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Children's dynamic RSA change during anger and its relations with parenting, temperament, and control of aggression☆

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Abstract

This study examined the moderating effects of child temperament on the association between maternal socialization and 4–6-year-old children's dynamic respiratory sinus arrhythmia (RSA) change in response to anger-themed emotional materials ($N = 180$). We used latent growth curve modeling to explore adaptive patterns of dynamic RSA change in response to anger. Greater change in RSA during anger-induction, characterized by more initial RSA suppression and a subsequent return to baseline, was related to children's better regulation of aggression. For anger-themed materials, low levels of authoritarian parenting predicted more RSA suppression and recovery for more anger-prone children, whereas more authoritative parenting predicted more RSA suppression and recovery for less anger-prone children. These findings suggest that children's adaptive patterns of dynamic RSA change can be characterized by latent growth curve modeling, and that these patterns may be differentially shaped by parent socialization experiences as a function of child temperament.

Keywords

Children; Respiratory sinus arrhythmia; Autonomic flexibility; Emotion regulation; Anger; Aggression; Differential susceptibility; Goodness-of-fit

1. Introduction

Variation in the functioning of physiological systems likely underlies individual differences in the development of emotion regulation (Porges, 2007). One such system is reflected in parasympathetic regulation of cardiovascular activity, which has been linked to young children's ability to regulate their emotions (Beauchaine, 2001; Porges, 2007). How best to model parasympathetic regulation as a dynamic phenomenon remains an issue (Brooker and

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Buss, 2010). In addition, parental socialization and child temperament have been identified as important contributors to children's emotion regulation (Eisenberg et al., 2001), but how these factors jointly contribute to parasympathetic regulation of emotion is unclear. Some research suggests that it is important to consider the moderating effects of child temperament on the relation between parenting and adjustment, including physiological regulation of different emotion states, although few studies have considered this approach to date. In addition, some researchers have argued for the need for methods that are more sensitive to the temporal aspects of physiological regulation. We investigated whether modeling parasympathetic change over the course of anger-induction was related to better behavioral regulation of anger in the form of control of aggression.

1.1. Respiratory sinus arrhythmia (RSA) and emotion

Parasympathetic functioning has been widely studied as a physiological substrate of emotional reactivity and regulation (Blandon et al., 2010; Calkins and Dedmon, 2000). The myelinated vagus nerve is the main mechanism of parasympathetic innervation of the heart, often referred to as vagal tone. Increased vagal tone dampens firing of the sino-atrial node of the heart, resulting in slower heart rate, less sympathetic arousal, and a calmer state. Conversely, suppression of vagal tone supports an increase of sympathetic arousal and mobilization of resources for behavioral coping and defensive responses. Respiratory sinus arrhythmia (RSA) refers to the heart rate variability that corresponds with the natural respiration cycle, and is mainly under the control of the vagus nerve, suggesting that RSA is an appropriate measure of activity in the parasympathetic nervous system (Porges, 2007).

Polyvagal theory provides a framework for understanding RSA functioning in relation to emotion (Porges, 2007, but see Grossman and Taylor, 2007 for critique of polyvagal theory), and proposes that suppression of RSA reflects adaptive orientation and regulatory efforts in response to emotionally challenging events. Greater RSA suppression during emotionally challenging tasks has been associated with better emotion regulation in the form of less negative emotionality and fewer behavioral problems (Calkins and Dedmon, 2000; Calkins and Keane, 2004).

The dynamic nature of RSA activity coincides with theory suggesting that emotion regulation itself is a rapidly changing process that unfolds over time. Thus temporal changes in physiology should drive or correspond with temporal changes in emotion regulation. Some researchers have argued for the need for physiological measures that account for the dynamic nature of emotion (Brooker and Buss, 2010; Thompson et al., 2008). Traditional methods of quantifying RSA change observe the difference between RSA during baseline and task procedures either using arithmetic change scores or standardized residuals. These are static measures of RSA and might limit the ability to capture RSA change within an emotional event as it unfolds over time. In this study we attempted to address this limitation by observing RSA change during stimuli that progress from affectively neutral to emotionally valenced. Our approach differed from traditional methods in that we used latent growth curve analysis to model how children's RSA changed over the course of emotion and whether there were meaningful individual differences in this change (Brooker and Buss, 2010). This alternate method might better capture the temporal nature of dynamic RSA change associated with regulation in addition to the magnitude of RSA change.

1.2. Socialization, temperament and RSA

Parenting practices play a significant role in shaping children's development of emotion regulation. Authoritative parenting that is warm and involved, responsive, and democratic has been associated with children's development of adaptive emotion regulation and fewer externalizing and internalizing behaviors (Hart et al., 2003; Hastings et al., 2008b). Conversely, an authoritarian parenting style, including such behaviors and attitudes as hostility, high control, punitiveness and low responsiveness, is generally associated with poorer emotion regulation in children (Eisenberg et al., 2001; Mills et al., 2011).

Authoritative parents, through their provision of structure and appropriate support, may facilitate their child's management of challenges without interfering with the child's autonomy. Attaining experiences of mastery in this way might provide children with greater opportunity to practice effective emotion regulation and develop healthy physiological regulation. Children's RSA change during emotionally evocative events might be one mechanism by which parent behaviors help shape development of emotion regulation and associated behavioral outcomes. For example, critical and overcontrolling parenting has been found to be associated with lower RSA in a social context, which in turn mediated the association between parenting and behavioral self-regulation (Hastings et al., 2008a). However, a number of studies have failed to find significant associations between parenting and RSA (Kennedy et al., 2004; Rubin et al., 1997). These inconsistent findings suggest that other factors, such as child temperament, might also influence how socialization is related to children's RSA during emotion.

