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Vagal flexibility moderates the links between observed sensitive caregiving in infancy and externalizing behavior problems in middle childhood

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Abstract

This study explored how patterns of physiological stress reactivity underpin individual differences in sensitivity to early rearing experiences and childhood risk for psychopathology. To examine individual differences in parasympathetic functioning, past research has largely relied on static measures of stress reactivity (i.e., residual and change scores) in infancy which may not adequately capture the dynamic nature of regulation across contexts. Using data from a prospective longitudinal study of 206 children (56% African Americans) and their families, this study addressed these gaps by employing the latent basis growth curve model to characterize the dynamic, non-linear patterns of change in infants' respiratory sinus arrhythmia (i.e., vagal flexibility) across the Face-to-Face Still-Face Paradigm. Furthermore, it investigated whether and how infants' vagal flexibility moderates the links between sensitive parenting, observed during a free play task when children were 6 months of age, and parent-report of children's externalizing problems at 7 years of age. Results of the structural equation models revealed that infants' vagal flexibility moderates the predictive relations between sensitive parenting in infancy and children's later externalizing problems. Simple slope analyses revealed that low vagal flexibility, characterized by less suppression and flatter recovery patterns, exacerbated risk for externalizing psychopathology in the context of insensitive parenting. Children with low vagal flexibility also benefited most from sensitive parenting, as indicated by the lower number of externalizing problems. Findings are interpreted in the light of the biological sensitivity to context model and provide evidence for vagal flexibility as a biomarker of individual's sensitivity to early rearing contexts.

Keywords

Sensitive Parenting; Vagal Flexibility; Externalizing Problems; Respiratory Sinus arrhythmia; Still Face Paradigm

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Introduction

The quality of early caregiving exerts a profound and enduring influence on children's social and emotional development (Rodrigues et al., 2022). Research demonstrates that sensitive caregiving promotes children's adjustment and well-being, whereas harsh and intrusive parenting confers risk for behavior problems, such as externalizing and internalizing psychopathology (Kok et al., 2013; Van Zeijl et al., 2007). At the same time, there is substantial individual variability in how early experiences with caregivers predict risk for psychopathology (e.g., Hastings et al., 2011; Oshri et al., 2021; Shakiba et al., 2022; Wagner et al., 2017). The biological sensitivity to context model (Boyce & Ellis, 2005) suggests that patterns of physiological stress reactivity may provide insight into individual differences in sensitivity to early rearing experiences, including nurturing and harsh rearing environments (Belsky & Pluess, 2009; Ellis et al., 2011). Despite a growing number of studies indicating that infants' physiological stress responses may moderate the links between caregiving experiences and later outcomes (e.g., Conradt et al., 2013; Somers et al., 2019), most studies have relied on static measures of infants' physiological regulation (e.g., baseline, difference scores), which may not adequately characterize and capture the dynamic nature of regulation across contexts (Burt & Obradović, 2013; Miller et al., 2013). The current study advances this literature by modeling non-linear patterns of infants' physiological regulation across a social stressor task and tests whether these patterns of regulation and observed sensitive parenting in infancy uniquely and interactively predict externalizing psychopathology later in childhood.

Extensive research highlights the critical role that parenting behaviors play in maintaining, mitigating, or exacerbating risk for a wide range of externalizing behavior problems in children, including antisocial and conduct problems, aggression, oppositionality, and callous-unemotional traits (Repetti et al., 2002; Wagner et al., 2015, 2019; Waller et al., 2013). Parental sensitivity during infancy and early childhood, characterized by a high degree of warmth, sensitivity, and responsiveness to the child's needs (Ainsworth et al., 1978), reduces the risk of developing externalizing problem behaviors (Wang et al., 2013), and supports children's prosocial behaviors (Spinard & Gal, 2018; van der Storm et al., 2022). Despite a preponderance of literature documenting the unique contribution of parental sensitivity to child development and mental health outcomes, research has also established that children vary in their susceptibility to early caregiving experiences (Belsky et al., 2007; Belsky & Pluess, 2009). Advancing our understanding of the regulatory mechanisms underlying the differential influence of early experience on children's development will inform efforts to personalize support and intervention strategies. The primary aim of the current study was to identify whether and how infants' dynamic patterns of reactivity and recovery across a social stressor moderate the influences of parenting on later externalizing problems.

When examining the developmental origins and causes of mental health problems in children, it is crucial to consider both neurobiological and environmental factors, as heterogeneity in children's responses to their rearing environment and subsequent health and developmental outcomes is partially embedded by how physiologically responsive they are to psychosocial stressors (Boyce & Ellis, 2005; Ellis et al., 2011). Research has identified patterns of children's psychophysiological regulation, both at resting condition and in response to external stressors and stimuli, as important moderators of the effects of familial influences on children's development and behavioral adjustment (Boyce & Ellis, 2005; Dunbar et al., 2021; Eisenberg et al., 2012; Obradović et al, 2010). The parasympathetic nervous system (PNS) is a branch of the autonomic nervous system that helps children to adaptively engage with the environment and maintain their physiological homeostasis (Beauchaine, 2001; Porges, 2007). The functioning of the PNS, indexed by the respiratory sinus arrhythmia (RSA), in particular, provides insight into key regulatory processes. RSA indexes parasympathetic influences on cardiac output and represents the rhythmic fluctuation of the heart rate variability across the respiratory cycle (Porges, 2007). Mean RSA changes to stressors relative to the resting state (i.e., reactivity) and following stressors (i.e., recovery) are reliable peripheral measures of emotion regulatory capacity (Beauchaine, 2001, 2015; Calkins, 1997; Porges, 2007).

