ABSTRACT

Title of Thesis:	INDIVIDUAL AND INTERACTIVE EFFECTS OF CHILD AND PARENT ANXIETY ON BEHAVIORALLY INHIBITED YOUTH'S RSA ACROSS SOCIAL STRESSOR TASKS
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Children with elevated behavioral inhibition (BI) show context-inappropriate fear and dysregulated RSA across stressor tasks. However, few studies have examined dynamic RSA within tasks and relations to parent and child anxiety. Using piecewise growth modeling and multi-method baseline data from an intervention study of 151 3.5-5 year old children and their parents, the individual and interactive influences of child social anxiety (SA) and parent anxiety (via diagnostic interviews) in predicting children's RSA across social stressor tasks (e.g., learning about unfamiliar peers, Trier Social Stress) were tested. Children high in SA showed RSA responses indicative of avoidant coping, whereas those low in SA showed responses suggesting attention in anticipation of meeting unfamiliar peers. The relation between child SA and RSA across tasks was moderated by parent anxiety, specifically for dyads matched in anxiety. Findings provide support for the influence of both child and parent anxiety on children's RSA response across specific stressor and non-stressor tasks.

INDIVIDUAL AND INTERACTIVE EFFECTS OF CHILD AND PARENT ANXIETY ON BEHAVIORALLY INHIBITED YOUTH'S RSA ACROSS SOCIAL STRESSOR TASKS

by

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Chapter 1: Introduction

Behavioral inhibition (BI) is a biologically based temperamental disposition to withdraw and/or demonstrate negative affect when faced with unfamiliar situations or people that presents in 15-20% of children in infancy and early childhood (Coll et al., 1984; Fox et al., 2005). Stable BI is one of the most robust predictors of later anxiety, specifically social anxiety (Chronis-Tuscano et al., 2009; Clauss & Blackford, 2012). Significantly, more than half of all children with elevated BI do not go on to develop social anxiety (Clauss & Blackford, 2012), highlighting the importance of identifying *who* is most at risk (Chronis-Tuscano et al., 2009; Hirshfeld-Becker et al., 2008; Lewis-Morrarty et al., 2012). Two moderators that have been identified are children's self-regulation in fear-eliciting situations (Buss et al., 2018; Buss & Qu, 2018) and parental anxiety (Borelli et al., 2015; Perlman et al., 2022).

While BI is widely characterized by increased physiological reactivity (e.g., heart rate, cortisol) to perceived threats, BI can also result from *dysregulated* self-regulatory processes (Buss & Qu, 2018). That is, children experiencing BI who can self-regulate physiologically may be able to refrain from inhibition or withdrawal in stressful situations (Rubin & Coplan, 2004). Indeed, lower vagal tone, an index of reactivity and regulation of arousal tends to occur in children high in inhibition (Coll et al., 1984; Fox, 1989), although in other samples this was not the case (Calkins & Fox, 1992; Rubin et al., 1997; Stevenson-Hinde & Marshall, 1999). The polyvagal theory posits that adaptive functioning, such as self-regulation, depends on reliable withdrawal and engagement of the autonomic nervous system (ANS) to effectively respond to environmental and social demands (Porges, 2001; Porges et al., 1996). One commonly used measure of such self-regulation via vagal tone is respiratory sinus arrhythmia (RSA). RSA is the natural variability in heart rate occurring during breathing (i.e., faster during inhalation and slower during exhalation), which serves as one measure of the parasympathetic nervous system's (PNS) control of heart rate, via the vagus nerve. In the absence of stress, RSA is an indicator of the PNS maintenance of the heart (i.e., serves as a "brake" on the heart). Amidst ongoing coactivation of sympathetic and parasympathetic system processes (Beauchaine, 2001), when encountering a stressor, an individual's PNS "lifts the vagal brake" (i.e., decreases RSA) and facilitates the recruitment of resources to address the stressor (Calkins, 2007; Porges et al., 1996). Thus, a decrease in RSA during non-stressful social contexts may indicate an unnecessary stress response in a harmless environment (Beauchaine, 2015), and too much RSA during a stressor might suggest an inability to recruit necessary resources to respond to the stressor (DePasquale, 2020). Additionally, mild to moderate RSA decreases in response to stimuli indicates attention and orienting to cues (Porges, 2007), whereas an RSA increase can facilitate a calm state for social engagement (Hastings et al., 2008).

As suggested above, research linking RSA responses with internalizing symptoms is quite mixed (Graziano & Derefinko, 2013). Some researchers theorize that extreme RSA decreases suggest over vigilance to potential threats in the environment, resulting in symptoms such as anxiety (Thayer & Lane, 2000). Other researchers theorize that the lack of RSA decreases might result in the inability to flexibly cope with the stressful situation at hand (Schmitz et al., 2011). This is also reflected in the various interpretations of adaptive and maladaptive RSA responses in children with BI. Prior work indicates that children with elevated inhibition who show context-inappropriate fear (i.e., high fear in both low and high threat situations) also show high RSA. Authors interpreted the high RSA as an indicator of the failure to decrease RSA which would be maladaptive. Temperamentally fearful children who exhibit decreases in RSA show less fear in novel situations and lower risk for social anxiety (Buss et al., 2018). This suggests that RSA decreases may buffer children at risk from developing inhibited social behavior (Brooker et al., 2013; Cho & Buss, 2017). In another study, high fear toddlers showed both increases and decreases in RSA at quicker rates compare to the low fear toddlers across tasks, suggesting the importance of interpreting the adaptiveness of RSA responses across various contexts (Brooker & Buss, 2010). Keeping in mind these various approaches to interpretation, overall, these studies suggest that not only can RSA changes be a marker of context-inappropriate fear, but also evaluating the adaptiveness of RSA responses across stressful and non-stressful contexts is important.

At the focus of many models of social anxiety is the dysregulation of physiological symptoms (Clark & Wells, 1995). Overall researchers studying the physiological correlates of social anxiety have found no significant differences in 7-12 year-old children with social anxiety compared to other anxiety disorders, although those experiencing higher anxiety overall regardless of anxiety diagnosis showed less change in RSA during stressors (Alkozei et al., 2015). In another study, children ages 8 – 12 years with social anxiety disorder shower lower levels of baseline RSA and limited RSA reactivity during social stressor compared to matched controls (Schmitz et al., 2011). However, researchers have not examined differences in RSA responses based on social anxiety in a sample of highly behaviorally inhibited children of preschool age. Preschool is an important age for the development of self-regulation as children being transitioning from dependency on parents and teachers (Calkins, 2007). Furthermore, given the heterogeneity in social anxiety outcomes of children high in BI (Buss et al., 2018; Chronis-Tuscano et al., 2009; Hirshfeld et al., 1992), identifying factors that differentiate highly behaviorally inhibited children, including the presence of social anxiety, is important.