Temperament can be defined as biologically based individual differences in the probability of experiencing different emotions and arousal states (Goldsmith et al., 1987). As such, children's temperament has been found to be associated with characteristic patterns of emotional responsiveness. Difficult, negatively reactive, or anger-prone children have a lower threshold for anger arousal and are slower to calm or soothe (Rubin et al., 1998). Some research has shown that children with different temperaments vary in their patterns of RSA response to emotional stimuli (Blandon et al., 2010; Calkins, 1997; Huffman et al., 1998). For example, RSA suppression during challenging situations has been associated with greater temperamental soothabilty in infancy (Huffman et al., 1998), and greater emotion regulation and fewer behavioral problems in preschool children (Calkins, 1997; Calkins and Keane, 2004). However, other studies have failed to find significant associations between RSA suppression and difficult temperament (Blandon et al., 2010). These inconsistent findings again suggest that simple, direct associations between temperament and RSA might be quite modest, strengthening the argument that both temperament and parenting factors should be considered when studying physiological aspects of children's emotion regulation.

1.3. Biopsychosocial approaches to emotion regulation

Biopsychosocial models provide a conceptual framework for integrating temperament and parenting contributions to emotion regulation. Current models of the interaction between parenting and child temperament differ with regard to their predicted outcomes for children's emotional development. The differential susceptibility to environment hypothesis posits that children with difficult temperaments, or who are highly physiologically reactive, are more susceptible to environmental influences such as parenting, for better or worse (Ellis et al., 2011). By this model, difficult children are likely to have higher rates of problems related to poor emotion regulation when raised in adverse environments, but lower rates when raised in supportive ones. A number of studies have found significant interaction effects between parenting and difficult temperament in support of these hypotheses (Klein Velderman et al., 2006; Pluess and Belsky, 2010). Conversely, diathesis-stress perspectives propose that some individuals have an inherent vulnerability to be adversely affected by stressful environments, but are not more susceptible to the benefits of positive environments (Zuckerman, 1999). A third perspective, goodness-of-fit, proposes that child outcomes depend on the interplay of various combinations of parenting characteristics and temperament qualities (Chess and Thomas, 1999).

While a number of investigators have applied such biopsychosocial models to the development of reported or observed measures of children's emotion regulation, fewer studies have considered their relevance for understanding children's emotional physiology. Gilissen et al. (2007) found that temperamentally inhibited children had stronger sympathetic reactions to fear inducing stimuli if they had insecure, compared to secure, attachments to their mother. Conversely, Burgess et al. (2003) did not find that temperament moderated associations between children's attachment security and their RSA or heart rate. It is still unclear which factors might influence the development of individual differences in RSA change during other emotions, specifically anger. Poorly regulated anger is linked to increased aggression (Berkowitz, 1990; Denson et al., 2012). More research is needed that considers the temporal aspects of RSA change as well as magnitude to determine whether there might be joint contributions of parenting and temperament to children's dynamic RSA change during anger, and whether this dynamic RSA change is related to behavioral regulation of anger as reflected in control of aggressive behaviors.

1.4. Current study

In this study we used latent growth curve modeling to quantify children's dynamic RSA change during an anger-induction film clip. This method provides more information about the temporal variation of RSA, and magnitude of RSA change at different points in time (in relation to children's starting or intercept RSA value), than traditional methods of capturing RSA change (i.e., arithmetic change scores and standardized residual scores). We predicted that this dynamic measure of RSA change in response to anger would be associated with children's behavioral regulation of anger-states (i.e., control of aggression). Furthermore, we examined the moderating role of children's anger-prone temperament on the relations between maternal parenting style and dynamic RSA change. Two alternative hypotheses were evaluated, to contrast the conflicting predictions of the biopsychosocial models described earlier. According to the differential susceptibility perspective, one would predict that more anger-prone children would show a more adaptive pattern of dynamic RSA change when mothers were either low in authoritarian or high in authoritative parenting, but a less adaptive pattern of dynamic RSA change when mothers were high in authoritarian or low in authoritative parenting. Conversely, according to the diathesis-stress perspective, one would expect more anger-prone children to show less adaptive dynamic RSA change when mothers were more authoritarian, but to not be different from other children under authoritative parenting conditions.

2. Method

2.1. Participants

This study included 180 children (95 boys, 85 girls) and their mothers. Children were age 4.0–4.9 years (n = 98) or 6.0–6.9 years (n = 82) at screening. Most lab visits occurred less than 3 months after screening, but there were four younger and eight older children who had turned 5 or 7 years old before being tested at the lab. Children's age at the lab visit ranged from 4.08 to 7.37 years (M = 5.58, SD = 1.10). There were 146 children tested in English and 34 children tested in French. Families were predominantly Caucasian (78.7%) and middle- to upper-middle socioeconomic status (M = $79,700 CND, SD = $43,470, Mode = $50–60,000, range from less than $10,000 to over $220,000). Most mothers had some college education (M = 14.79 years, SD = 2.30). Families were recruited with advertisements administered via direct mailing to families and distribution of letters through preschools and elementary schools. Some advertisements or letters specifically targeted families of children with disruptive behaviors, including words such as “hitting,” “difficult,” and “yelling.” Interested families contacted the lab by phone to learn more about the study and complete a screening for inclusion criteria, which were child age (4 or 6 years), child living with mother, and 6 year olds being enrolled in first grade. The Child Behavior Checklist (CBCL; Achenbach and Rescorla, 2000, 2001) was administered in order to assess targeted recruitment and oversampling for children with aggression and externalizing problems, but was not used as part of the inclusion criteria for the study. Children with serious cognitive or physical challenges that might interfere with their ability to understand or complete procedures were excluded from the study. Mothers were financially compensated for their participation and children received a T-shirt.

