DYNAMIC AUTONOMIC COORDINATION, YOUTH MALADJUSTMENT, AND THE MODERATING ROLE OF CONTEXT

by

CORY A. CARVALHO

(Under the Direction of Assaf Oshri)

ABSTRACT

The goal of the present study was to model youth autonomic coordination between the sympathetic and parasympathetic nervous systems and examine its role in youth psychosocial development. Here, we used pre-adolescent's (N = 101; M_{age} = 10.28 years; SD_{age} = 1.19; 50.5% female) sympathetic (via cardiac pre-ejection period) and parasympathetic (via respiratory sinus arrhythmia) activity during a conflict task with a parent to calculate dynamic autonomic coordination and test its associations with adjustment problems. Then, the moderating roles of family cohesion and flexibility in this link were examined. More reciprocal autonomic coordination (i.e., branches demonstrate opposite activity) was found to be a risk factor for later adjustment problems. However, the negative effects of reciprocal ANS coordination were absent in children from high cohesion families. These findings underline the advantage of modeling autonomic nervous system reactivity as the dynamic coordination between its branches as well as the important role of context.

INDEX WORDS: Autonomic nervous system, autonomic coordination, sympathetic nervous system, parasympathetic nervous system, family functioning

DYNAMIC AUTONOMIC COORDINATION, YOUTH MALADJUSTMENT, AND THE MODERATING ROLE OF CONTEXT

by

CORY A. CARVALHO

BS, Pennsylvania State University, 2010

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2022

DYNAMIC AUTONOMIC COORDINATION, YOUTH MALADJUSTMENT, AND THE MODERATING ROLE OF CONTEXT

by

CORY A. CARVALHO

Major Professor: Assaf Oshri
Committee: Kalsea Koss
Geoffrey Brown

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
December 2022

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Autonomic nervous system (ANS) functioning is a promising biomarker for neuroregulatory capacities that underlie the development of youth adjustment problems (Beauchaine, 2015; Susman et al., 2021). Growing evidence suggests the associations between ANS functioning and the development of such problems may vary by family and parenting contexts (El-Sheikh et al., 2013; McLaughlin et al., 2015). However, several methodological limitations in how the ANS is frequently modeled in developmental research prevail. First, many studies model ANS functioning via activity of either one of its branches, the sympathetic or parasympathetic nervous systems (SNS and PNS, respectively). Yet, examining either branch independently omits information about the joint functioning capacity of the two systems (Bauer et al., 2002). Second, studies often use mean-level change scores to measure changes from baseline in SNS or PNS activity during lab-based tasks. However, analyzing mean values may obscure moment-to-moment fluctuations in SNS and PNS activity (Berntson & Norman, 2021; Burt & Obradović, 2013). Lastly, although autonomic effects on youth behavior are documented to be conditional on family contexts (El-Sheikh et al., 2013; Zhang et al., 2021), scarce research tests for the potential moderating effects of family functioning on the association between coordinated intra-individual ANS activity and the development of youth maladjustment. To address these limitations, the present study employs a multilevel modeling approach to model dynamic ANS coordination, defined as the within-person, epoch-to-epoch cross-correlation between the SNS and PNS (Cui et al., 2021; Weissman & Mendes, 2021), during a dyadic conflict task. Then, we test whether the effects of ANS coordination on youth adjustment problems are moderated by family functioning.

The Autonomic Nervous System and Child Psychological Development

ANS functioning is underlain by the SNS and PNS, which coactively facilitate metabolic outputs to support homeostasis and respond to stressors and other experiences (McCorry, 2007). Innervating most physiological systems, activity in the SNS and PNS branches evokes opposing effects from target organs. Activity in the sympathetic branch promotes physiological arousal (e.g., increased heart rate) in response to environmental stimuli that are evaluated to necessitate physical or cognitive action (McEwen, 1998). Alternatively, parasympathetic activity promotes low arousal (e.g., decreased heart rate) and the allocation of resources that advance resting-state processes for bodily maintenance, restoration, and preparation for future challenges. During acute stress, the rapid withdrawal of parasympathetic activity quickly increases arousal and functions as a first responder to perceived stressors (Porges, 2007). Because the SNS and PNS cannot be measured directly, non-invasive biomarkers are widely used in research. Specifically, pre-ejection period (PEP) and respiratory sinus arrhythmia (RSA) are well-validated cardiac indicators of the SNS and PNS, respectively (Berntson et al., 1993; Houtveen et al., 2005).

ANS functioning has been studied extensively for its role in the development of children's maladjustment. This is due to its bioregulatory role in responding to normative, daily stressors such as social engagement, interpersonal conflict, and cognitive tasks (Porges, 2007; Thayer & Lane, 2000). Yet, knowledge gaps on the linkages between the ANS and risks for the development of adjustment problems in youth prevail, in part because of conflicting and null findings. For example, in single systems studies (SNS or PNS), empirical evidence suggests that autonomic under-arousal (Roubinov et al., 2021; Scott & Weems, 2014), over-arousal (Kalvin et al., 2016), or both (Acland et al., 2019; Boyce et al., 2001; Dietrich et al., 2007; Miller et al., 2017) can indicate biobehavioral dysregulation and increased risk for psychopathology. To address these gaps, researchers have argued for studies that employ multi-system approaches that more accurately characterize the ANS to more precisely examine its associations with behavioral and psychological adjustment (Bauer et al., 2002; Beauchaine, 2001; Gatzke-Kopp & Ram, 2018).

Autonomic Nervous System Coordination

The Autonomic Space Model (ASM) delineates critical aspects of autonomic functioning for research (Berntson et al., 1994). First, the ASM suggests that, although the SNS and PNS exert opposing effects on target organs, their activity is not necessarily reciprocal. Thus, the activity of one branch of the ANS cannot be inferred from the activity of the other branch (Berntson et al., 1994). Rather, SNS and PNS activity can be positively correlated and evoke competitive metabolic effects (e.g., co-active or co-inhibited), negatively correlated and evoke cooperative effects (e.g., sympathetic or parasympathetic dominant reciprocal), or any combination of degree of correlated SNS and PNS activity. Second, according to the ASM, individual variability in autonomic reactivity to stressors (e.g., social stress) exists based on differences between individuals' perceptions of experiences and physiological predispositions (Berntson & Norman, 2021). Last, autonomic activity is dynamic and continuously updates according to changing environmental demands (Berntson et al., 2008). ANS modeling strategies that do not consider this range of properties may not be comprehensive.