Parental anxiety is a well-established risk factor in the development of children's social anxiety (Bernstein et al., 2005; Ryan & Ollendick, 2018). In particular, children experiencing BI whose parents have a diagnosis of an anxiety disorder (e.g., social anxiety, panic disorder), are at increased risk of developing social anxiety (Bernstein et al., 2005; Biederman et al., 2001). Outside of shared genetic vulnerabilities, one of the methods by which parents might "transmit" anxiety to their children is by influencing their children's regulatory responses to stress. For example, in a sample of 8 - 12-year-old girls and their parents, parents' anxiety prospectively predicted their children's physiological response to stress if children ranged in medium or high fearful temperament (Borelli et al., 2015). Given parents often serve as external regulators for their children during infancy and early childhood (Lunkenheimer et al., 2015), parental factors, such as anxiety, can heavily influence their children's own regulatory responses and subsequently their children's risk for the development of social anxiety. Indeed, parental anxiety has been associated with behaviors such as modeling regulatory responses, accommodation of children's anxious avoidance, anxious talk, and intrusive-controlling parenting (Aktar et al., 2014; Hastings et al., 2019; Perlman et al., 2022), which have all been shown to impact children's social anxiety. Thus, it is especially important to examine the impact of parents' anxiety on children's physiological response to stress, especially for those who are high in BI.

Furthermore, the developmental-transactional model of BI posits that interactions between parent and child factors (e.g., anxiety) contribute to BI and related outcomes (e.g., adaptive physiological response; Chronis-Tuscano et al., 2018; Rubin et al., 2009). Indeed, prior research supports the integration of parent and child factors influencing children's physiological responses to stress (Borelli et al., 2015; Wetter & El-Sheikh, 2012). Specifically, children already at risk for poor regulation (e.g., low baseline RSA, fearful temperaments) are more likely to show dysregulated self-regulatory responses if their parents have internalizing symptomatology. In a longitudinal study of children at ages 4-10 years old, higher RSA decreases were associated with children's internalizing symptoms between the ages of 4-7 (but not after 7 years) when maternal internalizing symptoms were high based on a median split (Shanahan et al., 2014). Thus, it is important to consider both parent and child anxiety, and their interaction as indicators of poorer child self-regulation in children high in BI.

Current Study

The overall aim of this study was to examine the independent and interactive effects of parent and child anxiety as they relate to child RSA response during non-stressful and stressful social laboratory tasks within a sample of highly inhibited children participating in an early intervention program. First, we modeled children's RSA responses across four tasks (Video 2, Kids, Introduction, Video 3 discussed below). Prior research indicates dynamic measures of RSA change (e.g., linear and quadratic growth) provide unique information above and beyond traditional static change scores (i.e., subtracting average RSA from baseline), specifically for high fear toddlers (Brooker & Buss, 2010). In addition, self-regulation is dynamic and needs to be studied across time and various contexts (Dennis-Tiwary, 2019).

It was hypothesized that overall, children would show RSA decreases during the Kids task, indicating adaptive attention (Calkins & Keane, 2004) and RSA increases during the Introduction task, supporting social engagement (Hastings et al., 2008; Porges & Furman, 2011). Then, we tested relations between child social anxiety (given the target of the intervention) and changes in RSA responses across tasks, since anxiety symptom severity more broadly has been shown to interact with BI and RSA responses (Viana et al., 2017). Extant studies suggest children with social anxiety may show less RSA change (Alkozei et al., 2015; i.e., extended to non-significant slopes in this study) during stressors, therefore it was hypothesized that children high in social anxiety would respond less physiologically compared to those low in social anxiety during the social stressors. Lastly, we tested whether the interaction between parent anxiety and child social anxiety was related to children's RSA responses across tasks. Based on prior research, it was hypothesized that the presence of parent anxiety would result in maladaptive patterns of RSA response in children (e.g., lack of RSA decreases; Borelli et al., 2018).

Chapter 2: Method

Participants. Data were collected at baseline from 151 children aged 45-64 months (*M* = 52.9, *SD* = 5.7) and their primary parent (*M age* = 38.7 years, SD = 5.2; 85.8% mothers) who were recruited for a randomized controlled trial comparing two early interventions targeting behavioral inhibition and parenting (R01MH103253 MPIs: Rubin & Chronis-Tuscano; for description see Chronis-Tuscano et al., 2021). Families were recruited through community organizations, pediatricians, preschools, and media/print advertisements. Families were included if children were reported to show elevated scores (> 85th percentile) on the Behavioral Inhibition Questionnaire (BIQ; Bishop et al., 2003), in line with conceptual models of BI (Kagan et al., 2007). Exclusion criteria included a diagnosis of autism spectrum disorders or selective mutism, a score above the clinical cutoff (≥ 15) on the Social Communication Questionnaire (SCQ; Eaves et al., 2006; Rutter et al., 2003), and active participation in psychosocial treatment for child anxiety.

Procedure. After completing a phone screen to assess inclusion criteria, eligible parent-child dyads were invited to the baseline assessment visit, during which the data for this study were collected. Parents provided informed consent, completed diagnostic interviews and questionnaires. Parents and children also completed physiological measures during a series of child laboratory tasks (described below). All procedures were approved by the University of Maryland Institutional Review Board (ClinicalTrials.gov registration: NCT02308826).

Task Sequence (see Figure 1). Children first watched a 3-minute calming video (i.e., Andrea Bocelli singing to Elmo) to measure baseline RSA (*Video 1*). Calming videos are commonly used in samples of preschoolers before measuring RSA during tasks to acclimate them to a new environment (Elmore-Staton et al., 2012; Miller et al., 2017; Sulik et al., 2015).

Then, a research assistant dressed as a clown entered the room, introduced themselves to the child, and asked the child's name (*Clown*). This segment is adapted from well-established methods of eliciting children with BI's responses to strangers (Buss, 2011; Kagan et al., 1989; Nachmias et al., 1996) and lasted about 60-70 seconds. Children were then shown the same initial video to examine recovery (*Video 2*). Afterwards, children were told that some kids "couldn't be here today, but they might be visiting here soon and they want to get to know you better." Children then participated in a social learning segment where they were introduced to photos of unfamiliar peers (from the Child Affective Facial Expression set; LoBue & Thrasher, 2015) and facts about each child who they would supposedly "meet" (*Kids*) which lasted about 60 seconds. This segment was designed to maximize the ecological validity of the next segment, where children were asked to introduce themselves (e.g., name, age, favorite things) to a camera (*Introduction*) to the kids they would "meet" lasting about 90 seconds. *Introduction* is a developmentally-appropriate adaptation of the Trier (Kirschbaum et al., 1993), an established social stress test typically administered with psychobiological measures. Studies of BI have successfully used introduction tasks (i.e., speeches) before to elicit anxiety within this age and population (Fox et al., 1995; Rubin et al., 2002). Lastly, children watched the initial video again (Video 3).