Research has established RSA reactivity and recovery patterns as biomarkers of an individual's sensitivity to rearing contexts (e.g., Boyce & Ellis, 2005; Gueron-Sela et al., 2017; Wagner et al., 2018). For example, Dyer and colleagues (2016) showed that high RSA reactivity exacerbated the risk for externalizing problem behaviors, only among adolescent boys (but not girls) who had highly authoritarian mothers. Similarly, Obradović et al. (2010) found that exposure to family adversity, characterized by high levels of financial stress, marital conflict, maternal depression, harsh parenting, and parenting overload predicted higher levels of externalizing symptoms, lower levels of prosocial behaviors and school engagement, only among preschoolers who demonstrated heightened RSA reactivity to laboratory challenges. However, children demonstrating high RSA reactivity showed lower levels of externalizing symptoms and higher levels of school engagement in the context of low family adversity exposure. In another study, Blandon and colleagues (2008) found evidence for the association between maternal depressive symptomology at age 4 and greater emotional negativity at age 7 among children who had higher vagal suppression to the effortful attention task. These findings collectively suggest *high* RSA reactivity as an indicator of biological sensitivity to family context and children's adjustment.

Importantly, this literature is also characterized by inconsistent findings. For example, other empirical work indicates that *low* RSA reactivity may also function as a vulnerability factor that exacerbates the risk of developing pathology under adverse family conditions (e.g., Keller et al., 2014; McLaughlin et al., 2014). Davis and colleagues (2016) illustrated that lower RSA reactivity or suppression exacerbated the risk of internalizing symptoms among children of anxious and depressive mothers, while higher RSA reactivity buffered the risk among these high-risk children. Similarly, El-Sheikh and Whitson (2006) found that in the context of marital conflicts, greater RSA suppression (i.e., heightened RSA reactivity) appeared as a protective factor for childhood development of internalizing problems, whereas lower RSA reactivity exacerbated the risk.

Taken together, the effects of family contexts on children's adaptation appear to vary, in part, as a function of children's PNS functioning, with studies reporting inconsistent results for the magnitude and direction of the RSA reactivity as a moderator of these effects. The analytic approaches used to assess RSA reactivity may contribute partially to these discrepant findings. For example, most studies on this topic use (un)standardized residual scores (i.e., regressing the mean RSA value during the stress task on resting RSA) or arithmetic change scores (i.e., subtracting the mean RSA value during the stress task from resting RSA; Burt & Obradović, 2013; Miller et al., 2013) to compute and conceptualize RSA reactivity. However, these methods are limited in their ability to quantify the adaptive dynamic and non-linear patterns of RSA changes that occur across different contexts, stress-inducing laboratory challenges, and over time (see Burt & Obradović, 2013 for review).

Miller et al. (2013, 2015), Ugarte et al. (2021), and others argue that *vagal flexibility* could provide better insight into children's physiological regulation by operationalizing RSA reactivity and recovery as a dynamic physiological and emotion regulation process. Typically, children demonstrate RSA suppression (i.e., decreases in mean RSA values from baseline RSA) in response to arousing or stressful stimuli, which is followed by augmentation or recovery (i.e., increases in mean RSA) when the source of stress is removed. The non-linear and dynamic patterns of change in RSA over the course of challenge represent vagal flexibility (Miller et al., 2013, 2015, 2016).

An adaptive response to changing rearing environment is achieved when children adaptively regulate their physiological regulatory systems, behaviors, and emotions to meet their contextual demands. Cardiac vagal flexibility has been identified as a physiological index of social-emotional sensitivity, with individuals with greater vagal flexibility are more likely to be responsive and influenced by social cues and feedback, either positive or negative feedback, than their less flexible counterparts (Muhtadie et al., 2015). Past research links greater vagal flexibility or patterns of RSA suppression followed by recovery with a host of positive outcomes in children, including better emotion regulation and self-control and cognitive performance, and more empathetic and prosocial behaviors (Balzarotti et al., 2017; Miller, 2018; Spangler et al., 2020). Greater vagal flexibility to a sad film also predicted better treatment response six months later in depressed individuals (Rottenberg et al., 2005). By contrast, research reports low vagal flexibility, a flat pattern of RSA change, or reduced RSA reactivity followed by slow recovery as a potential neurobiological underpinning of psychopathology. For example, low vagal flexibility was associated with more anxiety among behaviorally inhibited preschoolers (Wagner et al., 2023), and social phobia in typically developing children aged 8 to 12 years old (Schmitz et al., 2011). These findings suggest that reduced vagal flexibility may reflect an individual's reduced regulatory capacity to actively cope with external demands.