There was incomplete data for 34 children either due to mothers not reporting child temperament or parenting practices, children refusing to wear the cardiac monitor, or not providing useable cardiac data during the video mood induction procedure. Thus, there were 146 children with complete data and 34 with partial data for the current analyses. Full information maximum likelihood (FIML) estimation was used to treat missing data (Schafer and Graham, 2002). FIML uses all of the available data to estimate the model parameters rather than impute missing data values.

2.2. Procedure

Families were recruited through direct mailing, letters distributed to daycares, preschools and elementary schools, and advertisements in local free magazines. Parents interested in participating in the study contacted the laboratory and were screened with items on the age-appropriate externalizing sub-scale of the CBCL. Those families whose children met the inclusion criteria visited the laboratory for mother and child participation in the study. Testing at the laboratory lasted approximately 3 h and was conducted in the child's first language (French or English). Only activities related to the current analyses are described here.

One hour into the laboratory visit, two adhesive electrodes were attached to the upper portion of the child's chest, under the shirt in a cross-chest fashion, to record inter-beat intervals (IBI). After the monitor was attached, several baseline physiology procedures were performed which do not pertain to the current analyses. Once children were comfortable with the monitor, mothers left the testing room. Subsequently, children were instructed to sit quietly and watch a 7.5-min mood induction video showing a child experiencing five emotionally evocative events. Cardiac data were collected during children's viewing of the mood induction video. Approximately 90 min after the video, children were administered the "Me-Not Me" interview to assess their self-perceptions, involving forced-choice selections between pairs of statements that endorsed versus rejected specific behaviors, feelings or thoughts.

2.3. Measures

2.3.1. Questionnaires—To assess children's temperamental anger-proneness, mothers completed items from the *Colorado Childhood Temperament Inventory (CCTI*; Rowe and Plomin, 1977) and Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001). Thirteen items from the CCTI and CBQ were aggregated to form an index of children's anger-prone temperament (e.g., "temper tantrums", $\alpha = .87$). Mothers also completed the *Parenting Styles and Dimensions Questionnaire* (Robinson et al., 2001) to assess authoritarian (20 items: e.g., "I use punishment more than reason.", $\alpha = .85$) and authoritative parenting (27 items: e.g., "I comfort my child when he/she is upset.", $\alpha = .85$).

2.3.2. "Me-Not Me" interview—In the "Me-Not-Me" interview, the experimenter put a box in front of the child with the child's name printed on the front of the box. The experimenter explained that she would read the sentence printed on each of two cards, and the child needed to decide which sentence described him or her and then take that card and put it in the box. The sentences were identically worded except for endorsing or not endorsing the action, feeling or thought expressed in the sentence (e.g. "I like" versus "I do not like"). Children were taught the definition of "describe," and completed a series of practice trials (e.g. "I do not like to play." "I like to play.") prior to completing the interview. Embedded in the interview were four sentence pairs that described not using versus using aggression in response to social situations (e.g., "I do not say mean things about other children when they make me mad." [coded 1] "I say mean things about other children when they make me mad." [coded 0]). The mean of children's score across the four pairs of cards was used as the index of anger regulation (possible range 0–1; $\alpha = .72$).

2.3.3. Emotional vignette—Child cardiac activity was recorded while they watched portions of the *Mood Induction Stimulus for Children* (MISC; Cole et al., 1990; see Hastings et al., 2000). The shortened MISC showed a series of five emotionally evocative vignettes on video, including scenes of a child experiencing anger in the context of a mother–child conflict over watching television. This vignette lasted 1 min, starting with a 15-s set up of the vignette in a neutral tone, then 15-s of introducing an emotional event, followed by intensifying the emotional content for another 15-s, and ending with a 15-s mildly positive resolution. Emotion during the two middle epochs was conveyed through the characters' vocal intonations, repeated emotional phrases (e.g., "You're making me angry!" "I'm mad at you, Mommy!"), stereotyped emotional expressions on characters' faces, and evocative musical scores. Each vignette was preceded by a 15-s distracter section of non-emotional material (shimmering stars and soothing music).

2.3.4. Cardiac data—Cardiac data were collected using a Minilogger Series 2000 ambulatory cardiac monitor (Mini-Mitter Company, Inc., 1999). IBI data were inspected and edited for recording artifacts and outliers using the MXedit software program (Delta Biometrics, Inc., Bethesda, MD). Inspection and editing of the data was done by trained, reliable editors, as outlined by Berntson et al. (1997). For the anger-theme vignette presentation, 152 children had useable IBI data for MXedit processing. RSA for each vignette section was computed from IBI data using Porges' (1985, 1988) algorithm in MXedit. The frequency band-pass parameters to quantify RSA were set to range from .24 to 1.04 Hz, which is the frequency band of young children's natural respiration (Huffman et al., 1998), and sampling rate was set at 250 ms. The IBI data were chunked into 15-s epochs corresponding with the vignette content (non-emotional and emotional segments), and RSA was calculated for each epoch. The 21-point rolling algorithm developed by Porges can take advantage of the fact that young children have a greater number of IBI than would adults within a relatively brief sample in order to compute reliable measures of RSA (Porges, 1985), and 15-s is a common epoch length in developmental studies using shorter tasks (Calkins and Dedmon, 2000; Huffman et al., 1998).

During cardiac data collection, children were seated with an experimenter standing behind them. No children got out of their seats while viewing the emotional vignette. The accelerometer built into the cardiac monitor recorded essentially no gross motor movement; hence there was not enough variability to include children's movement as a covariate in our analyses. Furthermore, research has shown that RSA is not influenced by children's slight motor movements during engagement in simple, non-exercise tasks (Porges et al., 2007).

