; Repetti et al., 2002). Conversely, negative parenting practices that impede the development of children's emotion regulation increase children's risk of internalizing and externalizing problems, as well as poor social relationships with peers (see Scaramella & Leve, 2004). Efforts to characterize critical parenting behaviors have focused on micro-coded dyadic exchanges as parents and children navigate a challenging task together in order to understand how parents respond behaviorally to aversive child behaviors. This work highlights the importance of parents' ability to regulate their own negative emotions in supporting their ability to respond to negative child behaviors effectively (Forgatch & Patterson, 2010; Skowron, 2015). More recently, research has begun to examine how parents' ability to regulate their own physiological arousal in the context of parent–child interactions relates to parents' ability to respond supportively to aversive child behaviors. Measures of high-frequency heart rate variability (HF-HRV), often associated with parasympathetic regulation of cardiac arousal, are frequently examined as an index of physiological reactivity and regulation. However, methodological differences in the measurement of behavioral and physiological variables typically results in comparing these variables on markedly different time scales. Specifically, parenting behavior is often examined on an event-level, wherein a parental response is identified at the moment following a given child behavior, whereas physiological variables are typically examined as an aggregate measure across the duration of an interaction. Utilizing a technique for examining HF-HRV on a second × second-level resolution (Gates, 2018; Gates et al., 2015), the present study examines whether event-level physiological reactivity, which captures parental responding to discrete episodes of aversive child behavior, predicts individual differences in parental behaviors that promote dyadic functioning.

1.1 | Parent–child dyadic dynamics

Parenting is one component of the parent–child relationship, which transpires across repeated transactional exchanges. The ability for each partner to shape the other was well illustrated by Patterson and colleagues, who found that families with children high in externalizing behaviors were often characterized by cycles of coercive exchanges in which aversive behavior by one member of the dyad is met with a more aversive response, leading to an escalation in the negativity of the exchange until one partner relents (Forgatch & Patterson, 2010). This work illustrates the importance of moving beyond broad characterizations of parenting behaviors as trait-like individual differences and considering how discrete parenting behaviors emerge in the course of a dynamic interaction.

Parents contribute to positive dyadic exchanges by providing warmth and affirmation of the child in ways that support the child's autonomy. Sustained periods of mutual positivity between parent and child, particularly with a high degree of support for children's autonomy, establish strong emotional bonds, and serve as a model for adaptive social interactions (Leclere et al., 2014). Achieving states of mutual positivity also requires the dyad to respond appropriately to negative behaviors that occasionally "rupture" the positive connection (Harrist & Waugh, 2002). For instance, a mutually positive interaction in which the parent and child are playing can be disrupted if the child becomes frustrated or angry. Adaptive parent–child dyadic functioning is marked by the ability to recover from an aversive event and return to a state of mutual positivity or coordination (Jameson et al., 1997; Skowron et al., 2010), which supports children's development of emotional self-regulation (Kemp et al., 2016; Scholtes et al., 2021). Repairing dyadic ruptures reinforces the value of social bonds and the importance of reconciliation, as well as modeling de-escalation and establishing skills for responding to negative feelings and actions to reduce emotional distress.

Among preschool-aged parent–child dyads, negative emotional ruptures are common in response to transitions or changing demands, such as the parent asking the child to clean up, or shift to a new activity (Granic & Patterson, 2006; Harrist & Waugh, 2002; Lunkenheimer et al., 2016). Although it is typical for children to initiate ruptures more often, the burden of repair is likely to fall disproportionately to the parent (Jameson et al., 1997; Tronick, 2003). The inequitable distribution of this burden can be taxing for parents, and research indicates that mothers whose own regulation abilities are challenged (e.g., depression) are less likely to demonstrate these types of dyadic repair behaviors (Jameson et al., 1997). Similarly, mothers with a history of maltreatment may engage in more relationship ruptures and demonstrate fewer repairs, which can result in the child taking on the potentially overwhelming burden of relational repair (Skowron et al., 2010). Thus, it is important to examine how parental regulatory capacity in the context of aversive child behavior relates to the ability of parents to engage in warm and affirming actions, as well as repair ruptures in dyadic coordination.

1.2 | Parental regulatory capacity

Frustration is typically associated with an increase in physiological arousal that supports active behavioral responding to confront and overcome the situational challenge (Carver & Harmon-Jones, 2009; Herrald & Tomaka, 2002). However, such an increase in arousal may be counterproductive in the context of parenting if it results in behavior that is harsh or coercively controlling. Thus, how parents respond physiologically to children's aversive behaviors may provide insight into the mechanisms by which parents regulate arousal in the service of adaptive dyadic functioning. Physiological reactivity mediated by the parasympathetic nervous system has been posited to reflect an adaptive and regulated means of responding to situational challenges (Beauchaine & Thayer, 2015; Porges, 2001). The parasympathetic system exerts an inhibitory influence on heart rate, which varies across the respiratory cycle. As such, parasympathetic influence is often quantified by examining the extent to which heart rate varies as a function of respiratory frequency (i.e., high-frequency heart rate variability (HRV)). Increases in parasympathetic input slow heart rate and reduce physiological arousal, whereas decreases in parasympathetic input increase heart rate and physiological arousal. Research findings have been somewhat mixed with regard to whether adaptive responses to challenge are associated with increases or decreases in HF-HRV. Some studies have reported associations between HF-HRV decreases (i.e., withdrawal) from baseline to cognitive and affective challenges and better performance and affect regulation (see Beauchaine, 2001). However, other studies have found that patterns of increasing HF-HRV (i.e., activation) are more adaptive when the challenge situation involves an interpersonal context (Skowron et al., 2013; Smith et al., 2020).

Studies that have examined parasympathetic reactivity specifically in parent samples have also produced mixed evidence. For instance, one study found that mothers who demonstrated significantly greater initial increases in heart rate from baseline to the sound of infant crying showed more sensitivity when interacting with their toddler, and the heart rate increase appeared to be mediated by a reduction in parasympathetic influence (Joosen, Mesman, Bakermans-Kranenburg, Pieper, et al., 2013). In contrast, another study found a significant correlation between higher RSA during a moderate challenge task and lower levels of maternal negativity toward their child (Miller et al., 2015). This study further found that during a highly challenging task, mothers who displayed autonomic co-activation, defined as concurrent increases in both sympathetic and parasympathetic activation from baseline to the task, showed lower levels of maternal negativity. It is possible that increases in parasympathetic arousal are adaptive in challenging contexts in an effort to counteract the effect of sympathetic activation, effectively stabilizing the overall level of physiological arousal (Gatzke-Kopp et al., 2020).