Recently, some innovative studies have modeled ANS coordination, or the within-person coupling between physiological indicators of the SNS and PNS, using multilevel modeling analyses. Using this approach in a child sample, Gatzke-Kopp and Ram (2018) found that, although within-person reciprocal ANS coordination was more common across experiences, some heterogeneity in ANS coordination patterns were evident. Further, the level of coordination was found to vary by emotional context. In adults, two recent studies found that reciprocal within-person ANS coordination was typical during the speech preparation and delivery portion of the Trier Social Stress Task (TSST), whereas significant positive ANS coordination was found during the post-stress recovery period (Cui et al., 2021; Weissman & Mendes, 2021). Interestingly, although, Cui et al. (2021) found significant mean-level ANS coordination at rest and during each stage of the TSST, they found no significant ANS coordination during a back-and-forth conversation with a researcher. This finding may indicate between-person heterogeneity in ANS coordination during some social interactions. Taken together, emerging research has found evidence for individual differences in ANS coordination and that the degree of sympathetic and parasympathetic coordination is specific to the situation. Conflict with parents is a common social stressor in adolescence (Bradford et al., 2007). However, ANS coordination studies within a developmental framework are scarce (Gatzke-Kopp & Ram, 2018), and it is not yet known how preadolescent within-person ANS coordination during a parent-child conflict is related to between-person psychological functioning.

Family Functioning Context, the ANS, and Youth Adjustment Problems

The developmental psychopathology perspective suggests psychopathology rarely results from single causes (Cicchetti, 1993). Rather, such maladaptation is understood to emerge through complex, multilevel processes involving an individual’s biology and their environment (Beauchaine & McNulty, 2013). Indeed, a growing body of work has found support for investigating the impacts of joint ANS reactivity (i.e., concurrent SNS and PNS) on youth adjustment problems within environmental contexts. For example, El-Sheikh et al. (2013) found that high PNS (via RSA) activity accompanied by low SNS (via skin conductance level; SCL) activity in response to a cognitively challenging stress task was a risk factor for internalizing problems in childhood, especially in the context of high marital conflict. In another study, Philbrook et al. (2018) found that co-increases in PNS (via RSA) and SNS (via SCL) activity in response to a cognitive stressor predicted growth of externalizing problems from age 16 to 18 in the context of high marital conflict. Yet, the same ANS pattern was linked to decreased externalizing problems in low marital conflict environments. Thus, these studies highlight the critical role of context in the associations between joint ANS activity and youth risk for adjustment problems. However, to our knowledge, no studies have tested the effect of dynamic ANS coordination on the development of internalizing and externalizing problems, across different contexts, such as the family environment.

The family context is a multidimensional construct that bears significant effects on the development of psychopathology in youth (Davies & Cicchetti, 2004). This multidimensionality of the family functioning context is comprehensively characterized by the Circumplex Model (Olson et al., 2006). This model suggests that family functioning can be assessed across the dimensions of cohesion and family flexibility. Cohesion refers to emotional bonding between family members, while flexibility refers to adaptability in family negotiations, organization, rules, and relations. (Olson, 2011). Adequate levels of family cohesion and flexibility are documented to indicate a supportive and secure environmental context that can lead to enduring positive psychological development for children (Zahra & Saleem, 2021). For example, family cohesion is linked to children's increased self-control (Cho et al., 2018), overall better mental health (Jhang, 2017; Oshri et al., 2015), decreased externalizing problems (Richmond & Stocker, 2006), and improved affective aspects of well-being (Láng, 2018). Similarly, balanced levels of flexibility have been linked to lower depressive symptoms (Joh et al., 2013) and lower levels of addictive risk behaviors (Tafà & Baiocco, 2009). Further, family functioning is identified as a protective context for youth at risk for behavior problems (Daniels & Bryan, 2021; Deković, 1999; El-Sheikh & Buckhalt, 2003). However, less is known about the interactive roles of family cohesion and flexibility with ANS functioning to effectuate youth maladjustment.

The Present Study

In the present study, I longitudinally investigated the effect of ANS coordination (via PEP-RSA coupling) on youth internalizing and externalizing problems. I hypothesized that more negative ANS coordination (reciprocal SNS and PNS activity) during a parent-child conflict task would represent autonomic volatility and be associated with increased internalizing and externalizing problems. Alternatively, I hypothesized that less reciprocal or more positive coordination (co-activation/co-inhibition in SNS and PNS) would represent a more calibrated and adaptive autonomic strategy during a parent-child conflict task. Second, two aspects of family functioning (cohesion and flexibility) were modeled as moderators in the effect of ANS coordination on youth internalizing and externalizing problems. I hypothesized that high family functioning would be a protective factor in the links between reciprocal ANS activity and increased internalizing and externalizing problems.

CHAPTER 2

METHODS

Participants

Children and primary caregivers (*N* = 101) were recruited through community liaisons, flyers, and afterschool programs in a catchment area in a small city in the southeastern U.S. Data was collected from children and parents, ages 9-12 years at the first time point (M_{age} = 10.28 years; SD_{age} = 1.19; 50.5% female); however, 8 were excluded due to missing physiological data at all time points. All children were from families that were at or below 200% of the federal poverty line in 2017. Children were excluded for a history of heart conditions, type II diabetes, or significant developmental disabilities. The sample was diverse (72.5% African American; 10.9% Caucasian; 8.9% Latin American; 4% Other).

Procedures

All study protocols were approved by the University of Georgia Institutional Review Board for ethical conduct. Community liaisons were used to recruit and were compensated for each participant referred. At the first time point, trained research staff and licensed pediatric nurses collected survey and physiological data at a university-affiliated clinical research unit. Participants received $100 as compensation for the first session. Parents and children provided consent and assent, respectively, to participate in the first wave of data collection. After informed consent, children proceeded to be fitted with electrodes in preparation for psychophysiological data acquisition.

Participants (*N* = 71; 70.30% of T1 sample) who opted to be re-contacted were included in a second wave of survey questions (30-minute session), collected approximately one year later. Participants received $50 as compensation for the second session. Independent sample *t*-tests and chi-square tests demonstrated the sample for T2 was not significantly different from the sample from T1 on demographics or study variables (i.e., race/ethnicity, income, gender, physiological data, and behavior problems), except child age ($M_{\text{difference}} = -0.64$, $t = -2.49$, $p = .014$). Prior to data collection, primary caregivers and youth provided informed consent and assent, respectively.