The present study characterizes infants' vagal flexibility across the Face-to-Face Still-Face Paradigm (FFSFP; Haley & Stansbury, 2003; Tronick et al., 1978), a widely used laboratory task to elicit acute stress and to measure infant PNS functioning. Past research suggests that a non-linear pattern of RSA change should be expected across the FFSFP (Conradt & Ablow, 2010; Gao et al., 2022; Jones-Mason et al., 2018). The current study employs a latent basis growth curve modeling approach to explicitly model the non-linear patterns of RSA change across the FFSFP and test whether they may moderate the effect of observed sensitive caregiving during infancy on later externalizing problems. Rather than specifying the functional form of change as one would in a typical (e.g., linear, quadratic) latent curve model, the slope factor loadings in a latent basis model are freely estimated by the data, which allows for the characterization of non-linear patterns of change.

The use of a latent basis growth modeling framework will allow for a nuanced understanding of how children vary in their recovery to this well-established laboratory stressor. Moreover, we leverage the flexibility of the structural equation modeling (SEM) framework to gain insight into how infants' vagal flexibility moderates the influences of early experiences with caregivers. This work may provide more nuanced insight into individual variability in patterns of risk and resilience than would modeling approaches that rely on static metrics of change (e.g., difference scores). Using a similar analytic approach, Miller and colleagues (2013) found that vagal flexibility or the dynamic patterns of RSA change in response to emotional stimuli better characterized variation in parasympathetic activation and its contribution to emotion regulation, compared to simple and residual change scores. In the current study, the construct of vagal flexibility or the infant's dynamic and non-linear patterns of RSA changes across the episodes of the FFSFP is characterized and modeled through the latent slope factor in the latent basis growth curve model (Miller et al., 2013, 2016).

The Current Study

The goals of the current study were three-fold. First, latent basis growth curve models were used to characterize infants' vagal flexibility, or the dynamic, non-linear patterns of RSA change across the FFSFP, to index individual differences in the PNS regulation. Second, we expanded the structural equation growth models to test whether sensitive parenting behaviors observed during a free play task and children's vagal flexibility both assessed when infants were 6 months of age, predict children's externalizing behaviors at 7 years of age. Third, we examined whether and how infants' vagal flexibility moderates the association between observed sensitive parenting and later externalizing psychopathology. We hypothesized that *low* vagal flexibility, characterized by less suppression and flatter recovery (i.e., mild RSA suppression and augmentation) across the episodes of the FFSFP, would exacerbate the link between insensitive parenting experiences in infancy and later externalizing behavior problems. Conversely, we expected that the combination of sensitive caregiving experiences and *high* vagal flexibility (i.e., a more pronounced pattern of RSA suppression, followed by a recovery or RSA augmentation) would be associated with the lowest levels of externalizing behavior problems in middle childhood.

Methods

Participants

Participants were drawn from The Durham Child Health and Development Study (DCHDS), a prospective longitudinal study of 206 healthy, full-term children and their families. Participants were first recruited when the children were 3 months old, and subsequently participated in data collection in 6-month increments through 36 months, and again once a year from preschool through second grade. Families were recruited from a large urban community in accordance with stratified sampling to ensure variation in SES and approximately equal representation across self-identified racial categories and income distribution. The sample was 56% African American and 44% European American and approximately 53% were low-income (below 200% of the poverty level). Infant race was determined by the mother or primary caregiver; income status was assessed based on size of the family in relation to their household income in accordance with the 2002 federal poverty guidelines. About 13% of mothers had no high school degree, 43% had either a high school diploma or a General Education Development (GED) credential, 11%had some college or vocational school, and 33% had a 4-year bachelor's degree or higher. The average annual family income at the 6-month visit was approximately $49,400 (*SD* = $40,670), and the median family income was $44,660. Demographic information was collected during the first visit at 3 months of age and updated at each subsequent visit.

The current study used observational and parent-report data collected at the 6-month and 7-year time points. Ratings and observations occurred in both laboratory and home visit settings during these time points. Families were compensated $50 for their participation at each time point. All procedures and protocols were approved by the University of North Carolina at Chapel Hill Institutional Review Board.

Measures

Face-to-Face Still-Face Paradigm (FFSFP).—The FFSFP (Adamson & Frick, 2003; Tronick et al., 1978) was conducted during the laboratory visit when infants were 6 months of age to assess their regulatory capacities while experiencing stress. Infants were placed in a highchair and mothers were given a set of standardized instructions for each of the three episodes of the FFSFP (i.e., face-to-face, still-face, and reunion). Mothers were first instructed to talk and interact with their child for 2 minutes (face-to-face; *FF* episode), then to turn away from the child for 15 seconds. After returning to face the child, the mothers were instructed to maintain a fixed stare, refraining from facial movements or display of affect for 2 minutes (still-face; *SF* episode). After turning their head away for another 15 seconds, the mothers were asked to again interact normally with the child for two minutes (reunion; *RE* episode). Negative child affect was demonstrated most often during the face-to-face episode and still-face episodes (Ekas et al., 2013; Mesman et al., 2009).