Moreover, the behavioral implications of increasing or decreasing HF-HRV may not just be a function of the situational demands but also of the individual themselves. Research has shown that decreases in HF-HRV are associated with different patterns of parental behavior among maltreating and non-maltreating mothers (Skowron et al., 2013). In epochs in which mothers' HF-HRV was lower relative to their own average, there was a concurrent increase in positive parenting behaviors. However, among maltreating mothers there was an increase in hostile control in the subsequent epoch, suggesting that the association between physiological reactivity and parenting behavior may be moderated by maternal characteristics. This is consistent with the idea that parasympathetic cardiac regulation reflects a degree of cortical-autonomic integration in support of goal-directed behavior (Smith et al., 2017), the behavioral manifestation of which will be moderated by individual differences in goal selection. Parents who engage in maltreating behaviors often possess maladaptive cognitive schemas that prevent them from establishing compassion and selecting supportive responses to the child (Seng & Prinz, 2008). Thus, we examine whether parents' physiological reactivity to challenging child behaviors may be associated with parenting competence in different ways among mothers with and without a history of maltreatment.

1.3 | Event-based physiological arousal

Researchers have postulated that inconsistent findings across studies could also be a function of different timescales of measurement. In a recent review, Davis et al. (2020) examine the importance of temporal context for examining psychophysiological indices of regulation, pointing out that dynamic patterns of responding may better capture this process than average levels of HF-HRV across a task. Parasympathetic cardiac regulation has been shown to operate more rapidly than sympathetic innervation and is proposed to underlie rapid dynamic changes in cardiac reactivity in order to meet cognitive and affective demands (Smith et al., 2017). However, because HF-HRV reflects the amount of power in the respiratory frequency band, it is necessary to estimate it over a duration sufficient to observe multiple repetitions of the respiratory cycle, typically from no less than 30 s of data (Berntson et al., 2007). As such, many studies have compared average HF-HRV levels over the course of a parent–child interaction task with average HF-HRV levels during rest in order to quantify reactivity. This approach, however, presumes that the task represents a static level of challenge and that the average level of HF-HRV is reflective of the activity over the course of the task, which often lasts several minutes.

One study sought to examine more nuanced dynamics by estimating HF-HRV in a series of 30-s epochs across a 3-min task in which mothers helped their preschool-aged child complete a challenging puzzle task. Results indicated that dyads that maintained higher positive behavioral synchrony were characterized by an initial decrease in maternal HF-HRV in the first 30 s epoch relative to baseline, followed by a steady increase in HF-HRV across the subsequent epochs (Giuliano et al., 2015). The authors interpret this pattern to suggest that mothers initially orient to the challenge of the task, but then shift to increasing HF-HRV to enable them to serve as social support for their child, illustrating that adaptive parenting may be characterized by both decreases and increases in HF-HRV (Giuliano et al., 2015). Although this illustrates how a task average may obscure dynamic phenomena, examining HF-HRV dynamics as a linear sequence of epochs still does not provide specific insight into how parents respond acutely to discrete events of challenging child behavior. How dyadic interactions unfold is inevitably variable across dyads, with emotionally salient events (e.g., child non-compliance, sulking, withdrawal) happening at different frequencies and at different points of the interaction for different dyads. In other words, comparing all parents' HF-HRV across an interaction task, or any arbitrarily defined moment of that task, fails to account for the inherent variability in task demands which cannot be experimentally controlled (e.g. child's spontaneous behavior). What is needed, therefore, is an event-based framework for examining maternal HF-HRV reactivity *in the moment* following her child's negative behavior, at whatever moment that occurred for that dyad.

Although standard procedures for estimating HF-HRV require a minimum of 30 s of data, actual parasympathetic activation alters heart rate on a much more rapid time scale, acting within a single beat following a stimulus (Somsen et al., 2004). Recently, efforts have been made to estimate RSA on a second × second timescale, in order to capture dynamic changes at the level of temporal resolution the physiological phenomenon actually occurs by applying a short-time Fourier transform and a moving window approach (Gates et al., 2015). Although this approach continues to rely on longer epochs of data, the resultant time series reflects significant dynamic variability in HF-HRV. Using a comparable analytical approach, researchers have demonstrated the ability to detect changes in HF-HRV time series associated with a discrete event (postural change from sitting to standing) (Martinmaki et al., 2006). Research has further demonstrated that dyadic concordance of the resultant dynamic time series is more related to individual and dyadic features than concordance of aggregate HF-HRV in both parent–child (Creavy et al., 2020) and parent–parent samples (Gates et al., 2015). In addition, research has found that parent–child concordance of dynamic HF-HRV varied by dynamic changes in negative emotional intensity of a film stimulus, providing validation that second × second HF-HRV estimates can capture physiological changes coupled with rapid situational shifts (Ravindran et al., 2021).

The ability to estimate HF-HRV on the resolution of seconds allows researchers to examine the nature of maternal physiological reactivity in the precise moments following an aversive child behavior, to better understand how physiological arousal relates to regulatory capacity and parenting behavior. Thus, in the current study, we explored mothers' second × second HF-HRV responses to their child's negative behavior in order to examine the emotion-regulatory challenges parents face during the difficult moments of parent–child interaction. Specifically, we evaluated whether maternal RSA showed an immediate increasing or decreasing slope across the 10 s following the child's behavior. We then examined whether the direction or extent of HF-HRV reactivity in this context is predictive of two types of positive parenting behaviors (1) overall maternal warmth that contributes to establishing mutually positive exchanges- measured as the proportion of maternal behavior that was supportive and affirming, and (2) maternal contributions to returning to a mutually positive state following a dyadic rupture. We specifically examined both event-related reactivity and average maternal HF-HRV to determine whether HF-HRV measured at these different timescales had similar or distinct associations with behavior. We hypothesized that an increasing HF-HRV slope would reflect greater prefrontal cortical engagement that facilitated effective goal-directed behavior. Among non-maltreating parents, we hypothesize that this would manifest as maternal warmth and relational focus. We further examine whether mothers with a maltreating history (a) engage in less positive parenting behavior due to a tendency to decrease HF-HRV following a negative child behavior (main effect of maltreatment status and HF-HRV reactivity), or (b) fail to demonstrate positive parenting behavior despite an increase in HF-HRV (moderation of an association between HF-HRV reactivity and maternal behavior by maltreatment status). Finally, given evidence that parents' parasympathetic responses to positive child behaviors (e.g., prosocial compliance) may also differentiate mothers at risk for maltreatment (Wells et al., 2020), we examine the specificity of these hypotheses by also assessing maternal HF-HRV reactivity in response to a positive child behavior during the task.