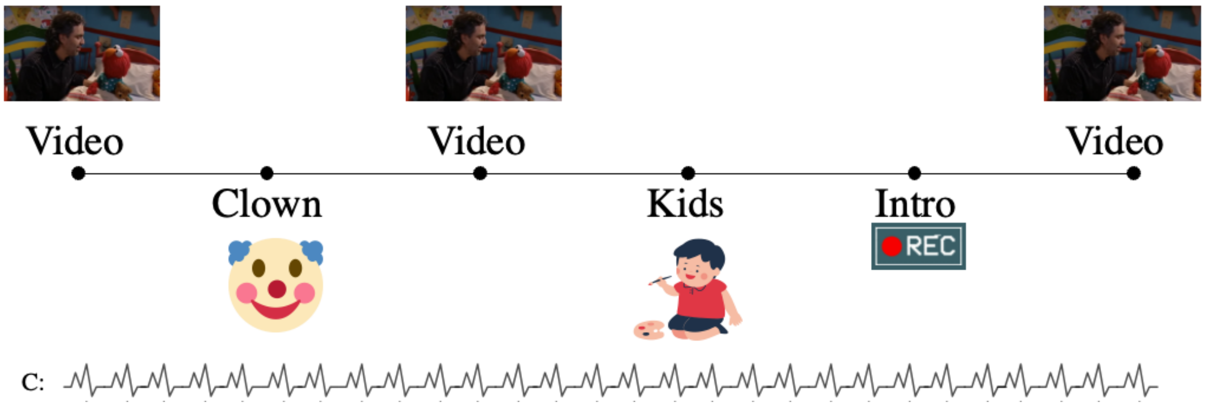


Figure 1. Full sequence of Non-stressor and stressor child tasks

Measures

Physiological Recordings/RSA. Children's RSA was assessed continuously during the standardized laboratory procedure in which children participated in a sequence of socially stressful and non-stressful tasks while their parents observed in the back of the same room (See Figure 1). Children wore a Biopac Nomadix PPG ED wireless transmitter on their left arm. They also wore a Biopac PPG sensor secured via a Velcro strip made to be secure enough so it can't change positions and loose enough so as not to limit blood flow. Children were introduced to "Freddie the Duck," a rubber duck fixed on the desk where the child was seated, and were told to "keep Freddie warm" by keeping their hand still on Freddie's back. Heart rate data via the PPG signals were collected at a sampling rate of 2000 Hz.

Editors of the heart rate data completed a rigorous training process of the *Cardio Edit* and *Cardio Batch* software to become reliable. First, they attended an hour-long workshop focusing on the neurophysiology influencing heart rate. Afterwards, they worked on editing a set of 20 files (with the option for feedback) provided by the Brain-Body Center at the University of Illinois – Chicago until they obtained RSA values within +/- .05 of the values in the software manual provided for the training file. Then they worked independently on a set of 20 reliability files and again had to obtain RSA values within +/- .05 of the reliability set. Only after successful completion of this training were edits allowed to work on the data collected in the present study.

Two video feeds capturing the room of the task sequence were used by these trained research assistants to identify the timestamps indicating the start and end of each task. Within each task, the interbeat intervals (IBI), or distance between heart rate "peaks," were identified using a peak identification algorithm ("BIOPAC Systems, Inc." 2005). The IBI were then used to derive RSA using the "Porges–Bohrer method," a moving polynomial method robust to the influence of respiration and non-stationary heart rate signal (Porges & Bohrer 1990; Pham et al., 2021). *Cardio Batch* (Brain-Body Center, 2007) was then used to calculate RSA estimates for each 15 second epoch, a common epoch length for studies of this age (Miller et al., 2013).

Behavioral Inhibition. The BIQ (Bishop et al., 2003) is a 30-item parent-report of behavioral inhibition that was used to determine inclusion. The BIQ items assess three domains: social novelty, situational novelty, and physical activity with minor risk of injury. The BIQ has shown good convergent and discriminant validity (Kim et al., 2011) and internal consistency (α = .72 - .95; Bishop et al., 2003; Kim et al., 2011). In this sample the Cronbach alpha ranged from 0.87 – 0.94.

Anxiety Disorders Interview Schedule for Children for DSM-5. The ADIS-V (Silverman, Albano, & Barlow, 1996) is the gold-standard semi-structured interview used to assess anxiety and social anxiety severity using the DSM-5 criteria. Clinician Severity Ratings (CSRs) were used for impairment for separation, specific, social, and generalized anxiety modules. CSRs ranged from 0 to 8, where scores ≥ 4 are clinically significant. The ADIS-IV-Child has demonstrated good reliability in preschool-aged children (K = 0.77 – 0.93; Chronis-Tuscano et al., 2021; Rapee et al., 2005). Similarly, the ADIS-V-Adult (Brown & Barlow, 2014) and its CSRs were used to assess anxiety in parents. Total parent anxiety severity was calculated as the sum of separation, specific, social, and generalized anxiety CSRs (Ginsburg et al., 2015). Child social anxiety was specifically of interest due to the social nature of the tasks in which they were the primary recipients and the target of the intervention. Twenty percent of clinician interviews were coded for inter-rater reliability (ICC = .93; Chronis-Tuscano et al., 2021).

Analytic Plan

Analyses were conducted in Mplus v. 7.4 (Muthén & Muthén, 1998). Maximum likelihood estimation with robust standard errors (MLR) was used to handle missing data. Growth curve modeling (GCM) is a common method used to model individuals' growth across time and interindividual differences in that growth, which is important since both the direction and magnitude of change inform the adaptability of RSA responding across contexts (Obradović & Finch, 2017). However, GCM utilizes only one slope which may not accurately reflect growth across varying task demands. Thus, piecewise growth curve modeling, where specific "change-points" are fixed to indicate shifts in intraindividual growth, is well suited to model RSA across a range of tasks of varying social demands (Ram & Grimm, 2007).

An attempt to estimate a model including all 6 tasks in a single model did not converge due to trying to estimate more parameters than allowed with our sample size. Thus, we focused on the latter 4 tasks, (*Video 2, Kids, Introduction, Video 3*) which have been shown to relate to children's anxiety in prior work (Wagner et al., 2023). Additionally, the *Kids* and *Introduction* tasks were intended to reflect common social experiences that may likely require self-regulation in children high in BI. Importantly, prior work with this data showed children recovered (i.e., returned to their initial RSA values) during *Video 2* (Wagner et al., 2023), or the first task used in the current analyses. For subsequent analyses eight epochs of the *Video* tasks, three epochs of the *Kids* task, four epochs of the *Introduction* task were used.