2.4. Analyses

Latent growth curve modeling was performed using Amos version 20 (Arbuckle, 2006) to examine intra- and interindividual RSA change across the four 15-s epochs during the anger-induction video. This analysis estimated latent factors for the initial RSA score (intercept) and change in RSA over the course of anger-induction (slope) with loadings on the manifest RSA measurements at each time point (epoch). For all models tested, the intercept was set to represent RSA at the first epoch of the vignette (neutral content). Different unconditional growth curves were tested and compared to determine which model best explained change in RSA. We estimated a no-growth, linear, quadratic, and a latent basis model in which some of the weights for the latent slope factor predicting RSA were estimated from the data (McArdle and Epstein, 1987). The latent basis model is similar to a linear model in the sense that the rate of change is represented by one latent slope factor. However, the latent basis model is more flexible and can be nonlinear because the basis coefficients at each time point are not equal (Grimm et al., 2011). Several fit indices were used, including χ^2, the Comparative fit index (CFI; Bentler, 1990) and the root mean square error of approximation (RMSEA; Browne and Cudeck, 1993) with a 90% confidence interval. Good fit is indicated by CFI values higher than .95, and RMSEA values lower than .06 (Hu and Bentler, 1995). Models with higher CFI values and lower RMSEA values are considered to be better fitting (Browne and Cudeck, 1993). χ^2 difference tests were used to compare models. Model parameters were tested for significance by observing critical ratios. The latent factors were allowed to covary in order to control for shared variance between them. RSA error variance at each time point was constrained to be equal, except in the latent basis model (discussed below).

In addition to defining an unconditional model of dynamic RSA activity, we were also interested in predicting variability in the latent slope of RSA. Path analysis was used to examine the effects of child demographics (sex, age), parenting, temperament, and parenting by temperament interactions on latent change in RSA. In order to establish an adaptive pattern of dynamic RSA activity, change in RSA was used as a predictor of children's non-aggression.

3. Results

Descriptive statistics are presented in Table 1. Zero-order correlations between child sex, child age, temperament, parenting style, child control of aggression, and RSA for each epoch during the anger-themed vignette are presented in Table 2. Mother's reports of authoritarian and authoritative parenting were moderately negatively correlated. Mothers who reported more anger-prone temperaments in their children described their parenting as more authoritarian and less authoritative. Children who reported more control of aggression were older, were described by mothers as less anger-prone, and had more authoritative but less authoritarian mothers. RSA during each epoch was not significantly correlated with mother- or child-reported measures. Given that sex was associated with parent-reported anger-proneness, we re-examined the correlations between anger-proneness and the other variables with the effects of sex removed. These partial correlations did not differ from the zero-order correlations.

To test for differences in RSA across the four epochs of the anger-induction video, a 2 × 2 × 4 (Age Group × Sex × Epoch) mixed analysis of variance (ANOVA) was performed. Epoch was the repeated measure and Age and Sex were between subject variables. Only the main effect of epoch was significant, $F(3, 144) = 4.75$, $p < .05$. Follow up analyses showed that RSA for epoch 2 was significantly lower than RSA for epoch 1, 3, and 4, which were not significantly different from each other. Thus, on average, there was significant RSA suppression from epoch 1 to 2, followed by significant recovery or augmentation from epoch 2 to 3, followed by non-significant change in epoch 4.

The primary analysis proceeded in three steps. First, we tested several unconditional growth models, including models of no-growth, linear growth, quantitative growth, and latent basis growth, to determine which model best described RSA change over the course of the anger-induction vignette. Second, we tested children's self-reported non-aggression as an outcome of the latent intercept and slope factors of RSA. Third, we examined a conditional growth model in which child age and sex, anger-prone temperament, authoritarian and authoritative parenting, and interactions between temperament and parenting predicted individual differences in the latent slope factor of RSA.

3.1. Unconditional latent growth curve model

Little's MCAR test showed that the data were missing completely at random ($\chi^2 = 20.74$, $df = 17$, $p = .238$), suggesting that the use of FIML for our analyses would not produce biased parameter estimates. Fit statistics for the no-growth, linear, quadratic, and latent basis models are presented in Table 3. When initially attempting to fit a latent basis growth model, error variance for RSA was constrained to be equal for each epoch. However, Amos could not estimate this model due to a not positive definite error. Further investigation revealed that the estimated residual error variance at epoch 2 was negative but not significantly different from zero. As a result, we constrained the error variance at epoch 2 to zero. Goodness of fit criteria for the latent basis model showed the best fit, $\chi^2(6) = 3.22$, $p = .78$, RMSEA = .00, CFI = 1.00. The intercept was set to represent initial RSA during the neutral content section of the anger-induction video (epoch 1). Based on the lower mean RSA during the first emotional content section of the video (epoch 2) than during the neutral content section (epoch 1), the slope factor loadings for the first two time points were set to 0 and −1 to represent initial RSA suppression. The slope factor loadings for the emotion continuation (epoch 3) and positive resolution sections (epoch 4) of the emotion induction video were freely estimated in order to model a potential nonlinear pattern of RSA change. The latent basis model was used for subsequent analyses.

The estimated means and variances for the intercept and slope of RSA were significant. The intercept ($M = 6.38$, $p < .001$) represented the average RSA level during the neutral portion of the anger-induction video (epoch 1). The significant slope ($M = .21$, $p < .01$) in conjunction with the latent basis coefficients (0, −1, −.02, .12) indicated a normative pattern for the sample of nonlinear change in RSA across the anger-induction video. This means that the average RSA at each epoch is a function of the interaction between the mean slope value and that epoch's latent basis coefficient. Children initially suppressed RSA during the introduction of emotional content (epoch 2), recovered to starting RSA levels during the continuation of emotional content (epoch 3), and slightly augmented RSA during the positive resolution of the vignette (epoch 4). The significant variability in the latent intercept and slope factors indicated that there were meaningful individual differences in children's initial RSA levels and RSA change over the course of the anger-induction video. The intercept and slope of RSA were not significantly correlated ($r = .16$, $p = .17$).