2 | METHOD

2.1 | Participants

A total of 222 mothers with children between the ages of 3–5 were enrolled in a study of how dyadic interactions relate to children's emerging regulatory skills. All mothers were over the age of 18, spoke fluent English, and resided with their child. Recruitment targeted mothers with a Child Protective Services documented history of perpetrating child maltreatment, as well as dyads without such history but who were socio-demographically similar to the maltreatment group. Among the 222 mothers, physiological data were collected from 161 during the child interaction task. For the present analyses, $n = 77$ mothers had data meeting the analysis criteria. Criteria are detailed further in the behavioral coding subsection, but briefly, 76 of the 161 dyads were excluded from the current analyses because the child did not display a qualifying negative and positive behavior. Additionally, 8 mothers did not have sufficient usable physiological data surrounding both the negative and positive behaviors to support the windowing-based estimation of second × second HF-HRV (e.g., the event happened at the very beginning or end of the task or the cardiac data were contaminated by movement). Compared to the 84 mothers who were excluded from the current analyses, the 77 included mothers were, on average, younger $t\,(158) = -3.74$, $p < .01$, and accordingly had younger children participating in the study with them, $t\,(159) = -2.45$, $p = .02$. The included families were also more likely than the excluded families to have an annual income lower than $30,000, $\chi^2\,(1, N = 161) = 6.94$, $p < .01$. However, the included and excluded families did not differ in child sex, maternal race (Caucasian or minority/multiracial), or maternal education (whether they had obtained a degree above high school). Excluded families also did not differ with regard to having a maltreatment history generally, the severity of maltreatment perpetrated, or a classification of physical abuse specifically. Dyads with a classification of emotional maltreatment were more likely to be included in the present analyses.

Mother's average age for the final sample ($n = 77$) was 28.36 years ($SD = 5.71$); 96% of mothers were Caucasian, 78% had no more than a high school degree, and 77% had incomes at or below $30,000 per year. Children's average age was 3.65 years ($SD = 0.70$), 51% were female, and 82% were Caucasian. Twenty-nine mothers in the included sample had no history of perpetrating child maltreatment, and the remaining 48 mothers had a documented history of perpetrating child maltreatment, including physical abuse ($n = 5$), physical neglect ($n = 24$), emotional abuse ($n = 7$), and involvement with Child and Youth Services without a specific maltreatment classification ($n = 12$). Table 1 presents the descriptive statistics and comparisons between the maltreatment and non-maltreatment groups. There were no significant differences in mothers' age, children's age and sex, or annual income between maltreating and non-maltreating families. However, mothers in the maltreatment group were less likely to have obtained

TABLE 1 Descriptions of and comparisons between families with and without a history of maltreatment

	***M* (*SD*)**			
Variable	**Non-maltreatment (*n* = 29)**	**Maltreatment (*n* = 48)**	***t***	***p***
1. Mother age	29.41 (5.51)	27.73 (5.80)	1.27	.21
2. Child age	3.76 (0.74)	3.58 (0.68)	1.04	.30
3. Child proportion of negative behavior	13% (15%)	12% (11%)	0.35	.73
4. Maternal proportion of affirmation	17% (11%)	11% (8%)	2.24	.03
5. Number of dyadic ruptures	3.83 (2.09)	4.48 (2.53)	−1.11	.23
6. Number of mother-initiated repairs	1.62 (1.15)	1.23 (1.10)	1.48	.15
7. Maternal task average HF-HRV	5.96 (1.03)	5.70 (1.41)	0.92	.36
8. Maternal HF-HRV intercept (N)	0.16 (1.30)	−0.10 (1.55)	0.78	.44
9. Maternal HF-HRV slope (N)	0.01 (0.05)	−0.01 (0.05)	1.85	.07
10. Maternal HF-HRV intercept (P)	0.22 (0.94)	−0.13 (1.60)	1.24	.22
11. Maternal HF-HRV slope (P)	0.0004 (0.05)	−0.0003 (0.06)	0.06	.95
	***n* (%)**	***n* (%)**	χ^2	***p***
12. Child sex			1.75	.19
Female	18 (62%)	21 (44%)		
Male	11 (38%)	27 (56%)		
13. Mother education			11.95	<.01
High school or below	16 (55%)	44 (92%)		
Above high school	13 (45%)	4 (8%)		
14. Family annual income			3.08	.08
At or below $30,000	19 (66%)	41 (85%)		
Above $30,000	10 (34%)	7 (15%)		

Note: (N) indicates HF-HRV measurements were taken following a negative child speaking turn, (P) indicates HF-HRV measurements were taken following a positive child speaking turn. The last two columns present the *t*-test or χ^2 test that compares the two groups on each variable.

Abbreviation: HF-HRV, high-frequency heart rate variability.

a degree above high school. All the statistics presented below are based on the final analysis sample.

2.2 | Procedure

Mothers and children completed three assessments in a 2- to 3-week timeframe comprised of two home visits and a 2.5-h laboratory session. Only the lab procedures related to the current report are summarized. Upon arrival to the lab and following informed consent procedures, mothers and children were fitted with electrodes for physiological data collection and first participated in a 5-min resting baseline period seated on a comfortable couch with the lights dimmed while viewing a neutral video. The dyads then completed a series of interactive tasks consisting of the preschool strange situation and two moderately challenging joint puzzle tasks, before a snack break and transition to a series of individual child and parent activities for the remainder of the visit. The current analyses focus on the second joint puzzle task (i.e., Duplo task), the more challenging of the two, designed to present the child with a challenging situation in which they must cooperate with parent instructions to accomplish a goal. The dyad was seated together at a small table and presented with a pile of Duplo Blocks and shown an assembled model that they were instructed to replicate, along with 12 disassembled blocks to construct the replica. Mothers were instructed to assist their child in building the replica but were told not to physically touch any of the block pieces. The task was 3–5 min length and ended when the child successfully recreated the model and a minimum of 3 min had transpired or the 5-min maximum time period was reached regardless of whether the replica had been built. Families were paid $150 as compensation for their time, and received transportation, snacks, and small children's toys/gifts. All procedures were approved by an Institutional Review Board.

2.3 | Observational coding

Videos were transcribed and unitized to document each "speech act" of mother and child, comprised of verbal, nonverbal and paralinguistics (e.g., smiling at mother, frowning at child, distinguishing warm guidance from harsh guidance or criticism). The beginning of each transcribed element was additionally identified by the exact time. Together with videotapes, the transcripts were coded by trained research assistants using the Structural Analysis of Social Behavior (SASB; Benjamin, 1974, 1996; Benjamin & Cushing, 2000). SASB coding involves three steps whereby each of the following is determined for each speaking turn: focus (dichotomously coded as other or self), degree of affiliation (ranging from −9, i.e., hostile, to 9, i.e., loving), and degree of autonomy (ranging from −9, i.e., control/submit, to 9, i.e., autonomy-granting) to assign one of eight prototypical parenting behaviors and one of eight typical child-like behaviors distributed across the circumplex shown in Figure 1 (Skowron et al., 2013). Interrater reliability was calculated on 15% of the full sample, with weighted kappas ranging from .73 to .84 for the task examined here. These values are on par with those reported in other studies of SASB-coded parent–child interactions (e.g., Florsheim et al., 1996; Skowron et al., 2010).