A four-piece piecewise latent GCM was fit to model RSA across the four tasks. The latent intercept was estimated to indicate the starting RSA value at the beginning of *Video 2.* Latent slopes across *Video 2, Kids, Introduction, and Video 3* were estimated to indicate change in RSA during the four tasks. Model fit was evaluated using fit indices such as chi-square, root mean square error of approximation (RMSEA), and the Comparative Fit Index (CFI)/Tucker-

Lewis Index (TLI) (Hooper et al., 2008). Then, the relationship between child social anxiety and the latent intercept and slopes was tested using two models: one using the dimensional measure of child social anxiety and one using the clinical cutoff of child social anxiety (high; CSR $\geq$ 4) in a multigroup approach. To account for differences in RSA response due to age, sex, and race, these variables were added as covariates in this model (El-Sheikh, 2005; Patriquin et al., 2014; Wagner et al., 2021)

In the multigroup approach, the Santorra-Bentler scaled chi-square test statistic was used to compare a freely estimated model to one where the parameters were constrained to be equal across groups. Additionally, models where individual latent slopes were fixed and freed were compared to identify the tasks in which the high social anxiety group differed from the low social anxiety group. Lastly, we tested the relationship between the latent factors and mean-centered child social anxiety, parent anxiety, and their interaction. We also probed the region of significance for parent anxiety to identify the values of parent anxiety where the regression of children's RSA on time transitions from non-significant to significant (Preacher et al., 2006).

Chapter 3: Results

Demographics variables for children with usable physiological data (N=132) is reported in Table 1. Bivariate correlations between demographic variables and the latent factors are presented in Table 2. The four-piece piecewise model showed acceptable - good model fit ($\chi^2(252) = 411.25$, $p < 0.001$, RMSEA = 0.69, CFI = 0.951, TLI = 0.951) with a significant intercept (M=6.51, $p < 0.001$) and significant variance around the intercept and first two tasks, p's < .01. The estimated residual variance for the slope of the last video task was not significantly different from 0 (b = 0.002, p = 0.080), therefore it was constrained to zero to improve model fit. Overall, children showed decreases in RSA during the calming videos and increases in RSA during the social stressor tasks, but these changes were not significant when collapsed across the entire sample (indicated by the black line in Figure 3). The child social anxiety variable using the clinical cutoff was related to the slope of the *Video 2* and the *Kids* task. Specifically, low and high child social anxiety groups differed in the direction and magnitude of RSA change within the first calming video ($b = -0.042$, $p = 0.008$) and anticipatory *Kids* task ($b = 0.180$, $p < 0.001$). Namely, children above the clinical cutoff for social anxiety showed less dynamic RSA during the video and showed more dynamic RSA during the *Kids* task.

To probe the significant pathways, a multigroup model was used to compare the unconditional model to one where parameters were fixed across groups using the clinical cutoff for social anxiety (CSR >=4; above cutoff N = 72, below cutoff N = 59). The model with freely estimated parameters showed better fit compared to the fully constrained model ($\triangle\chi 2 = 26.56$, $p < .001$), suggesting significant differences in RSA change between children below (low) and above (high) the clinical cutoff for social anxiety. The model where *Video 2* was freely estimated and where *Kids* was freely estimated also fit better than constrained models ($\triangle\chi2$ = 5.35, *p* = 0.021; $\triangle\chi2$ = 101.47, *p* < .001 respectively), providing additional support for the regression findings of differences in RSA between high and low social anxiety groups within these tasks. In these models, due to linear dependency the slope of *Introduction* was fixed to 0.

High and low social anxiety groups start off at similar levels of RSA (Intercepts 6.46, 6.57 respectively, *p*'s < 0.001). During *Video 2*, recovery after the *Clown* task, the low social anxiety group showed stable RSA (Slope = 0.14, *p* = 0.23), but the high social anxiety group showed decreases in RSA on average (Slope = -0.03, *p* = 0.004). Both low and high social anxiety groups also showed significant change in RSA during *Kids* and these changes were different between groups. Namely, the low social anxiety group showed decreases in RSA (Slope = -0.082, *p* = 0.009), whereas the high social anxiety group showed increases in RSA, on average (Slope = 0.102, *p* = 0.004). Outside of the direction of change, the magnitude of change for the high anxiety group was larger (Slope=0.102) compared to the low social anxiety group (Slope= -0.082), indicating greater change in RSA during the anticipatory task for children high in social anxiety.

To examine the influence of parent anxiety on child RSA across tasks, we regressed parent total anxiety, child social anxiety, and their interaction onto each of the latent slope factors, while accounting for demographic covariates (i.e., child age, sex, and race; see Table 3). Significant main effect associations indicated that child social anxiety predicted change in RSA during *Kids*, (*b* = 0.043, β = 0.311, *p* = .010). Parent anxiety did not significantly predict change in RSA during *Kids* above and beyond child social anxiety, p = .767. The interaction between parent total anxiety and child social anxiety significantly predicted children's RSA slope during *Kids* (*b* = -0.02, SE = 0.007, β = -0.35, *p* = 0.003).

Simple slopes analysis indicated the relations between RSA and child social anxiety was significant only for matched dyads. That is, children low in social anxiety showed significant decreases in RSA when their parents were also low in total anxiety (-1SD; simple slope = -0.26 [CI: -.30 to -.22], $p < .001$) but not when their parents were high in total anxiety (+1SD; simple slope = 0.09 [CI: -.14 to -.03], $p = .112$; see Figure 4). Region of significance (RoS) analysis indicated that this relationship was significant *outside* the bounds of 2.65 and 102.44 of total parent anxiety, or total CSRs less than 6 in our sample (79% of our sample; N=106; see Figure 4). Likewise, children high in social anxiety showed significant decreases in RSA when their parents were also high in total anxiety (+1 SD; simple slope = -0.13 [CI: -.17 to -.09], $p = .004$), but not when their parents were low in total anxiety (-1 SD; simple slope = .008 [CI: -.04 to .06], $p = 0.877$; see Figure 5). Region of significance analysis indicated that this relationship was significant *inside* the bounds of .079 and 75.37 total parent anxiety, or total CSRs greater than 3 in our sample (29% of our sample; N=39; see Figure 5). For additional interpretation, mean RSA across tasks by dyad groups is provided (see Figure 6).

Chapter 4: Discussion

This is the first study to characterize how parent anxiety and child social anxiety relate to young children's physiological response across a series of social stressor tasks in a sample enriched for BI. Three main findings emerged as a result of this study. First, modeling RSA change *within* tasks provides nuance to our understanding of children's physiological responses to stress due to the differential individual responses. Piecewise growth modeling was used to capture points of theorized change between tasks and establish significant changes in RSA within specific tasks across the sample. Significant variance around the intercept and *Video 2* and *Kids* indicated individual differences in change over time during those tasks, which may have been missed by examining only change between tasks. These results support the use of methods such as piecewise growth modeling to capture RSA changes at the epoch level within tasks as well as across a variety of distinct social and non-social tasks. Keeping in mind the non-significance, the overall trajectory of RSA across the sample was RSA decrease during the calming videos and RSA increase during the social stressor tasks, which is the opposite of what was hypothesized. These findings should be contextualized within the sequence of the tasks, where *Video 2* was a calming video watched *after* a stressful encounter with a stranger in a clown costume. In addition, given that this is a sample enriched for BI, these RSA responses may be indicators of dysregulated RSA responses. Overall, these findings show that children high in BI show differentiated PNS responses *within* and *between* tasks depending on the nature of the tasks, supporting the polyvagal theory (Porges et al., 1996) and the utility of piecewise modeling methods.