In order to test that this pattern of dynamic RSA change was associated with adaptive emotion regulation, we estimated the effects of the latent intercept and slope factors predicting child-reported control of aggression. We included an error residual term (i.e., disturbance) for control of aggression to represent its unexplained variance (Kline, 2010). The latent slope of RSA was positively associated with control of aggression ($\beta = .23$, $p <$.

05). Children who showed more dynamic change in RSA in response to anger, characterized by greater suppression during the introduction of emotional content and recovery to starting RSA levels during the anger-induction video, reported more control of aggression, whereas children who showed less change in RSA reported more aggression. Variability in the latent intercept factor of RSA did not significantly predict control of aggression ($\beta = -.03$, $p = .74$).

In a follow up analysis, we tested whether the significant association between latent slope of RSA and control of aggression could be explained by early RSA suppression or later RSA augmentation alone. Standardized residuals were used to represent change from epoch 1 to epoch 2 (suppression) and epoch 2 to epoch 3 (augmentation). RSA change from epoch 1 to epoch 2 tended to be associated with control of aggression, $r = -.17$, $p = .06$, and RSA change from epoch 2 to 3 was not significantly associated with control of aggression, $r = .09$, $p = .28$. Thus, the association between control of aggression and the dynamic RSA slope across epochs was stronger than the associations between control of aggression and specific components of RSA change between epochs.

3.2. Conditional latent growth curve model

The significant variability in the latent intercept and slope of RSA indicated that they could be used as dependent variables. The predictors of interest were child demographics (age, sex), authoritative and authoritarian parenting, anger-prone temperament, and interactions between parenting and temperament. Centered variables were used to form continuous interaction variables, and centered variables were entered into analyses (Aiken and West, 1991). The predictors of latent intercept and slope of RSA were simultaneously estimated while controlling for correlations between them. However, we found no significant associations between independent variables and the latent intercept factor. As a result of this and the fact that the latent intercept factor was not significantly related to control of aggression, we did not include the intercept as a dependent variable in our conditional model analyses. Fig. 1 presents the results for the conditional model.

The model accounted for 19% of the variance in the latent slope of RSA. There were significant main effects for child age ($\beta = .19$, $p < .05$) and sex ($\beta = .17$, $p < .05$) predicting the latent slope of RSA. Older children and girls showed greater dynamic RSA change than younger children and boys. There were no significant main effects for anger-prone temperament or parenting predicting latent slope of RSA, but both interactions of parenting by anger-prone temperament were significant. Examining the authoritarian interaction, more anger-prone children showed less dynamic RSA change (i.e., lower latent slope values) under conditions of highly authoritarian parenting, but more dynamic RSA change under low authoritarian parenting conditions ($\beta = -.35$, $p < .01$) (see Fig. 2); the slope for less anger-prone children was not significant ($\beta = .06$, $p = .70$). Examining the interaction involving authoritative parenting, more authoritative parenting predicted more dynamic RSA change (i.e., higher latent slope values) for less anger-prone children ($\beta = .32$, $p < .05$) (see Fig. 3); the slope for more anger-prone children was not significant ($\beta = -.12$, $p = .30$).

Based on the conditional latent basis model, Fig. 4 compares the estimated RSA trajectories for high anger-prone children under different authoritarian parenting conditions to low anger-prone children under different authoritative parenting conditions. Low anger-prone children with more authoritative mothers showed more dynamic RSA characterized by greater RSA suppression during the introduction of emotional content (epoch 2) and more RSA recovery during the continuation of emotional content (epoch 3) segments of the video. High anger-prone children with less authoritarian mothers showed the same pattern but to a stronger degree. High anger-prone children with more authoritarian mothers showed no change in RSA. Less anger-prone children with less authoritative mothers slightly augmented their RSA during the introduction of emotional content, but overall had very little dynamic RSA change.

4. Discussion

In this study, we used latent growth curve modeling to investigate children's dynamic RSA activity in response to an anger-induction video. We found that children in general showed RSA suppression during the introduction of anger-themed material, followed by RSA returning to initial levels during the continuation of anger-themed content, and non-significant change in RSA levels during the subsequent positive resolution of the emotional episode. This pattern of dynamic RSA suppression and recovery, which many researchers would consider to be an adaptive response to emotional stimuli (Calkins, 1997), was positively associated with children's control of aggression, offering evidence of validity for our interpretation of the dynamic slope as good parasympathetic regulation of anger. We also examined the moderating role of child temperament on the association between parenting and children's dynamic RSA change (i.e., latent slope of RSA) during anger. In accordance with the differential susceptibility to the environment perspective (Ellis et al., 2011), more authoritarian parenting predicted the less adaptive response of less dynamic RSA change in response to anger-themed stimuli, but only for the children who were more highly anger-prone. Conversely, children who were anger-prone evidenced the most dynamic RSA change when they experienced low levels of authoritarian parenting. Less consistent with the differential susceptibility model, however, it was the children who were less anger-prone who appeared more sensitive to the influences of authoritative parenting on parasympathetic regulation of anger.