For inclusion in the current study, a child had to have had at least one positive behavior directed toward the mother that was trusting/relying in nature (SASB cluster 2–4), and at least one negative behavior toward the mother that was

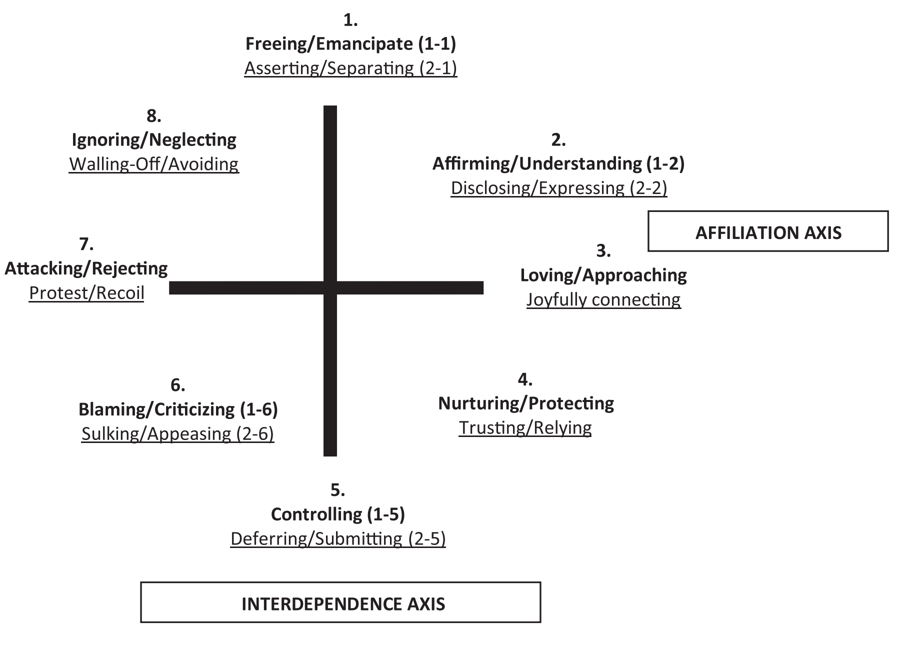

FIGURE 1 The structural analysis of social behavior (SASB) simplified cluster model

characterized as hostile submission, i.e., sulking or whining, (SASB cluster 2–6). To standardize the number of events analyzed across dyads, one positive, and one negative child behavior were selected for each dyad. For dyads in which more than one of these behaviors was present, the selection was guided by the following: (1) only the child behaviors around which sufficient maternal physiology was available were considered; (2) when there were multiple occurrences of child positive behaviors, the one (if any) that occurred before the negative behavior was selected, so as to avoid potential lingering effects of child negative behaviors; (3) there had to be a minimum of 10 s between the selected positive and negative behaviors, to avoid overlap of physiological estimation. If meeting all the criteria above, the first positive or negative child behavior to happen during the interaction was selected. Of the 161 dyads considered for this study, 77 met the criteria for having both a positive behavior and a negative behavior with sufficient maternal physiological data.

In addition to identifying individual events for the examination of HF-HRV trajectories, summary data were extracted to characterize the dyadic interaction.

2.3.1 | Proportion of child negative behavior

Proportion of child negative behavior was calculated as the number of child speaking turns with a SASB code of 2–6 (i.e., hostile submission) divided by the total number of child speaking turns directed to the mother during the interaction. In the analysis sample, the proportion of child negative behaviors ranged from 1% to 76% (M = 13%, SD = 12%), and did not differ significantly between the maltreatment and non-maltreatment groups (see Table 1).

2.3.2 | Proportion of maternal affirmation

Proportion of maternal affirmation was calculated as the number of maternal speaking turns with a SASB code of 1–2 (i.e., warm and autonomy-in-connection behaviors directed at the child) divided by the total number of maternal speaking turns directed at the child across the full duration of the interaction. In the current sample, the proportion of maternal affirmation ranged from 0–38% (M = 13%, SD = 9%). Mothers in the maltreatment group showed lower proportions of affirmation, than did non-maltreatment mothers (see Table 1).

2.3.3 | Number of dyadic ruptures

Ruptures are defined as instances in which positive dyadic synchrony [i.e., the dyad has established a minimum sequence of three reciprocal positive behaviors (mother–child–mother; child–mother–child)] is then disrupted by an instance of negative behavior. The total rupture score was computed as the number of ruptures during the interaction regardless of whether they were initiated by mother or child. Dyads demonstrated between 0–13 rupture events (M = 4.23, SD = 2.38) during their interaction, and there was no significant difference in the number of ruptures between the two groups (see Table 1).

2.3.4 | Number of mother-initiated repairs

A mother-initiated repair is defined as a sequence of 3 reciprocal positive behaviors led by the mother (mother–child–mother) that follows a dyadic rupture, reflecting a mother-initiated return to positive dyadic synchrony. The number of mother-initiated repairs ranged from 0 to 5 in the current sample (M = 1.38, SD = 1.12). Dyads in the non-maltreatment group showed more mother-initiated repairs, although the group difference was not statistically significant (see Table 1).

2.4 | Maternal HF-HRV

Disposable Ag/AgCl electrodes were placed on mothers' chests in a modified Lead II placement, on the right clavicle, lower left rib cage, and lower right rib cage. Electrocardiogram (ECG) data were acquired using Mindware Technologies ambulatory electrocardiograph MW1000A at a sampling rate of 500 Hz. ECG data were transmitted via a wireless signal to a computer, and the signal was synchronized with video recordings of behavior to allow for time-synchronized coding of ECG and behavioral data.

ECG data were processed offline using Mindware's HRV (v. 3.0–3.0.15) software. Trained RAs inspected cardiac waves and corrected any misidentified R peaks. Although not examined here, impedance cardiography data were available for approximately 2/3 of the sample. When impedance data were available, it was used to estimate respiratory frequency and ensure that peak maternal respiration frequency fell within the respiratory frequency band. After data were cleaned in Mindware, the raw inter-beat interval time series was exported and processed using the RSAseconds program available freely for download (Gates, 2018; Gates et al., 2015). The RSAseconds program uses a combination of two techniques, peak-matched multiple windows (PM MW) and a short-time Fourier transform (STFT), to produce estimates of HF-HRV at every second using a rolling 32-s window. The point estimate of HF-HRV is generated for the central second- and thus includes 16 s of data before and after the focal time point (Gates et al., 2015).