Infant Respiratory Sinus Arrythmia (RSA).—During the laboratory visit at 6 months, children were equipped with heart rate monitors. Heart rate data were continuously collected throughout the FFSFP procedure. Experimenters placed two disposable pediatric electrodes on the child's chest connected to a preamplifier and transmitted to a monitor for R-wave detection (VTM-1, Delta Biometrics, Inc., Bethesda, MD). After data collection, inter-beat interval (IBI) files were edited using MXEdit software to account for movement artifact (Delta Biometrics, Bethesda, MD). Measures of RSA were extracted using Porges' (1985) method, applying an algorithm to the sequential IBI data using a moving 21-point polynomial to detrend periodicities in heart period slower than RSA. A band-pass filter extracts the variance of the IBIs within the frequency band of spontaneous respiration in infants. This estimate of RSA is derived by calculating the natural logarithm of the variance, reported in units of $\ln(\text{msec})^2$. The data files were transferred to a computer and were edited by two reliable researchers using the MXEdit software. The two researchers were trained to reliability in MXEdit software (Delta Biometrics, Bethesda, MD) with Porges's Lab at the

University of Maryland and edited the files by visually scanning the data for outlier points relative to adjacent data and replacing those points by dividing them or summing them so that they would be consistent with surrounding data. Consistent with previous work (Moore et al., 2009), datafiles that required editing of more than 10% of the data or were incomplete due to technical problems were not included in the final dataset. RSA data were missing from approximately 20% of each of the episodes of the FFSFP, which is common in studies with young infants who tend to be noncompliant with physiological recording procedures. Some of the reasons for missing RSA data include, the infant became too fussy or fell asleep, artifacts due to movement or infant pulled off electrodes or chewed on lead or other equipment failure.

RSA was calculated within the 15-seconds epoch during each 2-minute episode (i.e., FF, SF, RE) and an average of the RSA values for all the epochs included in each individual episode were used to index vagal flexibility and individual variability in the PNS functioning across the paradigm. These durations are typical for studies of short duration tasks (Huffman et al., 1998).

Observed Sensitivity.—Mothers and their children were observed during a free play task at the home visit when the children were 6-months of age. A standard set of toys were arranged on a blanket laid across the floor and mothers were instructed to play with their child as they normally would for 10 minutes. The dyad interactions were videotaped for later coding by trained and reliable coders. Five subscales were used to evaluate sensitivity during the free play task: parental sensitivity/responsiveness (level of responsiveness and support offered to the child’s distress and non-distress), detachment/disengagement (the degree to which the parent is emotionally disengaged or distant), stimulation of development (the degree to which the parent engaged in age-appropriate behaviors fostering child’s development), positive regard (positive feelings and warmth directed toward the child), and animation (level of parental vocal, physical, and affective energy and excitement) (Cox et al., 1999). Independent coders rated maternal behaviors using a 5-point Likert scale ranging from “not at all characteristics” to “highly characteristic” for each subscale (Cox & Crnic, 2003). Reliabilities across each pair of coders were determined by maintaining intraclass correlation coefficients of 0.80 or greater on all subscales and composite measures (intraclass correlation range = 0.80–0.96). Following the previous factor analytic work with this sample (Barnett et al., 2008; Wagner et al., 2015), a *sensitive parenting latent factor* was created based on the five subscales of sensitivity, detachment (reversed scored), stimulation of development, positive regard, and animation.

Child’s Externalizing Problems.—Parents reported on their child’s externalizing behaviors using the Child Behavior Checklist (CBCL; Achenbach, 1991) when the child was 7 years old. This well-validated measure assesses children’s emotional and behavioral functioning relative to their same-aged and same-sex peers. On a 3- point Likert scale ranging from 1 (not true) to 3 (very/often true), parents reported the presence of each of the externalizing behavioral symptoms (e.g., attention problems: *Can’t sit still, restless, or hyperactive,* and aggressive behaviors: *Gets in many fights and hits others*) over the past 6 months (α = .89). T-scores were used in all analyses.

Covariates.—Covariates were selected based on their theoretical relations with the primary predictors and outcome to account for confounding contributions to the processes of interest. Demographic and income variables were included to control for the documented associations between parental sensitivity, infants' physiological functioning, and children's externalizing problems. Information on children's sex and race was collected upon entry into the study. Families' poverty status was calculated as the federal poverty threshold for the appropriate family size using income data provided by parents at the 6-month time point (U.S. Bureau of the Census, 2002).