In the unconditional latent basis model, we found the mean of the latent slope of RSA to be significant. In addition, the estimated loadings on the latent slope factor of RSA indicated nonlinear change. These findings suggested that children, on average, showed RSA suppression from the neutral content (epoch 1) to the introduction of emotion (epoch 2), then recovery to initial RSA levels during the continuation of emotion (epoch 3), and maintained these RSA levels during the positive resolution segment at the end (epoch 4). Other studies indicate that children have lower RSA in response to emotional challenge than during baseline measures (Calkins and Dedmon, 2000; Calkins and Keane, 2004), but few have considered RSA change as a dynamic process. Our findings indicate that temporal aspects of RSA change can be modeled using latent growth curve analysis, and that children may show nonlinear RSA change over the course of an emotional episode.

We also found significant variability in children's slope of RSA. Children's greater dynamic RSA change (i.e., higher values for slope) was related to better control of aggression, in accord with a previous study showing that measuring dynamic RSA is informative for children's emotion regulation (Brooker and Buss, 2010). Brooker and Buss found that toddlers who displayed later RSA suppression during a fear-eliciting episode were more at risk for anxiety problems than toddlers that showed earlier RSA suppression. Our findings expand on this work by considering a different affective context and emphasizing the importance of both RSA suppression and recovery. These findings are in line with the perspective that RSA is a marker of autonomic flexibility associated with emotion regulation capacity and that RSA suppression supports adaptive coping (Beauchaine, 2001; Porges, 2007; Thayer and Lane, 2000). Our findings suggest that dynamic measures of RSA can provide a clear illustration of flexible engagement and disengagement of the vagus nerve during emotion, and that this pattern of flexible RSA change is related to positive emotional and social engagement with the environment. In the context of watching a developmentally appropriate emotion induction video, children's initial RSA suppression may support orienting to emotionally salient events and coping efforts. Subsequent RSA recovery may be important for reinstating calm social engagement with the environment. Further research will be necessary to better understand the role of RSA change at different points in time during an emotional episode. In addition, future research should consider dynamic measures of RSA in other emotional contexts, such as happiness and sadness.

It should be noted that additional analyses using standardized residuals from epoch to epoch did not find significant associations between RSA change and control of aggression. Our findings imply that although the initial RSA suppression was the most salient aspect of RSA change, it did not account for children's effective control of aggression outside of the context of RSA flexibility (both suppression and recovery) in the full latent basis model. Thus, our findings would have gone unnoticed using more traditional measures of RSA change.

We found significant main effects for children's sex and age predicting dynamic RSA during anger. Girls and older children had more nonlinear change in parasympathetic levels over the anger video than boys and younger children. These findings are in accordance with research showing that girls tend to regulate anger and aggression better than boys (Card et al., 2008; Keenan and Shaw, 1997), and that children make gains in anger regulation during the transition from preschool to kindergarten (Lemerise and Dodge, 2008). Thus, these associations can be seen as further support for the validity of the interpretation of greater dynamic slopes being reflective of more effective emotion regulation.

We also found significant interaction effects between anger-prone temperament and authoritarian and authoritative parenting predicting individual differences in dynamic RSA change. These findings were in accord with proposals that parenting may affect children's emotion regulation differentially for children with different characteristics. To the authors' knowledge, this is one of the first studies to apply this approach to understanding children's parasympathetic regulation of anger. Depending on authoritarian socialization experience, more anger-prone children showed both greater and lesser amounts of dynamic RSA change in response to anger, which polyvagal theory posits as the most and least adaptive physiological responses, respectively, to emotionally challenging events (Porges, 2007). This finding is consistent with some behavioral findings reported in previous studies (e.g.

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Klein Velderman et al., 2006), indicating that parent socialization is more important for children with difficult temperaments for better or worse.

A divergent pattern of findings was evident in the observation that authoritative parenting was related to more dynamic RSA change for less anger-prone children only. This contradicts a differential susceptibility perspective under which experiencing the supportive context of authoritative parenting would be expected to promote emotion regulation in more anger-prone children. A lack of authoritarian parenting may be important for promoting difficult children's adaptive RSA response during anger, whereas less anger-prone children may benefit more from the presence of authoritative parenting shaping their anger regulation. In keeping with the goodness-of-fit hypothesis (Chess and Thomas, 1999) these findings suggest that children thrive in parenting contexts that match the needs and characteristics of their temperaments. Less flexible or dynamic RSA change during anger could be one mechanism by which anger-prone children with authoritarian parents develop externalizing problems (Belsky et al., 1998; Rubin et al., 2003). Conversely, parents who avoid being authoritarian with their anger-prone children might help their children to manage their angry arousal more effectively, improving their prospects for healthier adjustment. Furthermore, flexible RSA change during anger might be one mechanism by which authoritative parents support their children's development of effective emotion regulation and social competence (Hart et al., 2003).

It should be recognized, though, that authoritative versus authoritarian parenting are not opposite ends of a dimension, and parents are not consistent and polarized in their use of these "styles" (Hastings et al., 2007). Within this sample, the use of authoritative and authoritarian practices was only moderately negatively correlated. A parent might use more authoritative behaviors in one context but more authoritarian techniques in another, with these different approaches being appropriate to the varying contexts and parenting goals (Hastings and Grusec, 1998). The current findings could be taken to mean that children can differ in their sensitivity to various aspects of their childrearing experiences, with some children reacting more to times when parents are strict or harsh, whereas other children react more to times when parents are supportive and even-handed.