Second, children showed differentiated RSA change within tasks based on their level of clinical social anxiety. Such distinctions would be missed if analyzed solely at the sample level.

Using regression and multigroup models, we found that children low in social anxiety showed decreases in RSA suggesting attention allocation while learning about unfamiliar peers in anticipation of meeting them (i.e., *Kids*) whereas children high in social anxiety show increases in RSA, suggesting avoidant coping. The fact that both children high and low in social anxiety showed significant RSA change, albeit in opposite directions, was contrary to what was hypothesized. This may reflect the *Kids* task being sufficiently engaging or stress inducing to constitute a physiological response regardless of social anxiety level. However, these results are also consistent with prior findings suggesting that RSA decreases may act as a buffer for at-risk children from developing inhibited social behavior and later anxiety (Brooker et al., 2013; Buss et al., 2018; Cho & Buss, 2017), in that children low in social anxiety seemed to show attempts to engage with information regarding future social interactions. Furthermore, these results indicate that measuring social anxiety within preschoolers can be informative, especially among children high in BI. This is supported by accounts of similar rates of DSM anxiety and depressive disorders in US preschoolers (10 - 15%) as people diagnosed later in adolescence or adulthood (Egger & Angold, 2006). Furthermore, children diagnosed in preschool are at risk of developing more severe mental health problems later, emphasizing the importance of measuring social anxiety early on (Tandon et al., 2009). The current findings add to this literature by showing that youth high in inhibition show differentiated responses in their physiology across tasks based on their clinically relevant social anxiety levels.

Third, parent anxiety modifies the relations between children's social anxiety and their RSA across specific tasks. Specifically, any anxiety, regardless of whether it's in the child or parent, relates to children's RSA responses across the *Kids* task. For children and parents matched in low anxiety, children showed what we have characterized as "adaptive" response to the *Kids* task or decreases in RSA representative of orienting and attention when learning about potential peers they will meet. While not statistically significant, these children also showed increases in RSA during the *Introduction* task representing recruitment of resources to engage socially. For dyads where either parent or child were high in anxiety, children showed opposite responses (i.e., increases in RSA during the *Kids* task), indicative of avoidant coping while learning about unfamiliar peers, which would be maladaptive in social interactions. Specifically for dyads that were both high in anxiety, children seemed to show sharp increases and then sharp decreases (i.e., attempts to self-regulate) into the next task, where they were asked to introduce themselves though the overall decrease during the *Introduction* task was not statistically significant. Due to the linear modeling approach, this slope was represented as a decrease in RSA, however, non-linear modeling approaches could potentially better clarify this speculation (discussed further in Limitations and Conclusions).

Within the framework of diathesis stress and differential susceptibility models, children are heavily influenced by their environments - whether vulnerable children have worse outcomes if they experience a negative environment or for better or for worse (Ellis et al., 2011; Zuckerman, 1999). These results, however, provide some nuance to the narrative in that children are also active agents in their environments and for some (e.g., low social anxiety), their self-regulatory mechanisms may be quite developed. The RoS analyses suggest that children low in social anxiety may potentially be leaning on their own self-regulation to be able to tolerate higher levels of parent anxiety (up to CSRs 5-6) compared to children high in social anxiety (RoS CSR's > 3). However, the RSA change of children low in social anxiety with high parent anxiety indicates that while they seem to have higher RSA levels overall (indicative of greater capacity for self-regulation; Beauchaine, 2001; Porges, 2001), parent anxiety may still influence their RSA responses within tasks (i.e., show similar directions of change as the children with high social anxiety).

The findings specific to the learning/anticipatory *Kids* task are surprising, given the expectation that children would self-regulate mainly during the more stressful *Introduction* task, where they are asked to introduce themselves to the peers (like in the Trier Social Stress Task). However, these results suggest that even the *anticipation* of social interactions may be enough to warrant changes in physiological responses as attempts to self-regulate. Prior research supports this possibility, in that children high in temperamental shyness show dysregulated emotional and autonomic responses in the anticipation of a speech (Poole & Schmidt, 2021). Furthermore, children high in BI and social anxiety may benefit from interventions that specifically target coping skills for the anticipation of social events or encounters, not just exposure to the encounters themselves. In addition, these children's' parents may benefit from learning how to manage their own anxiety to help support their children who respond in maladaptive ways physiologically. Parents may unknowingly serve as external regulators for their at-risk children; thus, it is imperative that parental anxiety (and any contributing behaviors such as intrusive-controlling parenting; Borelli et al., 2018) is directly targeted. Low parental anxiety may buffer effects of child social anxiety on children's physiological reactions during socially stressful tasks, emphasizing the importance of targeting parental anxiety in interventions for children high in BI.

Overall, these results inform the further refinement of understanding which children among those high in BI are at risk based on their RSA responses across social stressor tasks and dyadic anxiety loads, further supporting developmental-transactional models of BI and social anxiety (Chronis-Tuscano et al., 2018; Rubin et al., 2009).

Limitations and Conclusions

The present study had a number of methodological strengths, including the use of piecewise growth curve modeling, gold standard diagnostic interviews, and the physiological measures of self-regulation via RSA. However, the results of this study should be interpreted with certain limitations in mind. Given that we recruited specifically for preschoolers high in BI, our results should not be generalized to other clinical or community samples. Our sample was also relatively homogenous in terms of socioeconomic status and race/ethnicity; thus, it is unclear how these results would generalize to other populations. In addition, RSA was used as a proxy of self-regulation, as done in prior studies (Buss et al., 2018; Lunkenheimer et al., 2015; Viana et al., 2017); however, extensions of this work to include concurrent measures of the sympathetic nervous system (SNS) and behavioral measures (e.g., parent-child observations, mobile eye tracking) would greatly strengthen and clarify the interpretation of these results (Borelli et al., 2018; Gunther et al., 2021; Wagner et al., 2021; Zeytinoglu et al., 2022).

Regarding the analytical approach, a strength of this study was the ability to examine RSA change *within* a variety of tasks; however, since prior research supports the use of quadratic RSA change measures during stressor tasks, the use of non-linear models may provide more nuanced information about potential differences in the rate of RSA change between high and low social anxiety groups and their parents. Researchers using quadratic slope approaches have found that *later* RSA suppression in toddlers during a fear-eliciting episode is associated with increased risk for anxiety problems, but not earlier RSA suppression (Brooker & Buss, 2010). These results have yet to be extended in a sample enriched for high BI. Specifically for this sample, this approach may be useful for additional insight into the patterns of RSA response for the children high in social anxiety with parents high in total anxiety. RoS analyses assume normality in the predictors, which was not the case for parent total anxiety. However, we provided the percentage of the sample by which the RoS applies to increase transparency and facilitate interpretation.