Data Analytic Plan

We applied a multi-method analytic approach to test the study aims. Figure 1 demonstrates the conceptual model tested in the current study. First, we performed a saturated latent basis growth curve model to characterize the dynamic and non-linear patterns of infants' RSA changes across the FFSFP. Given the well-documented regulation patterns across this laboratory challenge (e.g., reactivity followed by recovery), a linear growth model would be misspecified. On the other hand, latent basis growth curve models (Meredith & Tisak, 1990) characterize the pattern or shape of non-linear change by adopting a data-driven approach to specifying the "shape" vector (i.e., slope factor loadings are freely estimated). The latent basis approach allows the model to determine the optimal functional form of patterns of change, allowing for the characterization of individual variability in non-linear patterns of reactivity and recovery. Unlike quadratic or cubic growth models, which require two more time points than the degree of polynomial being estimated (e.g., quadratic models require four time points), latent basis models can be estimated with as few as three time points (Bi et al., 2022; Duncan et al., 2006; Soloski & Dusrtschi, 2019; Stevens et al., 2022). The latent basis model was performed using Mplus version 8.6 (Muthen & Muthen, 1998–2017). The model was specified such that the intercept represented model-implied mean RSA during the FF episode. Given the well documented "still-face effect" in which infants display reactivity during the SF episode and recovery during the RE episode (Conradt & Ablow, 2010; Gao et al., 2022; Jones-Mason et al., 2018), as well as the lower mean RSA ($M = 3.41$; greater RSA suppression) during the SF episode relative to the FF ($M = 3.57$) and RE ($M = 3.49$) episodes, the slope factor was identified (i.e., scaled) by fixing the factor loadings for the FF and SF to 0 and −1, respectively. We freely estimated the slope factor loading for the RE episode to characterize the dynamic and non-linear patterns of RSA recovery during the final episode (Miller et al., 2013).

Next, we expanded the latent basis growth curve model to examine the main effects of infants' vagal flexibility across the FFSFP and observed sensitive parenting on children's externalizing problems while controlling for the effects of the covariates. Finally, we examined whether and how infants' vagal flexibility moderates the associations between observed sensitive parenting and children's externalizing problems by computing a latent interaction between the slope of RSA and sensitive parenting. We allowed all the exogenous predictors to covary in all models. Significant interactions were probed by estimating simple slopes at $\pm$ 1*SD* of infants' vagal flexibility and by examining the regions of significance (RoS). All the analyses were conducted using Mplus version 8.6 (Muthen & Muthen, 1998–2017). The exploratory analyses for probing the significant interactions were performed by using a web-based application developed by R. Chris Fraley (https://www.yourpersonality.net/interaction/). Missing data were handled using the full-information maximum likelihood estimation (Enders & Bandalos, 2001).

Results

Descriptive statistics and zero-order bivariate correlations for study variables are presented in Table 1. The latent basis growth model was saturated. The intercept latent factor score, $M = 3.57$, $p < 0.001$, represented the model-implied mean of RSA during the FF, the first episode of the FFSFP. The slope mean, $M = 0.14$, $p = 0.03$ (coefficients 0.0, −1.0, −0.55), indicated a non-linear pattern of change in infant's RSA across the three episodes of the FFSFP. These estimates suggest that children's RSA significantly decreased (RSA suppression) during the SF episode, and slightly augmented or recovered to nearly half of the starting RSA levels during the RE episode.

Table 2 summarizes the results of the prediction models. Unstandardized and standardized coefficients for the main effect and interaction models are reported as estimates of the effect sizes in the Table. No statistically significant main effect associations were found between observed sensitive parenting ($\beta = -0.04$, $b = -0.40$, $p = 0.67$) and children's vagal flexibility ($\beta = -0.01$, $b = -0.09$, $p = 0.90$) in the prediction of children's externalizing problems.

Tests of moderation revealed a statistically significant interaction ($\beta = 0.25$, $b = 2.30$, $p = 0.03$) between sensitive parenting and children's vagal flexibility in the prediction of children's externalizing problems. Simple slope analyses revealed (Figure 2) that more sensitive parenting during infancy predicted fewer externalizing problems at age 7 years, but only among children who showed low vagal flexibility (−1*SD* simple slope = −3.51, $t = 2.04$, $p = 0.04$) across the FFSFP. The association was not significant for children who showed high vagal flexibility (+1*SD* simple slope = 1.10, t = 0.90, $p = 0.37$). Furthermore, the RoS analyses indicated that the negative association between sensitive parenting and children's externalizing problems was significant outside the lower and upper bounds of latent vagal flexibility at −0.81 and 3.61, respectively ($M = 0$ and $SD = 1$). Note that the upper bound of the RoS was outside our range of observed data and was not interpreted. These findings suggest that the negative association between sensitive parenting during infancy and childhood externalizing problems was significant for children demonstrating low but not high levels of vagal flexibility across the three episodes of FFSFP at 6 months.