There are limitations to this study that must be considered. Maternal reports were used to assess parenting style and child temperament which could have contributed common-source variance, although this study was not focused on the relation between temperament and parenting. Our study design was unable to address the possibility that the association between temperament and parenting reflected a gene–environment correlation. Given the contemporaneous measurement of variables and correlational design of the study, causal relations cannot be inferred and the implied direction of effects in our interpretations, of parenting and temperament shaping RSA, is hypothetical. Respiration was not assessed and statistically controlled for, although there is some debate as to whether this is necessary (Denver et al., 2007; Ritz, 2009). One could also question the assumption of a linear association between dynamic RSA change and adaptive physiological regulation. Research has yet to thoroughly address whether there is such a thing as too much RSA suppression, which might support an over-exaggerated fight/flight response that would be inappropriate in some contexts, such as watching a brief, developmentally appropriate video. Although

Fig. 4 presents estimated trajectories of RSA change, there are other possible patterns of change that could account for deviations from the average dynamic slope value, such as late RSA suppression or early RSA suppression without recovery. Different patterns of deviation from typical slope might be associated with different kinds of difficulty with emotion regulation. Autonomic regulation of emotion should be recognized as involving dynamic changes in sympathetic influences as well as parasympathetic. Finally, we did not test for associations between dynamic RSA and concurrent observed behavior; this will be important to address this in future studies.

In response to these issues, future research efforts should use multi-method approaches to explore the meaning of dynamic RSA change in different emotional contexts. Examining children's dynamic RSA during negative emotional events such as frustration tasks, or positive emotional events such as free play or receiving a gift, might produce stronger associations with parenting and temperament. Longitudinal designs with multiple assessments of parent socialization, temperament, and RSA at different time points would allow more definitive inferences to be made about causality and direction of effects. Finally, RSA is only one mechanism of physiological emotion regulation. Using biopsychosocial models to study other physiological processes may improve our understanding of the multiple factors that influence the development of emotion regulation.

5. Conclusion

This study presented a possible method for capturing temporal aspects, in addition to measuring magnitude, of children's RSA change during an emotional event as it unfolds over time. We found evidence for nonlinear change in RSA over time in response to anger, and for significant individual differences in children's dynamic RSA change, and we showed that this change was related to children's regulation of anger-states in the form of control of aggression. Furthermore, this study provided evidence for a biopsychosocial model of children's developing physiological regulation of emotion. The extent to which children had anger-prone temperaments moderated the associations between their parenting experiences and dynamic RSA change in ways that provided partial support for the differential susceptibility to the environment hypothesis.

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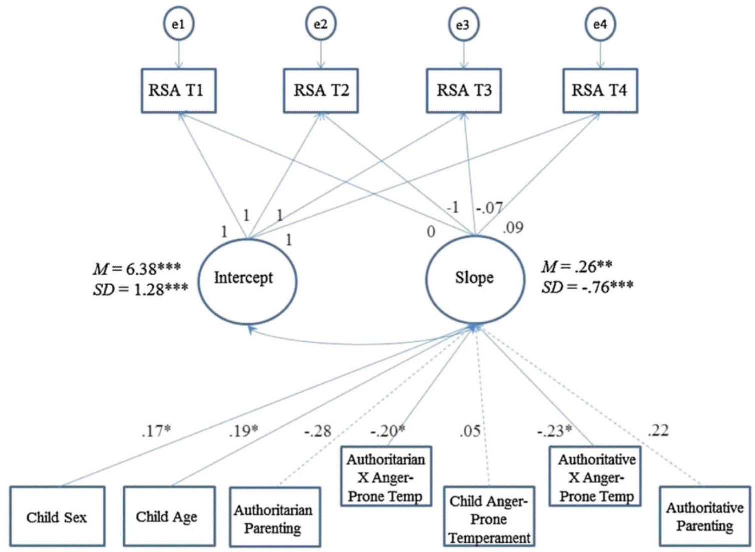

Fig. 1.

Conditional latent basis model with standardized path coefficients for child age, child sex, authoritarian parenting, authoritative parenting, child anger-prone temperament, the interaction of authoritarian parenting by anger-prone temperament, and the interaction of authoritative parenting by anger-prone temperament predicting slope of RSA during the anger-induction video.

Note. $^{\dagger}p < .10$, $*p < .05$, $**p < .01$, $***p < .001$, two-tailed.

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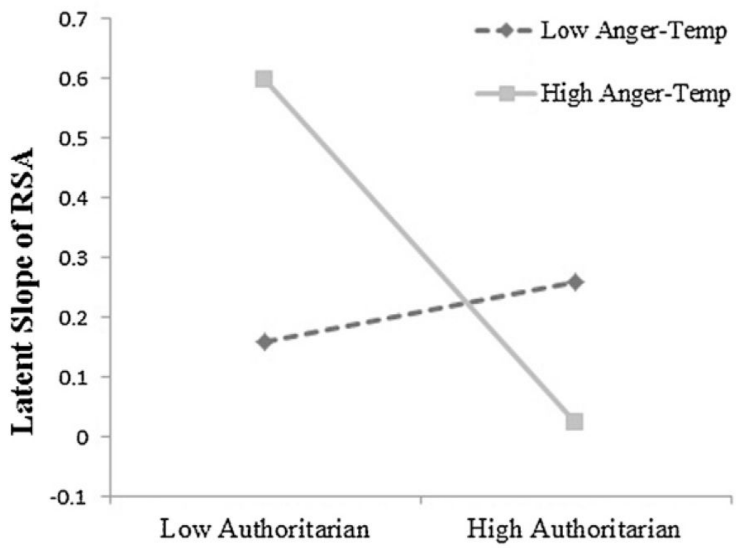

Fig. 2.

Authoritarian parenting is associated with less dynamic RSA change during the anger vignette for more anger-prone children.

Note. RSA = respiratory sinus arrhythmia.