Measures

Internalizing and Externalizing Problems (T1 &T2)

Child internalizing and externalizing problems were collected using a parent-report of the Child Behavior Checklist (CBCL; Achenbach & Edelbrock, 1991). Parents answered a series of 118 questions about child behavior using a 3-response set ranging from not true (0) to very often true (2). T-scores were calculated for broadband measures of internalizing and externalizing problems to indicate levels of both domains of adjustment problems. Internal consistency was high for both internalizing (α = .88) and externalizing (α = .91) problems.

Family Functioning (T1)

Child-reported family flexibility and cohesion were measured using the fourth version of the Family Adaptability and Cohesion Scale (FACES IV; Olson et al., 2006), which has been validated in various studies (Loriedo et al., 2013; Olson, 2011). Participants answered 42 items on Likert-type scales (responses ranged from 1 = strongly disagree, to 5 = strongly agree) that covered six dimensions of family functioning (7 items per dimension). These dimensions included two balanced subscales that reflect adaptive functioning; cohesion and flexibility, and four unbalanced subscales that assess family dysfunction; enmeshment, rigidity, chaos, and disengagement. The balanced cohesion subscale corresponds with the unbalanced enmeshment and disengagement subscales, whereas the flexibility subscale corresponds with the chaos and rigidity subscales. Ratio scores were calculated by dividing the balanced scores by the average of the corresponding unbalanced scores. Higher scores (greater than 1) represent a healthy, balanced system in each dimension (i.e., cohesion and flexibility), whereas lower scores (less than 1) represent an unbalanced family system (Olson et al., 2006). Reliabilities for the subscales were acceptable (cohesion, $\alpha = .71$; flexibility, $\alpha = .72$; disengagement, $\alpha = .76$; enmeshment, $\alpha = .67$; rigidity, $\alpha = .60$; chaos, $\alpha = .74$).

Parent-child conflict task (T1)

Baseline resting states were recorded while dyads were asked to relax and sit still with eyes closed and listen to a 3-minute recording of nature sounds. Children and their parents were then asked to participate in a videotaped ten-minute conflict task in which they pursued a resolution on topics of disagreement. Dyads were given index cards containing topics representing common points of contention in parent-child relationships, such as cleaning, bedtime, and homework. Then, dyads were instructed to choose the three most contentious topics, based on their prior disagreements. Adapted by Ehrlich and colleagues, this task is informed by prior parent-child dyadic conflict protocols (Ehrlich et al., 2012; Kobak et al., 1993). If time remained, dyads were instructed to choose and discuss additional topics. Conflict tasks between parents and children have been demonstrated to evoke physiological and psychological stress (Cui et al., 2015).

Observed parent and child behaviors were codified according to systems developed for Early Head Start Research and Evaluation Project (Martin et al., 2008). Parent and child behavior subscales were evaluated on a 7-point rating scale (1 = *very low,* 7 = *very high*). Intraclass correlation coefficients (ICCs; Shrout & Fleiss, 1979) for interrater reliabilities ranged from good to very good (ICCs ranged from .76 to .90). Parental positivity towards the child, parental negativity towards the child, and child engagement were selected as covariates in the current study to control for these aspects of the conflict-task. After the task, dyads proceeded to complete a series of surveys.

Physiological Data

Intra-individual synchrony between the SNS and PNS was assessed in children during the aforementioned laboratory-based conflict task. Respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) data were digitized using MindWare Bioloab 3.2.1 Software (MindWare Technologies, Ltd., Ghanna, OH). Next, trained research assistants cleaned the raw data.

Electrodes for RSA acquisition were placed on the child on the right collarbone, cleft of throat, at the base of the 10th rib on both left and right sides of the body, near the xiphoid process, midway down the spine, and roughly 2 cm below the base of the skull on the back. The EKG signal was digitized to 1,000 Hz and MindWare used a peak-identification algorithm to create an inter-beat interval series, or R-R interval. Artifacts in the data were highlighted by the software and inspected by trained research assistants. Abnormal R-R intervals were manually amended according to MindWare protocol by deleting extra beats and inserting midbeats. Segments (or epochs) were deleted if more than 10% editing was required (n = 5). RSA values were computed using the natural logarithm of the variance heart rate period within the frequency bandpass related to respiration (0.24-1.04 Hz for children). These components of HRV were collected using power spectrum analysis (Ernst et al., 1999). Duration of the conflict task was 10 minutes and data were divided into 30-second epochs (20 total).

Pre-ejection period is considered one of the best indices available to measure sympathetic influence of the heart. It is defined as the time between electrical stimulation of the left ventricle of the heart and ventricular ejection of blood into the aorta. Also, PEP is the time between the Q-wave in the ECG channel (i.e., beginning of electrical stimulation of the left ventricle) and the B-point in the impedance cardiogram (i.e., opening of aortic valve; Lozano et al., 2007). PEP is considered an inverse index of the SNS because lower values represent shorter time invervals and indicate higher sympathetic activity. Impedance data were ensemble-averaged into 30-second epochs and combined with R waves from the ECG with MindWare IMP 3.1.4 Software module. Trained research assistants cross-inspected and corrected abnormal R-R intervals (e.g., severe fluctuations, ectopic beats due to physical movement or breathing, inadvertent cardiac fluctuations). Like RSA data, PEP data was divided into 20, 30-second epochs.