In addition, the full sequence of tasks was not used in this analysis due to the lack of convergence in our model; further investigation of the first few task sequences may provide insight into children's ability to recover from other social stressors (e.g., meeting a stranger). Use of the full sequence of tasks, including the "true" baseline RSA level will allow for analyses that can capture various levels of withdrawal for individuals based on their range of RSA, and return to baseline levels of RSA. For instance, moderate withdrawal has previously been shown to be more adaptive than extreme levels of withdrawal (Beauchaine, 2001). The first sequence of tasks also includes a validated Clown task that has been previously used within BI samples (Kagan et al., 1989; Kiel et al., 2021), which has potential to extend these questions about self-regulation and influences of anxiety across a task of meeting a scary stranger.

Despite these limitations, the present findings contribute to the growing body of research establishing both parent and child anxiety as factors contributing to children's physiological self-regulatory responses. Children high in BI respond flexibly both within and across a series of social stressor tasks. Having clinically significant levels of social anxiety predicted differentiated RSA responses within the task specific to the learning about and anticipation of meeting unfamiliar peers. Furthermore, parents' anxiety levels impacted this relation, especially when matched with their children's social anxiety levels. These results provide preliminary support for the potential of targeting anticipation of social interactions in children high in BI and social anxiety, as well as helping parents with anxiety support their children's self-regulation.

Tables

Table 1. Child and primary parent characteristics at baseline assessment.

	M (SD)	n	%
CHILD			
Sex (% female)		70	53.03
Age in months	53.78 (0.65)		
Race			
Black or African-American		17	12.88
Other		51	38.64
White		77	58.33
Behavioral Inhibition (BIQ)	5.12 (0.65)		
Social Anxiety (CSR)	3.37 (1.39)		
PARENT			
Sex (% female)		114	86.36
Age in years	38.66 (5.13)		
Race			
Black or African-American		18	13.64
Other		30	22.73
White		84	63.64
Total Anxiety (CSR)	2.79 (3.04)		
Household Income > $150,000		72	54.55
Parent education			
Less than Bachelor's		10	7.58
Bachelor's or equivalent		30	22.73
Masters/Doctorate		88	66.67

Note. N = 132 consisting of children with usable physiological data to estimate RSA slopes across tasks. BIQ = mean score on the Behavioral Inhibition Questionnaire, CSR = Clinician Severity Rating on the ADIS-IV.

Table 2. Correlations and descriptive statistics

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Child Sex (1=female)	0.51	-								
2. Child Age (in months)	52.95	5.70	-.13							
			[-.28, .03]							
3. Child Race (1=white)	0.50	-	-.05	.02						
			[-.22, .12]	[-.15, .19]						
4. Child Social Anxiety	3.45	1.37	-.08	-.03	.08					
			[-.23, .08]	[-.19, .13]	[-.10, .24]					
5. Parent Total Anxiety	2.78	3.14	-.08	-.08	.16	.07				
			[-.24, .09]	[-.25, .08]	[-.02, .33]	[-.10, .23]				
6. Child Intercept	6.50	0.97	-.04	.01	.20*	-.08	-.00			
			[-.21, .14]	[-.17, .18]	[.03, .35]	[-.25, .09]	[-.18, .18]			
7. Child V2 Slope	-0.01	0.05	.03	-.09	-.19*	-.05	-.11	-.20*		
			[-.14, .20]	[-.25, .09]	[-.35, -.02]	[-.22, .12]	[-.28, .07]	[-.36, -.03]		
8. Child Kids Slope	0.02	0.14	.06	-.05	-.08	.21*	-.02	-.50**	.29**	
			[-.11, .23]	[-.22, .12]	[-.25, .09]	[.04, .37]	[-.19, .16]	[-.62, -.36]	[.13, .44]	
9. Child Intro Slope	0.02	0.05	.02	-.09	.05	.05	-.02	.30**	.20*	.45**
			[-.15, .19]	[-.26, .08]	[-.12, .22]	[-.12, .22]	[-.20, .16]	[.14, .45]	[.03, .36]	[.31, .58]
10. Child V3 Slope	-	-	-	-	-	-	-	-	-	-

Note. *M* and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). Child *Video 3* slope was fixed to 0 due to model fit.
* indicates $p < .05$. ** indicates $p < .01$.

Table 3. Multiple regression model with the interaction of child and parent anxiety predicting RSA slope factors across tasks, controlling for child demographics.

	Intercept			Slope of Video 2		
	B	SE	β	B	SE	β
Sex	-0.102	0.180	-0.051	0.005	0.018	0.036
Age	-0.003	0.017	-0.020	-0.002	0.001	-0.137
Race	**0.55	0.192	**0.273	**-0.047	0.017	**-0.359
Child SA	-0.102	0.006	-0.135	-0.001	0.006	-0.029
Parent TA	0.006	0.031	0.018	-0.004	0.003	-0.175
Child SA x Parent TA	-0.036	0.027	-0.120	0.005	0.002	0.249

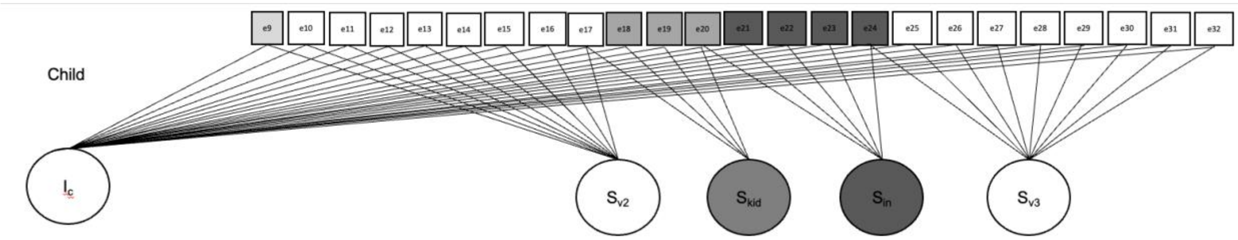
	Slope of Kids			Slope of Intro		
	B	SE	β	B	SE	β
Sex	0.023	0.046	0.061	-0.003	0.033	-0.017
Age	0.003	0.004	0.084	-0.004	0.003	-0.256
Race	-0.010	0.046	-0.027	0.000	0.034	0.000
Child SA	*0.043	0.018	*0.311	-0.009	0.010	-0.138
Parent TA	0.003	0.009	0.043	0.002	0.007	0.078
Child SA x Parent TA	**-0.019	0.007	**-0.352	0.002	0.005	0.074

	Slope of Video 3		
	B	SE	β
Sex	-0.001	0.015	-0.067
Age	0.001	0.001	0.597
Race	0.003	0.016	0.138
Child SA	-0.001	0.005	-0.171
Parent TA	-0.002	0.003	-0.637
Child SA x Parent TA	0.001	0.002	0.535