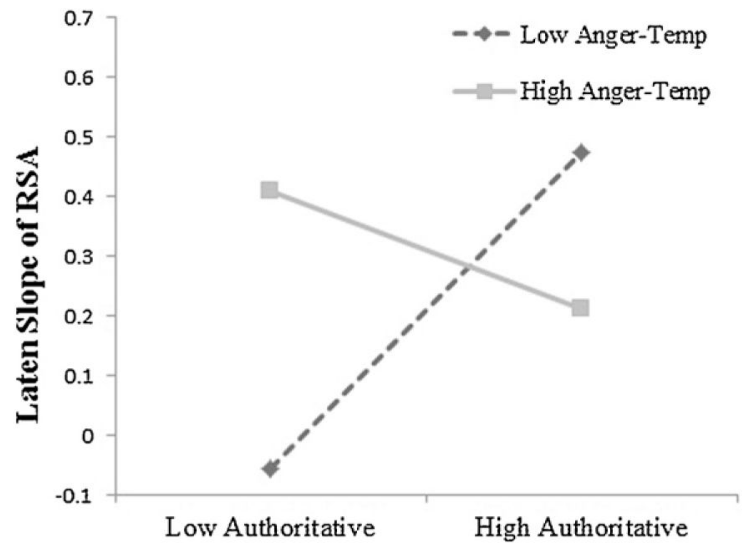

Fig. 3.
Authoritative parenting is associated with more dynamic RSA change during the anger vignette for less anger-prone children.
Note. RSA = respiratory sinus arrhythmia.

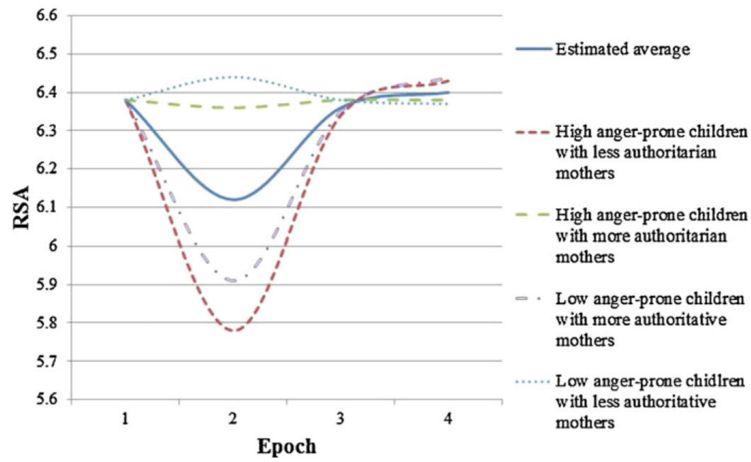

Fig. 4.

Estimated RSA trajectories during the anger-induction video for high anger-prone children under different authoritarian parenting conditions, low anger-prone children under different authoritative parenting conditions, and the average RSA trajectory for all children.

Notes. Epoch 1 = neutral content, epoch 2 = introduction of emotional content, epoch 3 = continuation of emotional content, epoch 4 = positive resolution.

Table 1

Summary statistics.

	N	Min.	Max.	*M*	*SD*
Age	180	4.08	7.37	5.58	1.10
CCTI and CBQ anger-prone temp	176	1.46	6.77	4.41	1.04
PSDQ authoritarian parenting	175	1.20	3.75	2.00	0.42
PSDQ authoritative parenting	175	2.70	4.89	4.00	0.39
Child control of aggression	152	0	1	.77	.30
RSA during neutral content (Epoch 1)	152	1.21	10.19	6.36	1.60
RSA during anger content 1 (Epoch 2)	153	2.93	9.60	6.16	1.40
RSA during anger content 2 (Epoch 3)	152	1.87	9.56	6.43	1.50
RSA during positive resolution (Epoch 4)	151	2.06	9.83	6.38	1.60

Note. CCTI = Colorado childhood temperament inventory; CBQ = children's behavior questionnaire; PSDQ = parenting styles and dimensions questionnaire; RSA = respiratory sinus arrhythmia.

Table 2

Zero-order correlations of variables.

	1	2	3	4	5	6	7	8	9
1. Child sex									
2. Child age	−.06								
3. CCTI and CBQ anger-prone temp	−.13$^{\delta}$	−.07							
4. PSDQ authoritarian parenting	−.03	.05	.44***						
5. PSDQ authoritative parenting	.08	.05	−.25***	−.40***					
6. Child control of aggression	.01	.38**	−.17*	−.24**	.16*				
7. RSA Epoch 1	−.08	.01	−.04	.03	.05	−.05			
8. RSA Epoch 2	−.15$^{\delta}$	−.10	−.06	.07	.02	−.13	.67***		
9. RSA Epoch 3	−.04	.00	−.05	.06	.07	−.02	.64***	.67***	
10. RSA Epoch 4	−.02	−.02	−.09	−.06	.15$^{\delta}$	.03	.68***	.65***	.68***

Note. CCTI = Colorado childhood temperament inventory; CBQ = children’s behavior questionnaire; PSDQ = parenting styles and dimensions questionnaire; RSA = respiratory sinus arrhythmia; Child Sex was coded as 1 = male and 2 = female.

$^{\delta}$ $p < .10$, two-tailed.

* $p < .05$, two-tailed.

** $p < .01$, two-tailed.

*** $p < .001$, two-tailed.

Table 3

Fit statistics for growth models fit to the RSA data during the anger-induction video.

	No-growth	**Linear**	**Quadratic**	**Latent basis**
$\chi^2(df)$	16.61 (11)	14.76 (8)	7.40 (4)	3.22(6)
CFI	.98	.98	.99	1.00
RMSEA (CI)	.05 (.00–.10)	.07 (.00–.12)	.07 (.00–.15)	.00 (.00–.06)

Note. *df* = degrees of freedom; CFI = comparative fit index; RMSEA = root mean square error of approximation; CI = 90 percent confidence intervals.