Peak-matched multiple windows technique is a multi-tapering algorithm that applies a series of tapers (tapering is the weighting of each time period of interest to maximally weight the range of data with the most observable information) to a spectral analysis that ultimately provides a single estimate within the frequency band of interest. The short-time Fourier transform refers to the calculation of sliding discrete Fourier transforms (which compute the power of heart rate variability in the respiratory frequency, 0.12–0.40 Hz, that is, the estimate used to calculate adult HF-HRV) across overlapping epochs of data across the entire task. The sum of the squared power estimates obtained in the STFT ultimately provides a series of time-varying HF-HRV estimates. Compared to a traditional epoch approach, where epoch 1 would result in an HF-HRV estimate for seconds 1–30 and epoch 2 would result in an HF-HRV estimate for seconds 31–60, the current approach results in an HF-HRV estimate extracted from seconds 1–32, an estimate extracted from seconds 2–33, and so on. Because the estimation for each second is based on the data surrounding it, no estimate of HF-HRV can be produced for the initial or final 16 s of the task. Using this approach, research has demonstrated concurrent correlations between dynamic child HF-HRV and dynamic ratings of emotional intensity in a film stimulus, indicating that the focal tapering is effective at capturing rapid transitions in HF-HRV and that a lagged analysis procedure is not necessary (Ravindran et al., 2021).

2.4.1 | Maternal event-specific HF-HRV

The resultant HF-HRV timeseries was then aligned with a variable denoting task time in order to align second × second HF-HRV with the time-stamped behavioral coding generated from the video. The time stamp for which the target behavior was recorded was then identified, and the subsequent 10 s of HF-HRV data were extracted. That is, each dyad had 10 repeated measures of second × second HF-HRV following a negative behavior and another 10 repeated measures following a positive behavior, which were later used to model mothers' event-specific HF-HRV trajectories.

2.4.2 | Maternal task average HF-HRV

In addition to the second × second HF-HRV following child behaviors, maternal HF-HRV during the puzzle task was also output in non-overlapping 30-s segments, from which an average level of task HF-HRV was computed. The average HF-HRV in the analysis sample was $M = 5.80$, $SD = 1.28$, and ranged from 1.90 to 9.21, suggesting substantial between-person differences in mothers' average parasympathetic activation across the task. No significant difference was found in mothers' task average HF-HRV between the maltreatment and the non-maltreatment groups (see Table 1).

2.5 | Data analysis

We first estimated the trajectories of maternal HF-HRV following specific child behaviors using a multilevel model specified as below. Maternal HF-HRV trajectories following the positive and the negative child behavior were examined in two separate models.

Level 1: $\text{Maternal HF}-\text{HRV}_{it} = \beta_{0i} + \beta_{1i}\left(\text{Time}_{it}\right) + e_{it}$.

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}; \beta_{1i} = \gamma_{10} + u_{1i}$.

For each model, at the within-person level (level 1), the repeated measures of maternal second × second HF-HRV following the child behavior for mother i at second t were modeled as a function of intercept (β_{0i}), time (β_{1i}), and residual (e_{it}). Time was coded as 0 to 9 corresponding to the 10 s since the onset of the child behavior. Thus, in the simultaneous modeling of between-person differences (level 2), γ_{00} represents the sample-average maternal HF-HRV at the onset of the child behavior (i.e., HF-HRV intercept), and γ_{10} represents the sample-average linear changes in HF-HRV afterward (i.e., HF-HRV slope). Accordingly, the random components u_{0i} and u_{1i}, respectively, represent the HF-HRV intercept and slope for each mother and were extracted and examined in the analyses below.

Independent sample t-tests were conducted to examine whether dyads with a history of maltreatment differed from those with no maltreatment history in the behavioral and HF-HRV measures (Table 1). Correlation analyses describing the associations among these variables were also conducted (Table 2). Finally, the hypotheses were tested using two separate linear regression models predicting the proportion of maternal affirming behaviors (model 1) and the number of mother-initiated repairs (model 2). In step 1, maltreatment status (coded as 0 for non-maltreatment group and 1 for maltreatment group), task average HF-HRV, HF-HRV intercept, and slope following the negative child behavior, along with covariates were entered as predictors. In step 2, the interaction term between maltreatment status and HF-HRV slope was entered to examine whether maltreatment status moderates the association between mothers' HF-HRV reactivity to negative child behavior and their behaviors during the task. All variables were centered around sample mean before being entered into the model. Two additional models were run to examine maternal HF-HRV slope following the positive child behavior.

Maternal age was entered as a covariate for all models, given its association with mothers' task average HF-HRV,

TABLE 2 Bivariate correlations among measures across the full sample ($N = 77$)

Variable	1	2	3	4	5	6	7	8	9	10
1. Maternal age	–									
2. Child age	.03	–								
3. Child proportion of negative behavior	−.02	−.04	–							
4. Maternal proportion of affirmation	.29*	.29*	−.23*	–						
5. Number of ruptures	−.04	−.04	−.25*	.02	–					
6. Number of mother-initiated repairs	.00	.12	.02	.14	.39***	–				
7. Maternal task average HF-HRV	−.30**	−.14	−.16	−.10	−.18	.01	–			
8. Maternal HF-HRV intercept (N)	−.31**	.02	−.22	.05	−.19	−.04	.73***	–		
9. Maternal HF-HRV slope (N)	.16	.00	.09	.08	.04	.32**	.04	−.09	–	
10. Maternal HF-HRV intercept (P)	−.30**	−.02	−.16	−.01	−.15	.06	.84***	.73***	.15	–
11. Maternal HF-HRV slope (P)	.07	.05	.04	.04	.05	−.02	−.17	−.01	−.17	−.27*

Note: (N) indicates HF-HRV measurements were taken following a negative child speaking turn, (P) indicates HF-HRV measurements were taken following a positive child speaking turn.

Abbreviation: HF-HRV, high-frequency heart rate variability.

*$p < .05$; **$p < .01$; ***$p < .001$.

HF-HRV intercepts, and affirming behaviors (see Table 2). Child age was also correlated with maternal affirming behaviors, but was not a significant predictor of affirming behaviors when included in the regression model together with maternal age, and was therefore not included in the final models. Child sex was considered as a covariate but was not included as it was not significantly correlated with any of the focal variables. Given the goal of examining how mothers' physiological regulation relates to their ability to engage in positive behaviors or to repair ruptures, we also controlled for variabilities in children's behaviors or dyadic negativity during the task. Specifically, the total number of child negative behaviors during the task was included as a covariate in the model predicting maternal affirmation, and the total number of dyadic ruptures was included as a covariate in the model predicting mother-initiated repairs. All analyses were conducted in R (R Core Team, 2016), and the multilevel model estimating HF-HRV trajectories were fit using the *nlme* package (version 3.1–148; Pinheiro et al., 2017). Statistical significance was evaluated at $\alpha = 0.05$, and bootstrapped confidence intervals of regression coefficients were provided.