Given the common comorbidity between internalizing and externalizing behavior problems, particularly in younger children (Dol et al., 2022; Willner et al., 2016), we also tested the study's aims with respect to internalizing problems, which were also assessed through the Child Behavior Checklist (CBCL; Achenbach, 1991). Furthermore, we estimated a model predicting total behavior problems (i.e., internalizing, externalizing, sleep, and other problems). Results indicated that observed sensitive parenting and vagal flexibility interact to predict externalizing problems but not internalizing or total behavior problems (see the online supplemental materials for more information).

Discussion

The early caregiving environment plays a prominent role in children's social and emotional development and risks for psychopathology. Developmental and clinical scientists are interested in not only characterizing the links between early parenting and psychopathology but also elucidating whether and how these links vary across individuals. This desire has motivated research demonstrating that children's physiological regulation may function as a potential moderator of the effects of early caregiving environments on childhood risks for behavioral problems (Boyce & Ellis, 2005). In the current study, we performed a latent basis growth curve model to characterize and quantify 6-month-old infants' vagal flexibility or the dynamic modulation of cardiac vagal control across the FFSFP. Next, we conducted a series of structural equation models to examine the associations between sensitive parenting and infants' vagal flexibility and children's externalizing problems in middle childhood. Finally, guided by the biological sensitivity to context model (Boyce & Ellis, 2005), we investigated whether vagal flexibility is an index of biological sensitivity to early caregiving environment that moderates the effects of sensitive parenting in infancy on later externalizing problems.

As predicted and consistent with the results of the prior studies (Gao et al., 2022; Jones-Maso et al., 2018), we observed a non-linear pattern of RSA change across the FFSFP, such that, on average, children's mean RSA levels decreased (RSA suppression) during the SF episode, the most stressful episode of FFSFP, and slightly increased (RSA augmentation) during the RE episode. Results from prediction models indicated that insensitive parenting in infancy was associated with higher externalizing behavior problems, but only for infants who also showed low vagal flexibility across the FFSFP. Conversely, results suggest that high vagal flexibility may be a protective factor in the context of insensitive parenting. Finally, the current findings suggest that children with lower vagal flexibility may benefit most from sensitive parenting, as indicated by the lower number of externalizing problems during middle childhood. In addition, we tested the study's aims with respect to internalizing, externalizing, and total behavior problems, and only found a significant interaction effect in the prediction of externalizing problems, but not internalizing and total behavior problems, suggesting the observed effects are specific to children's externalizing problems. These findings provide evidence of how *low vagal flexibility* may serve as a neurobiological index of sensitivity to the early caregiving environment.

Children's PNS regulation represents key neurophysiological substrates of individual differences in regulatory behaviors, and it provides insight into children's capacity for flexible physiological self-regulation (Porges 2007; Wagner et al. 2021). Reduced flexibility of the PNS hinders an individual's ability to adequately regulate and respond to the environment (Freidman & Thayer, 1998). As such, results from the current study could suggest that children who demonstrate lower vagal flexibility may rely more on external sources of regulation, which could increase the risk of externalizing behavior problems in the context of insensitive parenting. Indeed, recent work has demonstrated links between autonomic nervous system inflexibility during parent-child interactions and risk for externalizing problems in children ages 10 to 14 years (Perlstein et al., 2021). The notion that infants demonstrating lower vagal flexibility are more likely to be negatively impacted by insensitive caregiving is consistent with research suggesting that low vagal flexibility indicates a reduced capacity to draw on internal resources to cope with external challenges (Freidman & Thayer, 1998).

The current findings are consistent with those of Ugarte and colleagues (2021), who used dynamic, non-linear approaches to assess children's vagal flexibility. A longitudinal study of 4- to 6-year-old children found authoritarian parenting to predict increased externalizing problems two years later, but only in children who showed low vagal flexibility to a series of scenarios designed to induce negative emotions (i.e., sadness, fear, anger). By contrast, high vagal flexibility attenuated the links between externalizing problems and authoritarian parenting behaviors. The authors argued that children with higher vagal flexibility are more likely to attend to their emotionally evocative experiences with authoritarian parents. At the same time, these children are more able to adaptively regulate during these interactions, which would buffer the negative effects of having authoritarian parents on their health and well-being.

The current findings should be considered in the context of the following limitations. Although the longitudinal design is a strength, the current study cannot speak to the possibility that the moderating influences of children's vagal flexibility may change across early childhood. Although recent work has characterized children's RSA across infancy and early childhood (Wagner et al., 2021), we know less about how children's vagal flexibility may change across early development. As such, we recommend future investigations to examine vagal flexibility across early development to examine whether children demonstrating low vagal flexibility remain susceptible to other contextual influences (e.g., financial stress, parents' psychopathology). Additionally, the design of the FFSFP restricted our ability to model multiple cycles of infants' reactivity and recovery, a limitation that could be addressed in future studies by examining vagal flexibility across different contexts and tasks. Relatedly, our examination of individual differences in physiological regulation as a biological marker of sensitivity to early rearing experiences is limited to children's PNS functioning. Future studies should examine whether and how the dynamic physiological concordance between sympathetic and parasympathetic regulation may also function as a neurobiological susceptibility factor that moderates the effects of parenting behaviors on childhood adjustment. Furthermore, we recommend future investigations to examine whether and how the childhood risk of mental health problems may vary across different cultures, ethnic and racial groups (Pinquart, 2021), with a focus on the role that different parenting practices (e.g., authoritarian vs. authoritative parenting behaviors) may play in exacerbating or buffering the risks among children demonstrating low vagal flexibility.