SA social anxiety, *TA* total anxiety. $p < .05$*, $p < .01$**, $p < .001$***

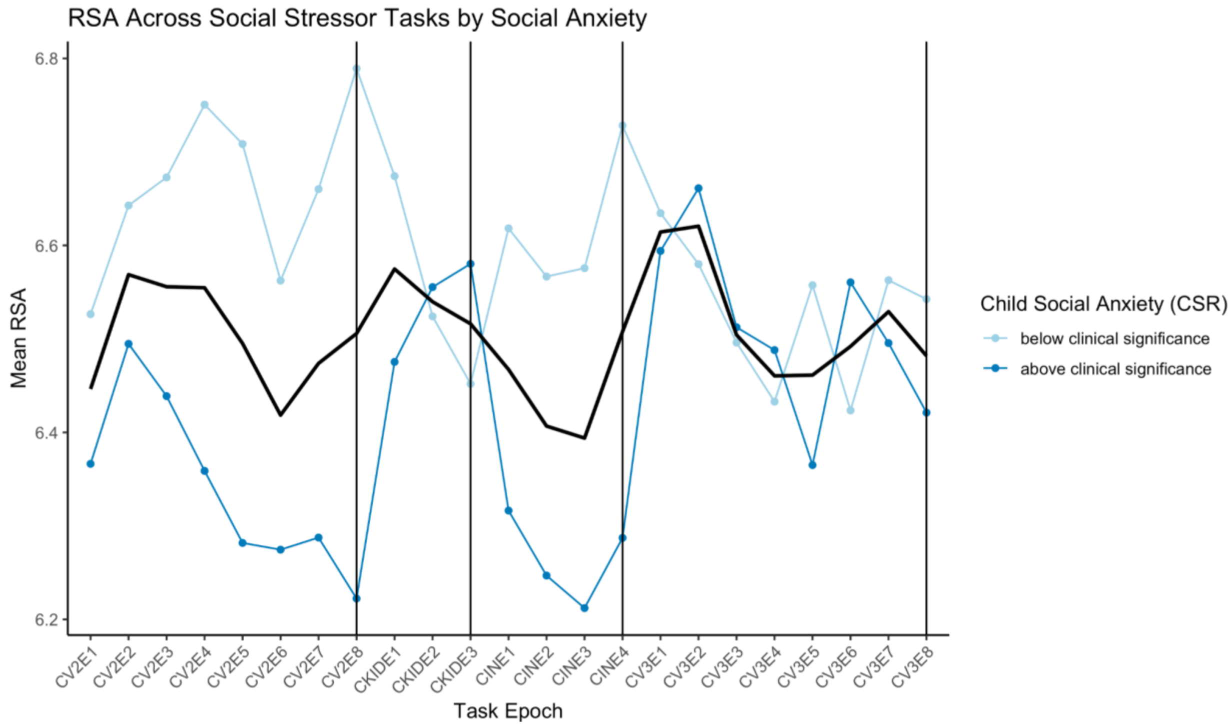
Figures

Figure 2. Piecewise latent growth curve model of 15 second epoch RSA across the four modeled tasks.



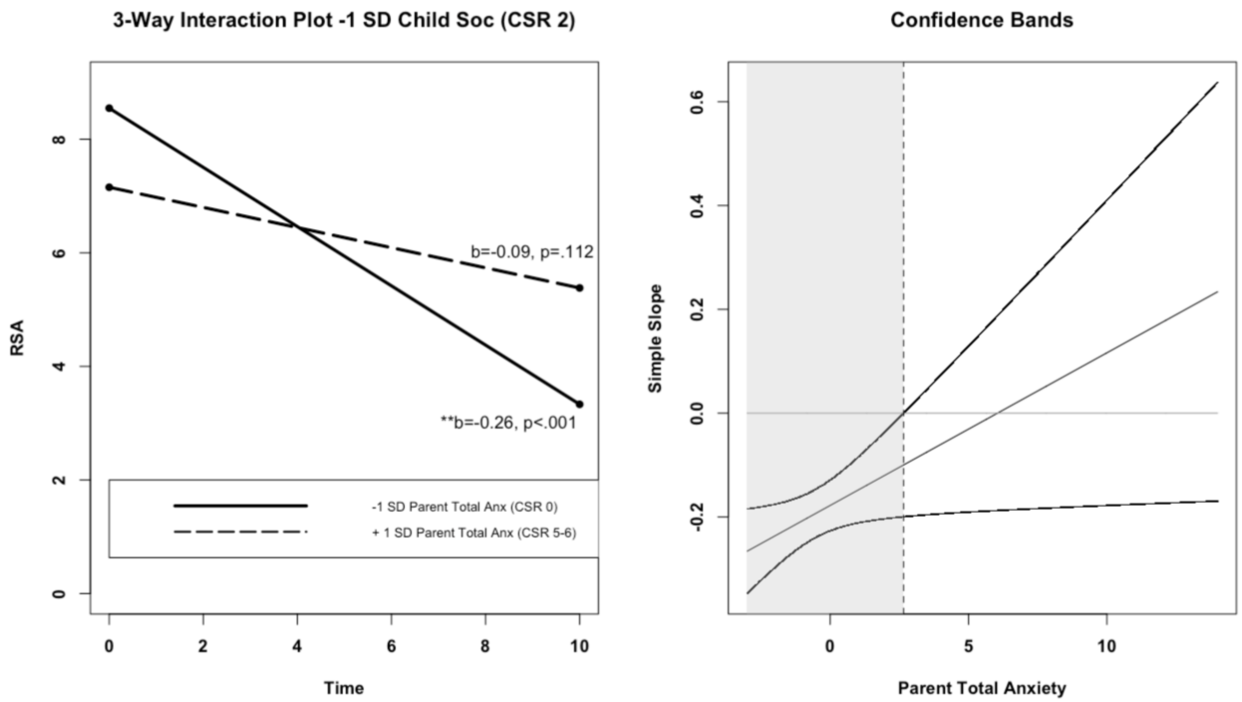
Note: Squares represent measured 15 second epochs and circles represent model implied latent intercept and slopes.

Figure 3. Overall RSA change across tasks and split between child clinical social anxiety cutoffs.