3 | RESULTS

3.1 | Maternal event-specific RSA trajectories

Using a multi-level model framework, we first examined whether there was statistically meaningful variation in individuals' HF-HRV slopes. Results indicate that mothers, on average, had an HF-HRV level of 5.24 at the onset of the negative child behavior (i.e., γ_{00}, $SE = 0.17$, $p < .01$, suggesting that this level was significantly different from 0), but did not show a significant linear change in HF-HRV afterward ($\gamma_{10} = 0.0006$, $SE = 0.01$, $p = .91$). However, estimates of the random components showed that there were significant between-person differences in mothers' HF-HRV intercepts ($\sigma_{u_{0i}} = 1.46$, 95% CI = [1.25, 1.71]) and slopes ($\sigma_{u_{1i}} = 0.05$, 95% CI = [0.04, 0.06]) following the negative child behavior. The same model incorporating second × second HF-HRV following the positive child behavior returned similar results. The sample average HF-HRV level was 5.26 at the onset of the positive child behavior (i.e., γ_{00}, $SE = 0.16$, $p < .01$) with no significant sample average linear changes in HF-HRV ($\gamma_{10} = -0.0005$, $SE = 0.01$, $p = .93$). As with the previous model however, there were significant between-person differences in mothers' HF-HRV intercepts ($\sigma_{u_{0i}} = 1.39$, 95% CI = [1.19, 1.63]) and slopes ($\sigma_{u_{1i}} = 0.06$, 95% CI = [0.05, 0.07]) following the positive child behavior. These results provided support for further examining how individual differences in mothers' event-specific HF-HRV intercepts and slopes were associated with other between-person variables.

We next examined whether individuals' HF-HRV intercepts and slopes varied as a function of maltreatment status, and how these event-related metrics compared with task-average HF-HRV. Table 1 reports maternal HF-HRV by maltreatment status. Task-average HF-HRV levels did not differ significantly by group. Intercept values were, on average, lower for maltreating mothers compared to non-maltreating mothers, although the differences between the groups were not significant. No group differences in maternal HF-HRV slope emerged for the positive child event. Although non-maltreating mothers had an average of increasing HF-HRV following the negative child event and maltreating mothers had an average of decreasing HF-HRV, this difference failed to reach significance ($p = .07$).

3.2 | Bivariate correlations

Prior to the main analytical models, we examined the bivariate correlations among variables (presented in Table 2). Older mothers and mothers of older children demonstrated higher proportions of affirmative behavior, but neither mother nor child age correlated with other behavioral measures. Not surprisingly, maternal affirmation was lower, and there were more dyadic ruptures among dyads where the proportion of child negative behaviors was higher. Mother-initiated repairs were observed more often in dyads with a higher number of ruptures, which reflects the definition of repair behavior as being dependent on the presence of a rupture event. Interestingly, there was no association between mother-initiated repairs and the number of child negative behaviors, suggesting that the ruptures being repaired by the mother were not necessarily initiated by the child.

Younger mothers in general had higher levels of HF-HRV, reflected in the task average as well as the intercept at the onset of positive or negative child behavior, compared to older mothers. However, maternal age and child age were not correlated with mothers' HF-HRV slopes. As expected, mothers' average HF-HRV across the task was highly correlated with their HF-HRV intercepts but was not correlated with their HF-HRV slopes, suggesting that event-specific HF-HRV reactivity may provide unique information beyond the average levels. Furthermore, while there was a strong correlation between intercepts for positive and negative child events ($r = .73$), reflecting the within-person stability in HF-HRV levels, there was no significant correlation between HF-HRV slopes following negative and positive child events ($r = -.17$). HF-HRV intercept did not correlate with slope for the negative child behavior but did for the positive behavior; indicating that mothers with higher HF-HRV at the onset of positive child behavior were more likely to show decreases in HF-HRV. HF-HRV levels were not correlated with any behavioral variable, but there was a positive correlation between HF-HRV slope following the negative child behavior and the number of mother-initiated repairs ($r = .32$), indicating that increasing maternal HF-HRV following a negative child behavior was associated with more mother-initiated repairs. This association was specific to HF-HRV slope following negative child behavior, as maternal HF-HRV response to a positive child behavior was not associated with any of the behavioral variables (i.e., maternal affirmation, child negative behaviors, dyadic ruptures, and mother-initiated repairs).

3.3 | Regression analyses

In our final analyses, we examined whether maltreatment status moderated the association between HF-HRV slope and the proportion of maternal affirming behaviors as well as the proportion of maternal-initiated repairs. Results of the regression model predicting the proportion of maternal affirming behaviors are reported in Table 3 (model 1). The main effects model (step 1) demonstrated a significantly better fit than a baseline model with no predictor, $F(6, 71) = 3.59$, $p < .01$, with an R^2 of .23 and an adjusted R^2 of .17. Consistent with the correlational analysis, older mothers showed a greater proportion of affirming behaviors, and a lower proportion of maternal affirmation was associated with more negative child behaviors. After controlling for these covariates, there was a significant main effect on maltreatment status, such that maltreating mothers showed a lower proportion of affirming behaviors. However, mothers' task average HF-HRV and their HF-HRV intercept and slope following the negative child behavior were not significant predictors of the proportion of maternal affirmation. When the interaction term between maltreatment status and HF-HRV slope was entered at step 2, it did not show a significant effect, and the change in R^2 was not significant ($\Delta R^2 < .01$).

Results of the regression model predicting mother-initiated repairs are reported in Table 4 (model 2). The main effect model (step 1) showed significantly better fit than a baseline model with no predictor, $F(6, 71) = 4.42$, $p < .01$, with the $R^2 = .27$, and the adjusted $R^2 = .21$. Maternal age did not predict the number of repairs initiated during the task. Consistent with the correlations, more dyadic ruptures were related to more mother-initiated repairs. After controlling for the effects of covariates, maltreatment status was not associated with the number of mother-initiated repairs. There was no association between mothers' average HF-HRV

TABLE 3 Regression model 1 examining the contributions of maltreatment status and maternal HF-HRV reactivity to a negative child behavior in predicting the task-level *maternal proportion of affirmation*

	B	*SE*	Bootstrapped 95% CI	*β*
Step 1: Main effects				
$R^2 = .23^*$				
Maternal age	0.39*	0.19	[0.01, 0.84]	.24*
Child proportion of negative behavior	−0.17*	0.08	[−0.34, −0.02]	−.23*
Maltreatment status	−4.62*	2.08	[−8.97, −0.08]	−.24*
Maternal task average HF-HRV	−2.04	1.13	[−4.97, 0.52]	−.28
Maternal HF-HRV intercept	1.69	1.00	[−0.45, 4.47]	.26
Maternal HF-HRV Slope	10.16	21.72	[−35.68, 62.40]	.05
Step 2: Moderation				
$\Delta R^2 < .01$				
Maternal HF-HRV slope × Maltreatment status	13.86	44.66	[−104.71, 128.57]	.03

Note: The un-standardized coefficient (*B*), *SE*, and adjusted bootstrap percentile interval (95% CI; with 1000 bootstrap samples) of *B*, and standardized coefficient were reported. Maltreatment status was coded as 0 for families without a history of maltreatment, and 1 for families with a history of maltreatment.