In sum, we provide compelling evidence for the importance of considering the interplay between early caregiving experiences (i.e., sensitive parenting) and children's physiological regulation in the prediction of externalizing behavior problems. Moreover, our findings join a growing literature that identifies vagal flexibility as a biological index of sensitivity to early context. An important methodological implication is that, as compared to the static measures of RSA reactivity, vagal flexibility may provide better insight into dynamic patterns of autonomic regulation which can be leveraged to elucidate patterns of developmental adaptation and maladaptation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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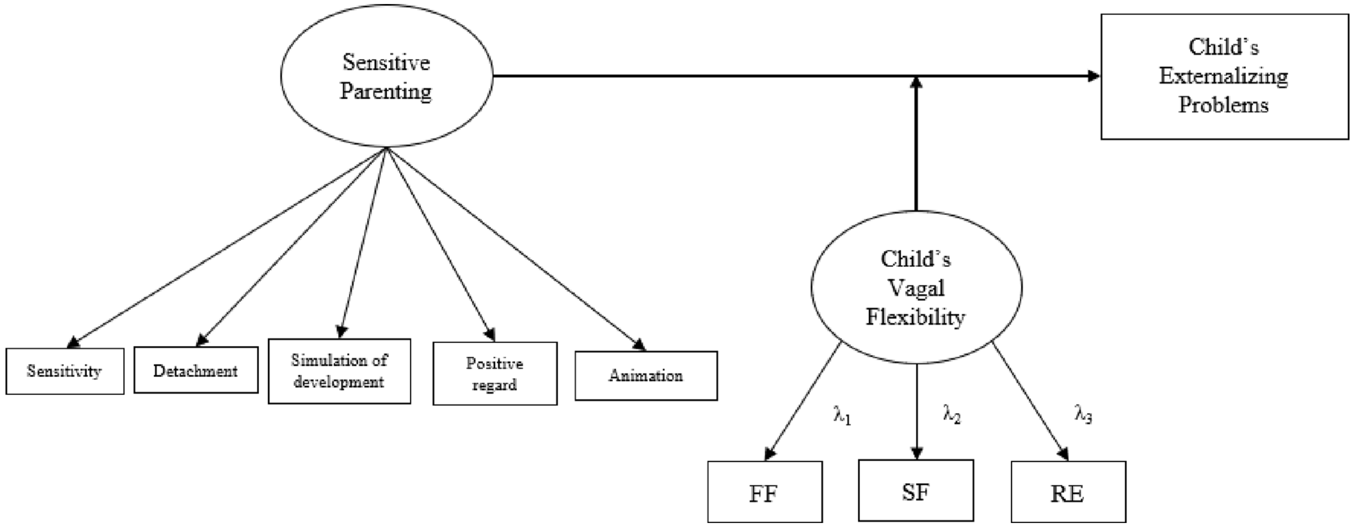

Figure1.
The conceptual model testing the main and interaction effects of observed sensitive parenting behaviors and child's vagal flexibility predicting child's externalizing behavior problems. The construct of vagal flexibility or the infant's dynamic and non-linear patterns of RSA changes across the episodes of face-to-face still-face paradigm was characterized and modeled through the latent slope factor in the latent basis growth curve model.
Note. FF = Mean RSA during the face-to-face episode, SF = Mean RSA during the still-face episode, RE = Mean RSA during the reunion episode.