Analytic Plan

All study hypotheses were tested with multilevel methods in Mplus version 8.4 using maximum likelihood estimation with robust standard errors (Muthén & Muthén, 2012; Yuan & Bentler, 2000). Baseline RSA and PEP were calculated as an average of activity over five minutes of rest. In the first level, ΔRSA and ΔPEP were calculated by subtracting raw RSA and PEP values from average baseline RSA and PEP values, respectively at each of the epochs (Weissman & Mendes, 2021). According to Helm et al. (2018), synchronous data results can be influenced by overall trends that occur over the duration of measurement. Thus, best fit lines were fitted to each individual's repeated ΔRSA and ΔPEP values and residuals were obtained to remove potential trends. Additionally, to normalize variances within subjects to examine bidirectional PEP-RSA coupling correlations, rather than covariances, ΔRSA and ΔPEP were standardized across the 20 epochs, for each individual (Helm et al., 2018; Weissman & Mendes, 2021). Then, PEP was regressed on RSA across the 20 epochs to indicate degree of ANS coordination, according to the first-level equation below. In this equation, $PEP_{i,t}$ and $RSA_{i,t}$ denote the *i*th ANS value at time *t*. The effect of the *i*th RSA value on PEP was calculated as the ANS coordination index (ANS-C_i).

$$PEP_{i,t} = Intercept_0 + ANS\text{-}C_i * RSA_{i,t} + \varepsilon_{i,t}$$

In the second level, longitudinal direct effects were examined between within-individual PEP-RSA coupling and between-individual internalizing and externalizing problems. Next, the moderating roles of family cohesion and family flexibility on the relations between ANS coordination and youth internalizing and externalizing problems were tested in separate models. Age, gender, race, observed positive and negative parenting, observed child engagement, and T1 internalizing and externalizing problems are also included as covariates. Non-significant covariates were trimmed.

CHAPTER 3

RESULTS

Preliminary analyses

Descriptive statistics and correlations among key study variables are presented in Table 1. Study variable correlations followed expected patterns. For example, youth age was associated with increased internalizing (r = .30, p = .005) and externalizing problems (r = .25, p = .019). Family cohesion was also negatively correlated with T2 internalizing problems (r = -.25, p = .035). PEP-RSA coordination was also highly correlated with T2 internalizing problems at T2 (r = .75, p < .001) and T2 externalizing problems (r = .48, p < .001).

Multilevel modeling results

Within-individual PEP-RSA coupling

Multilevel models were constructed to test study hypotheses (see Table 2). First-level (i.e., within-person PEP-RSA coupling) results demonstrated a non-significant intercept (b = -.01, SE = 0.06, 95% CI [-0.12, 0.10], p = .816) and mean (b = 0.04, SE = 0.04, 95% CI [-0.05, 0.12], p = .408) and significant residual variance (σ^2 = 0.83, SE = 0.16, 95% CI [0.56, 1.18], p < .001) and variance (σ^2 = 0.08, SE = 0.01, 95% CI [0.05, 0.12], p = .001). These first-level results suggest that, although mean PEP-RSA coupling was not significantly different from zero, there was significant heterogeneity in coupling across the sample.

Between-individual direct effects

At the second level, we first tested between-individual direct effects of PEP-RSA coupling, family cohesion and flexibility, and covariates on youth internalizing and externalizing problems. Covariates included youths' age, gender, race, observed child engagement, observed positive parenting, observed negative parenting and corresponding adjustment problems at T1. Of the tested covariates, only sex significantly predicted externalizing (*b* = 3.87, *SE* = 1.88, 95% CI [0.19, 7.54], *p* = .039), but not internalizing problems. Neither family cohesion nor flexibility significantly predicted internalizing or externalizing problems, however PEP-RSA coupling significantly and positively predicted both domains of maladjustment (internalizing: *b* = 34.33, *SE* = 11.78, 95% CI [11.10, 57.42], *p* = .004; externalizing: *b* = 22.60, *SE* = 7.00, 95% CI [8.90, 36.30], *p* = .001). This result indicates that more reciprocal SNS-PNS coordination was linked to increased risk for internalizing and externalizing problems.

Between-level moderating effects

Interactions between PEP-RSA coupling and dimensions of family functioning were tested in separate models (see Table 2). In model 1, family cohesion moderated the effect of PEP-RSA coupling on both T2 internalizing (*b* = -10.72, *SE* = 3.93, 95% CI [-18.43, -3.02], *p* = .006) and T2 externalizing (*b* = -23.94, *SE* = 5.26, 95% CI [-23.94, -3.32], *p* = .009) problems. However, in model 2, family flexibility did not significantly moderate these effects (internalizing: *b* = -3.26, *SE* = 1.80, 95% CI [-6.77, 0.24], *p* = .068; externalizing: *b* = -2.21, *SE* = 1.16, 95% CI [-4.48, 0.07], *p* = .057).

Post-hoc analysis

Significant interactions were probed with region of significance analyses and simple slopes tests to determine the ranges of family cohesion for which the interactions were significant. In model 1, PEP-RSA coupling was positively related to internalizing problems from low to moderate levels of family cohesion (cohesion ≤ 3.8; 73.3% of participants), but not at higher levels of family cohesion (see Figure 1). This indicates that more negatively correlated

SNS and PNS was linked to increased internalizing problems at lower and moderate levels of family cohesion. Also in model 1, PEP-RSA coupling was positively linked to externalizing problems at lower levels of family cohesion (cohesion ≤ 3.2; 83.0% of participants), but negatively linked to externalizing problems at very high levels (cohesion ≥ 4.8; 9.9% of participants; see Figure 2). Thus, at lower levels of family cohesion, more negatively correlated youth SNS and PNS was significantly associated with an increased risk for externalizing problems, yet lower risks at higher levels of family functioning.

CHAPTER 4

DISCUSSION

ANS functioning is increasingly used in developmental science as a biomarker of self-regulation. Although a promising body of such research has accumulated, frequently used ANS modeling approaches are evolving and this line of research may benefit from methodological reifications (Bauer et al., 2002; Berntson & Norman, 2021). Recently, some studies have modeled ANS coordination, or the dynamic coupling between the SNS and PNS over time, to reflect autonomic activity. In the present study, I modeled youth ANS coordination during a parent-child conflict task and examined its associations with youth behavioral adjustment problems, across different family functioning contexts. I first tested the direct effects of autonomic coordination, and then the moderating effects of family functioning (i.e., cohesion and flexibility), on youth internalizing and externalizing problems. I found that more reciprocal ANS coordination (indicated by more positive PEP-RSA coupling) predicted later risk for internalizing and externalizing problems. Second, family cohesion moderated the effect of autonomic coordination on both internalizing and externalizing problems. Specifically, for youth with reciprocal ANS coordination, high family cohesion was a protective factor for internalizing problems. Further, I found evidence that, at very high levels of family cohesion, reciprocal ANS coordination led to lower levels of youth externalizing problems.