Abbreviations: HF-HRV, high-frequency heart rate variability, *SE*, standard error.

*$p < .05$.

TABLE 4 Regression model 2 examining the contributions of maltreatment status and maternal HF-HRV reactivity to a negative child behavior in predicting task-level *mother-initiated repairs*

	B	*SE*	Bootstrapped 95% CI	*β*
Step 1: Main effects				
$R^2 = .27^*$				
Maternal age	−0.01	0.02	[−0.04, 0.03]	−.03
Number of dyadic ruptures	0.19**	0.05	[0.11, 0.32]	.41**
Maltreatment status	−0.39	0.24	[−0.79, 0.02]	−.17
Maternal task average HF-HRV	0.02	0.13	[−0.29, 0.29]	.03
Maternal HF-HRV intercept	0.01	0.12	[−0.23, 0.30]	.02
Maternal HF-HRV slope	6.48*	2.55	[0.59, 12.85]	.27*
Step 2: Moderation				
$\Delta R^2 = .04$				
Maternal HF-HRV slope × Maltreatment status	−9.86	5.24	[−23.27, 1.82]	−.20

Note: The un-standardized coefficient (*B*), *SE*, and adjusted bootstrap percentile interval (95% *CI*; with 1000 bootstrap samples) of *B*, and standardized coefficient were reported. Maltreatment status was coded as 0 for families without a history of maltreatment, and 1 for families with a history of maltreatment.

Abbreviations: HF-HRV, high-frequency heart rate variability, *SE*, standard error.

*$p < .05$; **$p < .001$.

during the task, or their HF-HRV levels immediately preceding the child's negative event and their propensity to repair dyadic ruptures. However, there was a significant effect of HF-HRV slope such that mothers who responded to negative child behaviors with an increase in HF-HRV were more likely to initiate repair processes after ruptures occurred (also see Figure 2). The interaction between maltreatment status and HF-HRV slope entered at step 2 was not significant and did not result in a significant improvement in the model (change $R^2 = .04$), indicating that this effect was unrelated to maltreatment status.

To verify the specificity of findings, both models were conducted with mothers' HF-HRV intercept and slope for the *positive* child behavior. No significant main effects were found for HF-HRV intercept of slope in either model, and no significant interactions with maltreatment status emerged.

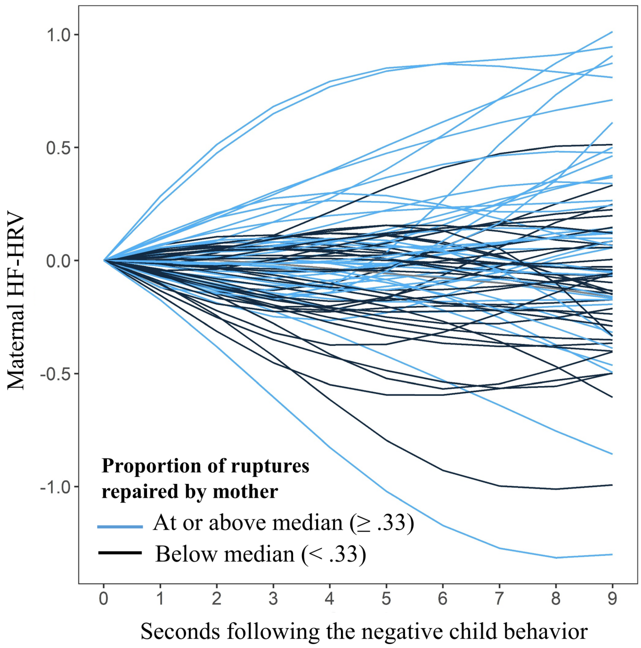

FIGURE 2 Maternal HF-HRV trajectories during the 10 s following the negative child behavior, grouped by the proportion of ruptures repaired by mothers

4 | DISCUSSION

This study provides insight into the maternal HF-HRV response as it unfolds in the first 10 s following the onset of negative child behavior. Analyzing physiological measures on a fine-grained time scale such as this provides an opportunity to understand how parents are regulating in the moment while they are interacting with their child, and to further understand how those regulatory responses are associated with parenting behaviors and dyadic processes. Between-person differences in maternal HF-HRV levels, either across the full dyadic interaction or at the moment of children's aversive behavior, were not associated with differences in maternal behaviors during the interaction. However, change in maternal HF-HRV immediately following children's aversive behavior was associated with how mothers responded to dyadic ruptures, evidencing the value of using an event-based measure of HF-HRV. Increases in HF-HRV, regardless of the initial HF-HRV level, were associated with more mother-initiated repairs, consistent with the notion that increases in HF-HRV support cognitive regulation toward goal-directed behavior, particularly in the context of social affiliation (Porges, 2003; Smith et al., 2020). These findings provide insight into the regulatory responses that support adaptive parenting even among high-risk parents.

Results indicate that the association between maternal HF-HRV reactivity to child behavior and mother-initiated repair behaviors was specific to how mothers responded to aversive child behaviors. Maternal reactivity to positive child behavior was unrelated to maternal warmth or frequency of repair behaviors. Interestingly, higher HF-HRV at the moment of a positive child event was associated with a tendency to decrease HF-HRV in response to the child (although not associated with maternal behavior), suggesting that HF-HRV withdrawal may be appropriate in contexts that do not require self-regulation. If the adaptive nature of HF-HRV reactivity is situationally dependent, this has important implications for how physiology is examined in conjunction with observed behavior. In contrast to experimental paradigms that standardize stimulus exposure across participants, observations of naturally occurring behavior introduce significant variation in stimulus exposure across participants. Because dyadic interactions unfold unpredictably, average HF-HRV across the duration of a task or sizeable task segment may not even include the primary event(s) of interest. As an illustration of this, despite the relatively high-risk nature of the sample and the challenging task presented to the dyads, 76 of the dyads (47% of the eligible sample) did not have any instance of aversive child behavior, indicating that nearly half of the sample did not experience explicit child-related challenges during the task. Inclusion of participants who did not experience a challenging child event is likely to dilute an examination of how parents respond to challenging behaviors. Furthermore, physiology averaged across longer durations likely includes multiple transactions that could move between negative and positive states. This dynamic "noise" may dilute the physiological process of interest, making effects more difficult to detect. This event-based analysis approach aligns the study of physiological reactivity with the event-based framework that guides the study of relational processes.