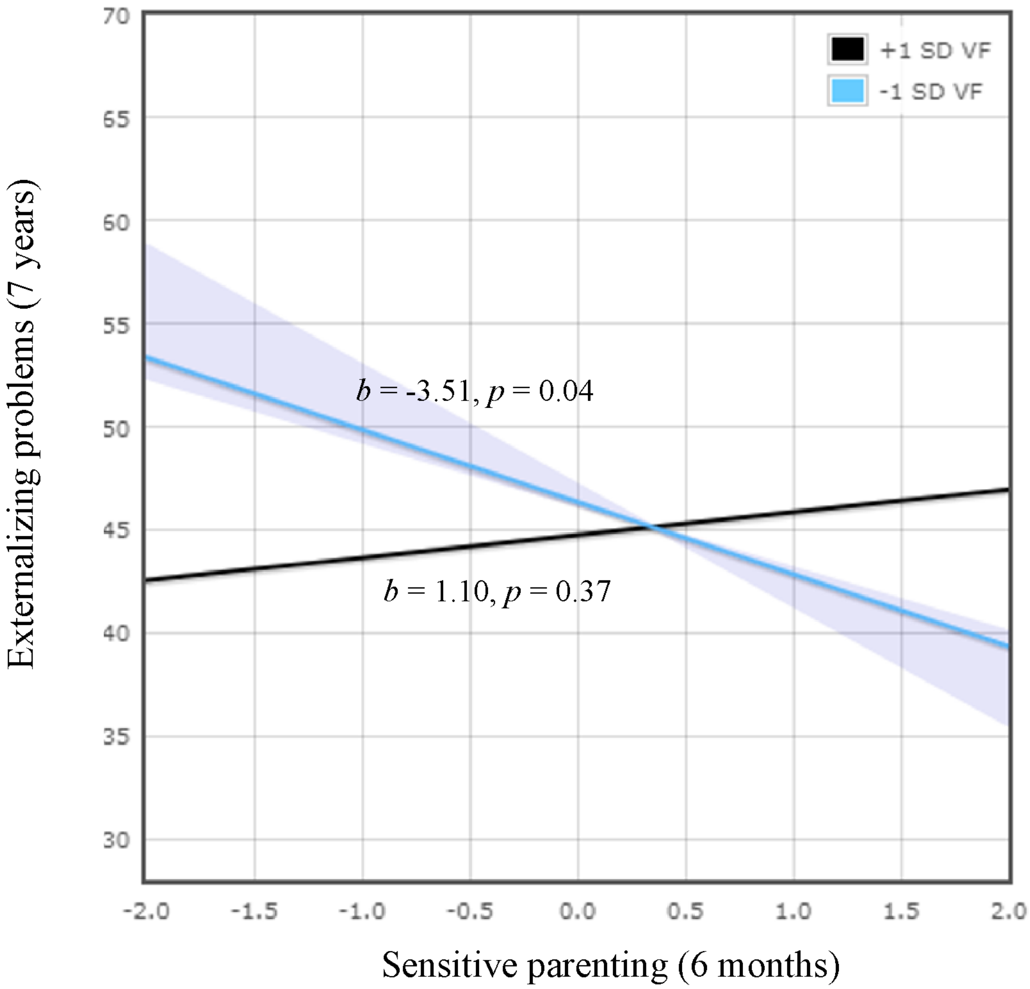

Figure 2.

Association between observed sensitive parenting and children's externalizing problems moderated by children's vagal flexibility (VF) across the FFSFP. Slopes are plotted at low (−1*SD*) and high (+1*SD*) levels of infants' VF. The shaded area represents the point at which sensitive parenting predicts externalizing problems for children demonstrating low levels of VF.

Table 1.

Zero-order Bivariate Correlations Between Study Variables

	1	2	3	4	5	6	7	8
1. Sex (Male= 1)	–							
2. Child Race (0=AA; 1=EA)	0.08	–						
3. Poverty Status	0.01	0.19**	–					
4. Sensitive Parenting (6m)	0.06	0.29**	0.41**	–				
5. Externalizing Behaviors (84m)	0.07	0.02	−0.24**	−0.12	–			
6. RSA, *FF* (6m)	0.01	−0.20*	−0.08	−0.08	−0.06	–		
7. RSA, *SF* (6m)	0.04	−0.24**	−0.09	0.01	−0.00	0.75**	–	
8. RSA, *RE* (6m)	0.03	−0.19*	−0.10	−0.15	0.03	0.80**	0.75**	–
Sample Size	206	206	206	175	131	112	108	104
Mean	0.5	0.5	0.48	1.00	42.03	3.57	3.41	3.49
Standard Deviation	–	–	0.50	0.00	9.10	0.97	1.03	1.00

Note. RSA = respiratory sinus arrhythmia, *FF* = face-to-face episode, *SF* = still-face episode, *RE* = reunion episode, *AA* = African American, *EA* =European American.

* $p \leq .05$,

** $p \leq .01$

Table 2.

Unstandardized and Standardized Estimates from Structural Equation Models Examining Direct and Interactive Effects in the Prediction of Externalizing Behavior Problems at Age 7 years

	Main Effects		Interactive Effects	
	B (*β*)	**95% CI**	**B (*β*)**	**95% CI**
Main effects				
Child Sex	1.18(0.06)	−1.85, 4.20	1.32(0.07)	−1.66, 4.31
Child Race	1.25(0.07)	−2.07, 4.57	1.20(0.06)	−2.05, 4.46
Poverty Status	−4.48(−0.24)*	−8.28, −0.69	−4.03(−0.22)*	−8.08, 0.02
Sensitive Parenting	−0.40(−0.04)	−2.26, 1.45	−1.20(−0.13)	−3.34, 0.94
Latent Intercept	−0.21(−0.02)	−2.58, 2.16	−0.62(−0.06)	−2.77, 1.51
Vagal Flexibility (Latent Slope)	−0.09(−0.01)	−1.56, 1.38	−0.81(−0.09)	−4.17, 2.56
Interaction				
Vagal Flexibility × Sensitive Parenting	–	–	2.31(0.25)*	0.22, 4.39

Note.

* $p < .05$,

** $p < .01$; CI = Confidence Interval