I first hypothesized that reciprocal ANS coordination would be associated with increased internalizing and externalizing problems. This hypothesis was supported by the results, which showed that more reciprocal ANS coordination was significantly associated with worsening internalizing and externalizing problems over time. Although we are unaware of studies linking dynamic ANS coordination to such problems, some studies have investigated the interactive effects of mean level SNS and PNS reactivity using other modeling strategies (Benito-Gomez et al., 2019; El-Sheikh et al., 2013; Oshri et al., 2021). For example, Benito-Gomez et al. (2019) found that concurrent high PNS activity and low SNS activity (via RSA and SCL, respectively) was linked to more internalizing problems. In contrast, high PNS and high SNS activity was linked to fewer internalizing problems. Similarly, it was found that the two-way interaction between RSA reactivity and SCL reactivity significantly predicted growth of internalizing problems, but not externalizing problems (Philbrook et al., 2018), which was supported by the results of the current study.

Our second hypothesis was that the effect of ANS coordination varies by family context. We found that family cohesion, but not flexibility, significantly moderated the effect of ANS coordination on both internalizing and externalizing problems. Specifically, reciprocal ANS coordination was a risk factor for both domains of behavior problems in children from low to moderate cohesion families, whereas among high cohesion families ANS coordination was no longer a risk factor. This finding may suggest that risks associated with some patterns of autonomic functioning are more likely to manifest in adverse environments, as has been found previously (Zhang et al., 2021), and that the positive emotional bonding inherent in families with high cohesion represents a protective environmental context.

In contrast to our prediction, in very high cohesion families, reciprocal ANS coordination predicted fewer externalizing problems. This finding partially supports results by Philbrook et al. (2018) that reciprocal sympathetic activation (i.e., average low PNS, high SNS) was linked to more externalizing problems in a high marital conflict context, but fewer in low marital conflict.

Theoretically, this finding may indicate the tendency for more reactive individuals to absorb the characteristics of their environment more thoroughly, for better or worse, as is proposed in biological sensitivity to context (Boyce & Ellis, 2005; Ellis & Boyce, 2008) and differential susceptibility to environment theories (Belsky, 2016; Belsky et al., 2007). Future studies may consider testing ANS coordination as a sensitivity factor in youth, especially for externalizing symptomology.

What explains ANS coordination? We found significant within-person variance in ANS coordination, yet the mean-level of ANS coordination was not significantly different from zero. This heterogeneity points to the limitation of relying on average statistics parameters to reflect autonomic activity during some experiences or lab-based tasks. Because some children's SNS and PNS were negatively coupled, while among others they were positively coupled, an average level of individual differences in ANS coordination may obscure important between-person variability. We also found that variability in ANS coordination could explain between-person differences in development of adjustment problems, particularly in families reporting low to moderate cohesion. Despite these notable results, the design of the current study did not allow us to test the foundations of differences in ANS coordination. We may suspect that differences in the children's engagement in the task contributes to differences in autonomic activity. Indeed results of previous research have found that preparing and delivering speeches during a social stress task were associated with negative ANS coordination, while resting before and recovery from the task was linked to positive ANS coordination (Cui et al., 2021; Weissman & Mendes, 2021). Findings from these studies may suggest that an individual's level of effortful participation in such activities contributes to changes in the direction of ANS coordination. However, ANS coordination was not significantly correlated with the child's observed level of engagement in the parent-child conflict task, which suggests that alternative aspects of the experience (e.g., emotional salience) likely explain individual differences in coordination.

Other research suggests that the emotional salience and associated neural influences related to the task may explain some of the differences in individual's ANS coordination. Gatzke-Kopp and Ram (2018) found that watching film clips characterized by approach emotions, such as anger or happiness, was associated with reciprocal ANS coordination. Yet, SNS and PNS activity was not clearly coupled on average during avoidance emotions, such as fear and sadness. Thus, variability in emotions evoked during the parent-child interaction may explain the heterogeneity in autonomic responses between youth. Emotional phenomena are mediated by higher-level brain structures known directly and indirectly to influence the ANS. For example, activation in the amygdala is known to both increase SNS activity and decrease PNS activity in response to some emotional stimuli (Weymar & Schwabe, 2016), which can be inhibited via connections with the medial prefrontal cortex (Akirav & Maroun, 2007). In the current study, children's emotions may have been differentially influenced by multiple aspects of the lab-based task, such as stress induced by engaging in a conflict or by the qualities of the parent-child relationship, leading to variability in ANS coordination.

Limitations and Future Directions

The present study has several limitations. First, pre-adolescent behavioral measures were based solely on mother-reported data. The inclusion of child- or observer-reported data would provide a more comprehensive estimation of the constructs of interest. Second, the parent-child task features multiple effects on ANS coordination, including the parent-child relationship, the act of participating in a conversation, and the conflictual nature of the task. Although significant associations remained after controlling for observed parenting (i.e., positive and negative) and child engagement during the task, it is difficult to isolate which aspects of the task drove the physiological reactivity. Future studies should compare children's ANS activity during parent-child conflicts with neutral interactions and across interlocutors, such as strangers or friends. Third, although ANS activity was measured during an ecologically relevant stress-task, the results may be more accurately interpreted as task specific. Indeed, research has demonstrated that patterns of autonomic reactivity are context-dependent (Obradović, 2012), and the effects of autonomic reactivity on psychological development have been found to depend on the nature of the lab-based stressor (Hinnant & El-Sheikh, 2009). Future studies should examine ANS coordination across other types of experiences. Last, although modeling epoch-to-epoch (30s per epoc) ANS coordination is a step forward in this line of research, this method still neglects momentary changes in autonomic activity. Despite these limitations, our findings highlight the potential benefits of modeling ANS coordination in a developmental framework and justify further investigation of its longitudinal effects, across contexts.

Conclusion

The ANS has been shown to be a relevant biomarker of emotion regulation in developmental science. In a field historically dominated by self- and parent-reported data, unbiased, transdiagnostic biomarkers have added substantially to current understandings of regulatory processes. However, most of this research has reduced this dynamic, multi-component system to average scores of the PNS (via RSA), and less often the SNS (via PEP or SCL). In the current study, I showed the benefits of studying the dynamic activity between both branches. Employed here, a multilevel modeling approach that incorporates the epoch-to-epoch coordination of the SNS and PNS is one such method that aims to capture the regulatory organization of both ANS component systems over time. Yet, I also showed the importance of studying this effect within the family cohesion context. Alternative ANS modeling methods are becoming more common in research (West et al., 2021) and will provide a deeper understanding of the role of the ANS in psychological development. Our findings suggest this is a promising method for quantifying ANS functioning to understand the its role in the development of regulatory dysfunction in children.