Whereas increases in maternal HF-HRV were associated with the number of mother-initiated repairs following a rupture, this pattern of reactivity was not associated with the overall proportion of maternal comments that were supportive and affirming in nature. Although both measures are considered to be important in supporting children's regulatory development, these parenting characteristics may not require the same degree of regulatory effort on the part of the parent. Interestingly, mother-initiated repairs and the proportion of affirming maternal behaviors were not correlated, indicating that higher levels of positivity were not necessarily associated with whether mothers successfully resolve dyadic ruptures. Indeed, these maternal behaviors are distinct in that maternal affirmation can be largely proactive - describing the quality of mothers' spontaneous actions, whereas mother-initiated repairs are reactive - present only when there is a dyadic need to restore positive exchanges following a rupture. Given this distinction, it is perhaps not surprising that HF-HRV reactivity measured specifically in response to an aversive child event is associated with maternal capacity to react to such events, but not necessarily her overall demeanor.

The association between maternal HF-HRV reactivity and her contributions to dyadic repair was not moderated by mothers' maltreatment status. On average, maltreating mothers demonstrated fewer affirming interactions toward her child overall, but there was no main effect of maltreatment status when predicting mother-initiated repairs, suggesting that even mothers with a maltreatment history are capable of restoring mutual positivity in the dyad when needed. T-tests indicate a modest tendency for mothers with a maltreatment history to demonstrate a decrease in HF-HRV following child negativity, whereas non-maltreating mothers showed an average increase in HF-HRV, but this did not reach significance ($p = .07$), potentially due to a lack of power from the relatively small sample size. Taken together, these findings suggest that mothers with a maltreatment history may be more vulnerable to dysregulated responding to negative child behavior, but that when they engage in a regulated way the dyadic benefits are just as likely to be realized.

The present findings reinforce the importance of helping parents regulate their physiological arousal and remain calm in the face of frustration. This may be necessary to maximize parent's ability to consciously and purposefully select a response to their child's negative behavior that serves to deescalate emotional arousal and foster children's development of emotion regulation. Several intervention programs already exist that focus on coaching parents on the quality of their momentary interactions with their child. Parent–Child Interaction Therapy (PCIT) provides real-time coaching to guide parents on responding to specific child behaviors in the moment (Chaffin et al., 2004; Skowron & Funderburk, 2022; Thomas & Zimmer-Gembeck, 2012). Additional programs utilize video-based feedback to work with parents to identify moments during interactions with their child where they were positively engaged and promoting effective emotion regulation for their children (Fisher et al., 2016). However, these existing programs do not directly address parents' awareness of their own affective arousal or the importance of recognizing and regulating their own affective state before responding to the child. Future work could incorporate physiological measures into these intervention tools to provide parents with feedback about their own arousal as part of the process of helping them recognize conditions that are more challenging for them.

5 | LIMITATIONS AND FUTURE DIRECTIONS

Several limitations should be considered with this study, perhaps most noteworthy the small sample size. The limitation in sample size was due, in part, to the low frequency of aversive child behavior during the challenging task. Nearly half of the sample (47%) completed the task with no incident of aversive child behavior. Future efforts to examine parenting in the context of negative child behavior should consider dyadic paradigms that increase the level of challenge for both parent and child, extend the duration of tasks to increase the chances of observing challenging behaviors, or employ standardized stimuli with the use of video vignettes. Additionally, this study examined parenting behavior among maltreating and non-maltreating mothers, but as with most studies of maltreatment, there was considerable variation in the nature and severity of the maltreatment perpetrated. Some evidence indicates that mothers with a history of physical abuse are more likely to demonstrate dysregulated physiological reactivity in response to child behavior relative to mothers with only a history of neglect (Norman Wells et al., 2020). The limitations in sample size due to the restricted event selection process did not permit an examination of moderation by maltreatment type, but it is possible that the null results related to maltreatment status are a function of the broadness of this category.

This study illustrates the unique value of examining HF-HRV as a dynamic process on the timescale at which dyadic interactions unfold. However, there are several methodological issues that are relevant to consider when examining HRV on a dynamic timescale. Firstly, the extent to which heart rate variability is driven by vagal (i.e., parasympathetic) cardiac innervation is predicated on the role of respiration. The extent to which respiration reflects a confounding influence is not fully agreed upon, resulting in different recommendations for accounting for its influence on HF-HRV; ranging from enforcing a standardized (paced) rate of breathing across all participants (e.g. Grossman & Taylor, 2007) to simply ensuring that actual respiration falls within the frequency band defined for extracting HF-HRV (e.g. Allen et al., 2007; Houtveen et al., 2002). Regulating participants' natural breathing patterns is not feasible in many experimental paradigms, including the one employed in the present study. Verifying participants' respiratory frequency band is typically done by quantifying the respiratory frequency within the epochs used to quantify HF-HRV. In the present study, we did not attempt to generate a dynamic respiration timeseries. As such, we cannot rule out the possibility that momentary changes in respiration patterns could have influenced the current results. While naturally occurring momentary changes in respiration could represent a nuisance factor that introduces measurement noise at random, respiratory changes that are systematically associated with the events of interest could systematically bias the effect. In the context of the present study, this could occur if mothers who demonstrated more repair behaviors overall had a tendency to react to instances of challenging child behavior by taking a deeper breath, resulting in a momentary increase in HF-HRV. Thus, it is unclear whether the association observed here reflects an internal regulatory process (e.g. vagal input to the heart) or an external regulatory process (e.g. a change in respiratory patterns). Future methodological research is needed examining dynamics in respiratory frequency as well as event-related tidal volume in order to better parse these distinct mechanisms. If the effect is determined to be driven by spontaneously occurring changes in respiration, this could reflect an effective coping mechanism these mothers have developed intrinsically, but that could be incorporated into parent-training programs.

Similarly, researchers have debated about the assumptions of stationarity and periodicity implied in the Fourier analysis technique. Naturally occurring IBI series are known to violate these assumptions, although some researchers have argued that, outside of major perturbances, cardiac time series are at least weakly stationary, and sufficient for the technique to be considered valid (Allen et al., 2007; Friedman et al., 2002; Houtveen & Molenaar, 2001). Violations of these assumptions are likely to increase the longer the time interval at which RSA is extracted, particularly in experimental task conditions which seek to emulate naturally occurring behavior in which cognitive and affective demands vary dynamically across the task. Even in the context of a standardized stimulus, such as a film clip, there can be substantial changes in emotional intensity over relatively short periods (see Ravindran et al., 2021). As such, it is important for researchers to ensure that potential confounds do not vary systematically between groups being compared or in association with any investigated trait of interest. In summary, the application of dynamic RSA time series offers the opportunity to examine behavioral processes with greater precision, provided that appropriate methodological considerations are attended to.

AUTHOR CONTRIBUTIONS

Lisa Michelle Gatzke-Kopp: Conceptualization; data curation; methodology; resources; supervision; writing – original draft; writing – review and editing. **Xutong Zhang:** Data curation; formal analysis; methodology; writing – review and editing. **Kristine L. Creavy:** Conceptualization; data curation; formal analysis; writing – original draft. **Elizabeth Skowron:** Conceptualization; funding acquisition; investigation; project administration; writing – review and editing.

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