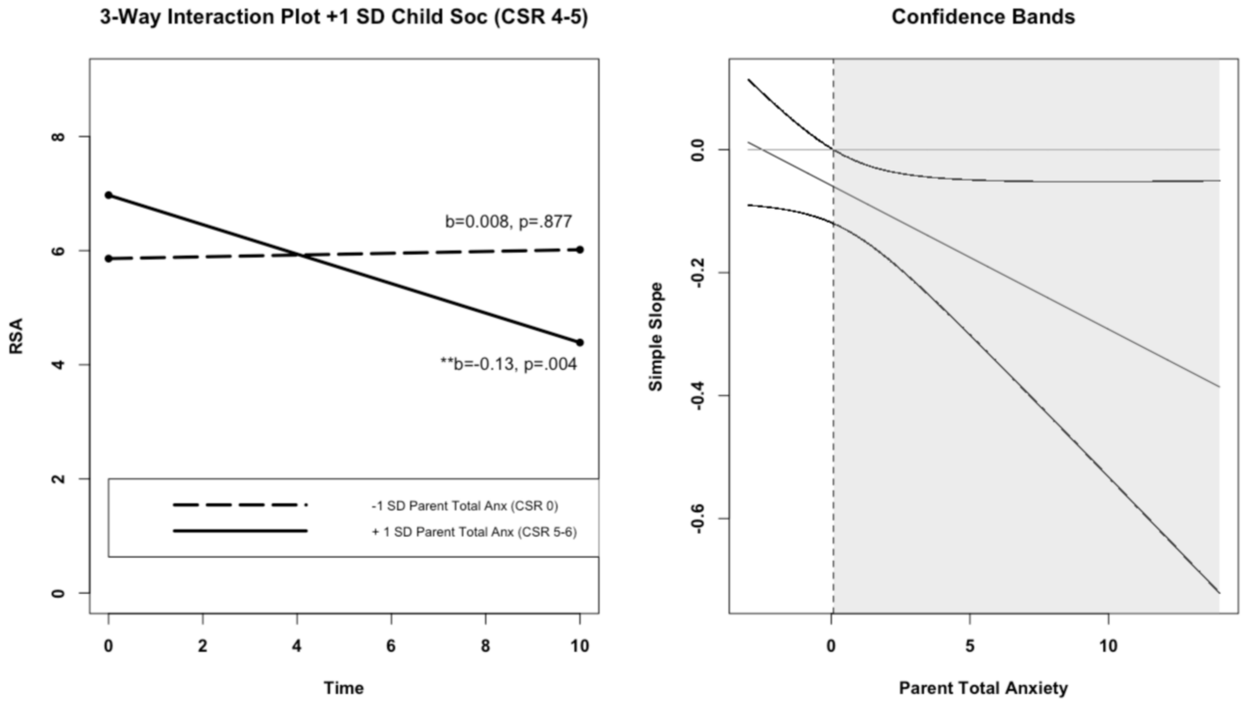
Note: Social anxiety groups differed in RSA change during the first two tasks, *Video 2* ($\triangle\chi 2$ = 5.35, p = 0.021) and *Kids* ($\triangle\chi 2$ = 101.47, $p < .001$). Youth below the clinical cutoff for social anxiety showed significant change during the *Kids* task (M = -0.082, p = .009). Youth above the clinical cutoff for social anxiety showed significant change during *Video 2* (M = -0.033, p = .004) and *Kids* (M = 0.102, p = .004).

Figure 4. Plotted interaction and regions of significance (RoS) plot probing the interaction between parent and child anxiety predicting childrens' RSA during the *Kids* task for the **low (-1 SD) social anxiety group**.



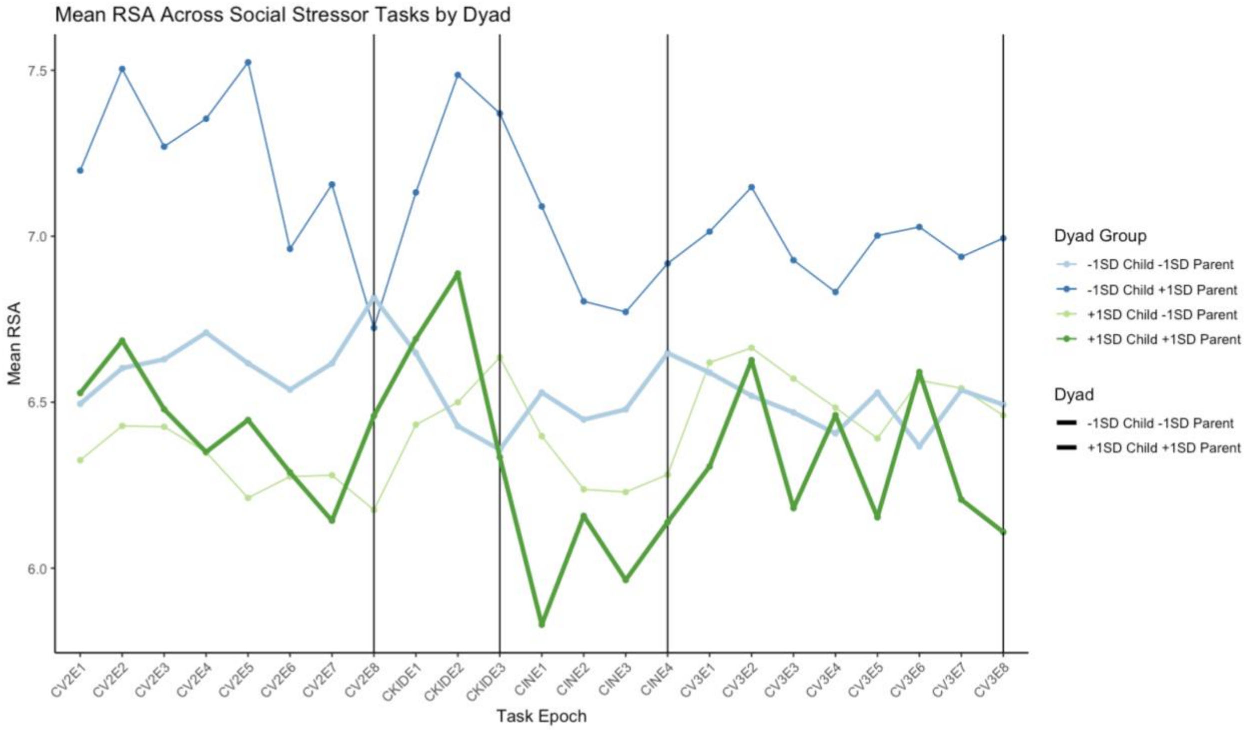
Note: The left plot of the interaction represents childrens' RSA across time for the low social anxiety group with lines differentiating low (-1SD) and high (+SD) parent anxiety. The right RoS plot shows the level of parent total anxiety (centered) where the regression of RSA on time (i.e., RSA across time) transitions from non-significant to significant (shaded area, < 2.65 or the centered equivalent of CSRs 6; 79% of sample). The solid line represents the change in RSA across time conditional on parent total anxiety. The curved lines represent the 95% confidence bands around the conditional slope.

Figure 5. Plotted interaction and regions of significance (RoS) plot probing the interaction between parent and child anxiety predicting childrens' RSA during the *Kids* task for the **high (+1 SD) social anxiety group**.



Note: The left plot of the interaction represents children's' RSA across time with lines differentiating low (-1SD) and high (+SD) parent anxiety. The right RoS plot shows the level of parent total anxiety (centered) where the regression of RSA on time (i.e., RSA across time) transitions from non-significant to significant (shaded area, > 0.08 or the centered equivalent of CSRs 3; 29% of sample). The solid line represents the change in RSA across time conditional on parent total anxiety. The curved lines represent the 95% confidence bands around the conditional slope.

Figure 6. Average RSA across 15 second epochs by dyadic group using +/- 1 SD.



Note: Groups with significant simple slopes after probing the 3-way interaction are highlighted under Dyad. N's for Dyad Group (from top to bottom: 44, 5, 48, 9, NA's = 6).

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