REFERENCES

Achenbach, T. M., & Edelbrock, C. (1991). Child behavior checklist. *7*, 371-392.

Acland, E. L., Colasante, T., & Malti, T. (2019). Respiratory sinus arrhythmia and prosociality in childhood: Evidence for a quadratic effect. *Developmental Psychobiology, 61*(8), 1146-1156. https://doi.org/10.1002/dev.21872

Akirav, I., & Maroun, M. (2007). The role of the medial prefrontal cortex-amygdala circuit in stress effects on the extinction of fear. *Neural Plasticity, 2007*, 1-11. https://doi.org/10.1155/2007/30873

Bauer, A. M., Quas, J. A., & Boyce, W. T. (2002). Associations between physiological reactivity and children's behavior: Advantages of a multisystem approach. *Journal of Developmental & Behavioral Pediatrics, 23*(2), 102-113. https://doi.org/10.1097/00004703-200204000-00007

Beauchaine, T. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology, 13*(2), 183-214. https://doi.org/10.1017/S0954579401002012

Beauchaine, T. (2015, 2015/06/01/). Respiratory sinus arrhythmia: a transdiagnostic biomarker of emotion dysregulation and psychopathology. *Current Opinion in Psychology, 3*, 43-47. https://doi.org/10.1016/j.copsyc.2015.01.017

Beauchaine, T., & McNulty, T. (2013). Comorbidities and continuities as ontogenic processes: Toward a developmental spectrum model of externalizing psychopathology. *Development and Psychopathology, 25*(4pt2), 1505-1528. https://doi.org/10.1017/S0954579413000746

Belsky, J. (2016). The differential susceptibility hypothesis: Sensitivity to the environment for better and for worse. *JAMA Pediatrics, 170*(4), 321-322. https://doi.org/10.1001/jamapediatrics.2015.4263

Belsky, J., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). For better and for worse: Differential susceptibility to environmental influences. *Current Directions in Psychological Science, 16*(6), 300-304. https://doi.org/https://doi.org/10.1111/j.1467-8721.2007.00525.x

Benito-Gomez, M., Fletcher, A. C., & Buehler, C. (2019). Sympathetic and parasympathetic nervous system functioning and experiences of peer exclusion: Links to internalizing problems in early adolescence. *Journal of Abnormal Child Psychology, 47*(4), 633-644. https://doi.org/10.1007/s10802-018-0472-0

Berntson, G. G., Cacioppo, J. T., & Fabro, V. T. (1994). Autonomic space and psychophysiological response. *Psychophysiology, 31*(1), 44-61. https://doi.org/10.1111/j.1469-8986.1994.tb01024.x

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology, 30*(2), 183-196. https://doi.org/10.1111/j.1469-8986.1993.tb01731.x

Berntson, G. G., & Norman, G. J. (2021). Multilevel analysis: Integrating multiple levels of neurobehavioral systems. 18-25. https://doi.org/10.1080/17470919.2021.1874513

Berntson, G. G., Norman, G. J., Hawkley, L. C., & Cacioppo, J. T. (2008). Cardiac autonomic balance versus cardiac regulatory capacity. *Psychophysiology, 45*(4), 643-652.

Boyce, W. T., & Ellis, B. J. (2005). Biological sensitivity to context: I. An evolutionary–developmental theory of the origins and functions of stress reactivity. *Development and Psychopathology, 17*(2), 271-301. https://doi.org/https://doi.org/10.1017/S0954579405050145

Boyce, W. T., Quas, J., Alkon, A., Smider, N. A., Essex, M. J., & Kupfer, D. J. (2001). Autonomic reactivity and psychopathology in middle childhood. *British Journal of Psychiatry, 179*(2), 144-150. https://doi.org/10.1192/bjp.179.2.144

Bradford, K., Vaughn, L. B., & Barber, B. K. (2007). When There Is Conflict: Interparental Conflict, Parent–Child Conflict, and Youth Problem Behaviors. *Journal of Family Issues, 29*(6), 780-805. https://doi.org/10.1177/0192513X07308043

Burt, K. B., & Obradović, J. (2013). The construct of psychophysiological reactivity: Statistical and psychometric issues. *Developmental Review, 33*(1), 29-57. https://doi.org/10.1016/j.dr.2012.10.002

Cho, I. Y., Kim, J. S., & Kim, J. O. (2018). Factors influencing adolescents' self-control according to family structure. *Journal of Child and Family Studies, 27*(11), 3520-3530. https://doi.org/10.1007/s10826-018-1175-4

Cicchetti, D. (1993). Developmental Psychopathology: Reactions, Reflections, Projections. *Developmental Review, 13*(4), 471-502. https://doi.org/10.1006/drev.1993.1021

Cui, L., Morris, A. S., Harrist, A. W., Larzelere, R. E., & Criss, M. M. (2015). Dynamic changes in parent affect and adolescent cardiac vagal regulation: A real-time analysis. *Journal of Family Psychology, 29*(2), 180. https://doi.org/10.1037/fam0000067

Cui, L., Sun, Q., Yu, F., Xu, J., & Wang, H. (2021). Exploring emotional dynamic within-person concordance across laboratory tasks: Moderation of between-person SES and sexual orientation. *Biological Psychology, 161*. https://doi.org/10.1016/j.biopsycho.2021.108055

Daniels, A. D., & Bryan, J. (2021). Resilience despite complex trauma: Family environment and family cohesion as protective factors. *The Family Journal, 29*(3), 336-345. https://doi.org/10.1177/10664807211000719

Davies, P. T., & Cicchetti, D. (2004). Toward an integration of family systems and developmental psychopathology approaches. *Development and Psychopathology, 16*(3), 477-481. https://doi.org/10.1017/S0954579404004626

Deković, M. (1999). Risk and protective factors in the development of problem behavior during adolescence. *Journal of Youth and Adolescence, 28*(6), 667-685. https://doi.org/10.1023/A:1021635516758

Dietrich, A., Riese, H., Sondeijker, F. E. P. L., Greaves-Lord, K., van Roon, A. M., Ormel, J., Neeleman, J. A. N., & Rosmalen, J. G. M. (2007). Externalizing and internalizing problems in relation to autonomic function: A population-based study in preadolescents. *Journal of the American Academy of Child & Adolescent Psychiatry, 46*(3), 378-386. https://doi.org/10.1097/CHI.0b013e31802b91ea

Ehrlich, K. B., Dykas, M. J., & Cassidy, J. (2012). Tipping points in adolescent adjustment: Predicting social functioning from adolescents' conflict with parents and friends. *Journal of Family Psychology, 26*(5), 776-783. https://doi.org/10.1037/a0029868

El-Sheikh, M., & Buckhalt, J. A. (2003). Parental problem drinking and children's adjustment: Attachment and family functioning as moderators and mediators of risk. *Journal of Family Psychology, 17*(4), 510-520. https://doi.org/10.1037/0893-3200.17.4.510

El-Sheikh, M., Keiley, M., Erath, S., & Dyer, W. J. (2013). Marital conflict and growth in children's internalizing symptoms: The role of autonomic nervous system activity. *Developmental Psychology, 49*(1), 92-108. https://doi.org/10.1037/a0027703

Ellis, B. J., & Boyce, W. T. (2008). Biological Sensitivity to Context. *Current Directions in Psychological Science, 17*(3), 183-187. https://doi.org/10.1111/j.1467-8721.2008.00571.x

Ernst, J. M., Litvack, D. A., Lozano, D. L., Cacioppo, J. T., & Berntson, G. G. (1999). Impedance pneumography: Noise as signal in impedance cardiography. *Psychophysiology, 36*(3), 333-338. https://doi.org/https://doi.org/10.1017/S0048577299981003

Gatzke-Kopp, L., & Ram, N. (2018). Developmental dynamics of autonomic function in childhood. *Psychophysiology, 55*(11), e13218. https://doi.org/10.1111/psyp.13218

Helm, J. L., Miller, J. G., Kahle, S., Troxel, N. R., & Hastings, P. D. (2018). On measuring and modeling physiological synchrony in dyads. *Multivariate Behavioral Research, 53*(4), 521-543. https://doi.org/10.1080/00273171.2018.1459292

Hinnant, J. B., & El-Sheikh, M. (2009). Children's externalizing and internalizing symptoms over time: The role of individual differences in patterns of RSA responding. *Journal of Abnormal Child Psychology, 37*(8), 1049-1061. https://doi.org/10.1007/s10802-009-9341-1

Houtveen, J. H., Groot, P. F. C., & De Geus, E. J. C. (2005). Effects of variation in posture and respiration on RSA and pre-ejection period. *Psychophysiology, 42*(6), 713-719. https://doi.org/10.1111/j.1469-8986.2005.00363.x

Jhang, F.-H. (2017). Economically disadvantaged adolescents' self-concept and academic achievement as mediators between family cohesion and mental health in Taiwan. *International Journal of Mental Health and Addiction, 15*(2), 407-422. https://doi.org/10.1007/s11469-017-9737-z

Joh, J. Y., Kim, S., Park, J. L., & Kim, Y. P. (2013, May). Relationship between family adaptability, cohesion and adolescent problem behaviors: Curvilinearity of Circumplex Model. *Korean J Fam Med, 34*(3), 169-177. https://doi.org/https://doi.org/10.4082/kjfm.2013.34.3.169

Kalvin, C. B., Bierman, K. L., & Gatzke-Kopp, L. M. (2016). Emotional reactivity, behavior problems, and social adjustment at school entry in a high-risk sample. *Journal of Abnormal Child Psychology, 44*(8), 1527-1541. https://doi.org/10.1007/s10802-016-0139-7

Kobak, R. R., Cole, H. E., Ferenz-Gillies, R., Fleming, W. S., & Gamble, W. (1993). Attachment and emotion regulation during mother-teen problem solving: A control theory analysis. *Child Development, 64*(1), 231-245. https://doi.org/10.1111/j.1467-8624.1993.tb02906.x

Láng, A. (2018). Family structure, family functioning, and well-being in adolescence: A multidimensional approach. *International Journal of Humanities and Social Science, 8*(2), 24-31.

Loriedo, C., Di Nuovo, S., & Visani, E. (2013). *FACES-IV reliability and validity in an adult Italian sample*. https://doi.org/10.13140/2.1.1866.1447

Lozano, D. L., Norman, G., Knox, D., Wood, B. L., Miller, B. D., Emery, C. F., & Berntson, G. G. (2007). Where to B in dZ/dt. *Psychophysiology, 44*(1), 113-119. https://doi.org/10.1111/j.1469-8986.2006.00468.x

Martin, A., Owen, M., Hetzner, N., & Brooks-Gunn, J. (2008). Early Head Start 5th Grade Follow-Up Study Videotaped Parent-Child Interaction Instructions for Coding Child and

Parent Scales. *Unpublished manual, National Center for Children and Families, Teachers College, Columbia University, New York, NY*.

McCorry, L. K. (2007). Physiology of the autonomic nervous system. *American Journal of Pharmaceutical Education, 71*(4), 78-78. https://doi.org/doi.org/10.5688/aj710478

McEwen, B. S. (1998). Stress, adaptation, and disease: Allostasis and allostatic load. *Annals of the New York Academy of Sciences, 840*(1), 33-44. https://doi.org/10.1111/j.1749-6632.1998.tb09546.x

McLaughlin, K. A., Sheridan, M. A., Tibu, F., Fox, N. A., Zeanah, C. H., & Nelson, C. A. (2015). Causal effects of the early caregiving environment on development of stress response systems in children. *Proceedings of the National Academy of Sciences, 112*(18), 5637. https://doi.org/10.1073/pnas.1423363112

Miller, J. G., Kahle, S., & Hastings, P. D. (2017). Moderate baseline vagal tone predicts greater prosociality in children. *Developmental Psychology, 53*(2), 274-289. https://doi.org/10.1037/dev0000238

Muthén, L., & Muthén, B. (2012). Mplus user's guide (Seventh). *Los Angeles, CA: Muthén & Muthén*.

Obradović, J. (2012). How can the study of physiological reactivity contribute to our understanding of adversity and resilience processes in development? *Development and Psychopathology, 24*(2), 371-387. https://doi.org/https://doi.org/10.1017/S0954579412000053

Olson, D. (2011). FACES IV and the Circumplex Model: Validation study. *Journal of Marital and Family Therapy, 37*(1), 64-80. https://doi.org/10.1111/j.1752-0606.2009.00175.x

Olson, D. H., Gorall, D. M., & Tiesel, J. (2006). FACES IV & the circumplex model. *Minneapolis, MN: Life Innovations*.

Oshri, A., Liu, S., Huffman, L. G., & Koss, K. J. (2021). Firm parenting and youth adjustment: Stress reactivity and dyadic synchrony of respiratory sinus arrhythmia. *Developmental Psychobiology, 63*(3), 470. https://doi.org/10.1002/dev.22019

Oshri, A., Lucier-Greer, M., O'Neal, C. W., Arnold, A. L., Mancini, J. A., & Ford, J. L. (2015). Adverse Childhood Experiences, Family Functioning, and Resilience in Military Families: A Pattern-Based Approach. *Family Relations, 64*(1), 44-63. https://doi.org/10.1111/fare.12108

Philbrook, L. E., Erath, S. A., Hinnant, J. B., & El-Sheikh, M. (2018, 09/01/). Marital Conflict and Trajectories of Adolescent Adjustment: The Role of Autonomic Nervous System Coordination. *Developmental Psychology, 54*(9), 1687-1696.

Porges, S. W. (2007). The polyvagal perspective. *Biological Psychology, 74*(2), 116-143. https://doi.org/10.1016/j.biopsycho.2006.06.009

Richmond, M. K., & Stocker, C. M. (2006). Associations between family cohesion and adolescent siblings' externalizing behavior. *Journal of Family Psychology, 20*(4), 663-669. https://doi.org/10.1037/0893-3200.20.4.663

Roubinov, D., Tein, J.-Y., Kogut, K., Gunier, R., Eskenazi, B., & Alkon, A. (2021). Latent profiles of children's autonomic nervous system reactivity early in life predict later externalizing problems. *Developmental Psychobiology, 63*(5), 1177-1189. https://doi.org/10.1002/dev.22068

Scott, B. G., & Weems, C. F. (2014). Resting vagal tone and vagal response to stress: Associations with anxiety, aggression, and perceived anxiety control among youths. *Psychophysiology, 51*(8), 718-727. https://doi.org/10.1111/psyp.12218

Shrout, P. E., & Fleiss, J. L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86*(2), 420-428. https://doi.org/10.1037/0033-2909.86.2.420

Susman, E. S., Weissman, D. G., Sheridan, M. A., & McLaughlin, K. A. (2021). High vagal tone and rapid extinction learning as potential transdiagnostic protective factors following childhood violence exposure. *Developmental Psychobiology, 63*(6), e22176. https://doi.org/https://doi.org/10.1002/dev.22176

Tafà, M., & Baiocco, R. (2009, 2009/09/28). Addictive behavior and family functioning during adolescence. *The American Journal of Family Therapy, 37*(5), 388-395. https://doi.org/10.1080/01926180902754745

Thayer, J. F., & Lane, R. D. (2000, 2000/12/02/). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders, 61*(3), 201-216. https://doi.org/10.1016/S0165-0327(00)00338-4

Weissman, D. G., & Mendes, W. B. (2021). Correlation of sympathetic and parasympathetic nervous system activity during rest and acute stress tasks. *International Journal of Psychophysiology, 162*, 60-68. https://doi.org/10.1016/j.ijpsycho.2021.01.015

West, K. B., Shaffer, A., Wickrama, K. A. S., Han, Z. R., & Suveg, C. (2021). Preschoolers' dynamic respiratory sinus arrhythmia (RSA) change during a challenging parent-child interactive task: Relations with preschoolers' socioemotional health. *Developmental Psychobiology, 63*(5), 1132-1145. https://doi.org/10.1002/dev.22054

Weymar, M., & Schwabe, L. (2016). Amygdala and amotion: The bright side of it. *Frontiers in Neuroscience, 10*. https://doi.org/10.3389/fnins.2016.00224

Yuan, K.-H., & Bentler, P. M. (2000). Three likelihood-based methods for mean and covariance structure analysis with nonnormal missing data. *Sociological Methodology, 30*(1), 165-200. https://doi.org/10.1111/0081-1750.00078

Zahra, S. T., & Saleem, S. (2021). The development of a family cohesion scale: A preliminary validation. *FWU Journal of Social Sciences, 15*(1), 120-131. https://doi.org/10.51709/19951272/spring2021/15-10

Zhang, H., Luo, Y., Davis, T., & Zhang, L. (2021). Interactive effects of childhood maltreatment and tonic respiratory sinus arrhythmia on young adults' depressive symptoms. *Psychophysiology, 58*(10), e13900. https://doi.org/doi.org/10.1111/psyp.13900

TABLES AND FIGURES

Table 1

Bivariate correlations and descriptive statistics for study variables (N = 101)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Gender (F = 1)	–												
2. Age	.14	–											
3. Race (Black = 1)	-.05	-.20*	–										
4. Obs Engagement (C)	.17	.01	.15	–									
5. Obs Positivity (P)	-.04	.06	.27*	.42***	–								
6. Obs Negativity (P)	-.07	.02	.18	-.20*	-.62***	–							
7. Family Cohesion	-.09	.10	-.09	.14	.07	.10	–						
8. Family Flexibility	-.10	.27**	-.14	.15	.11	.06	.62***	–					
9. Internalizing T1	.02	.30**	-.07	-.09	-.07	.04	-.05	.13	–				
10. Internalizing T2	.12	.08	-.06	.11	-.03	.05	-.25*	-.11	.58***	–			
11. Externalizing T1	.02	.25*	-.04	-.09	-.20	.08	-.07	.05	.69***	.34**	–		
12. Externalizing T2	.14	.17	-.02	.08	-.17	.21	-.18	-.03	.45***	.68***	.61***	–	
13. PEP/RSA-C	.04	.05	-.04	.08	.04	-.04	-.05	-.06	-.05	-.01	.75***	.48***	–
Mean	.52	10.29	.75	4.96	5.18	2.34	2.09	1.43	49.13	49.44	46.83	45.99	.04
SD	.50	1.19	.43	1.56	1.51	1.37	1.12	0.52	11.59	10.21	10.38	10.15	.28

Note. Obs = observed behavior during the parent-child conflict task, C = child, P = parent, PEP/RSA-C = correlation between PEP and RSA values over the duration of the 10-minute, parent-child conflict task. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 2

Parameter estimates for multi-level analysis

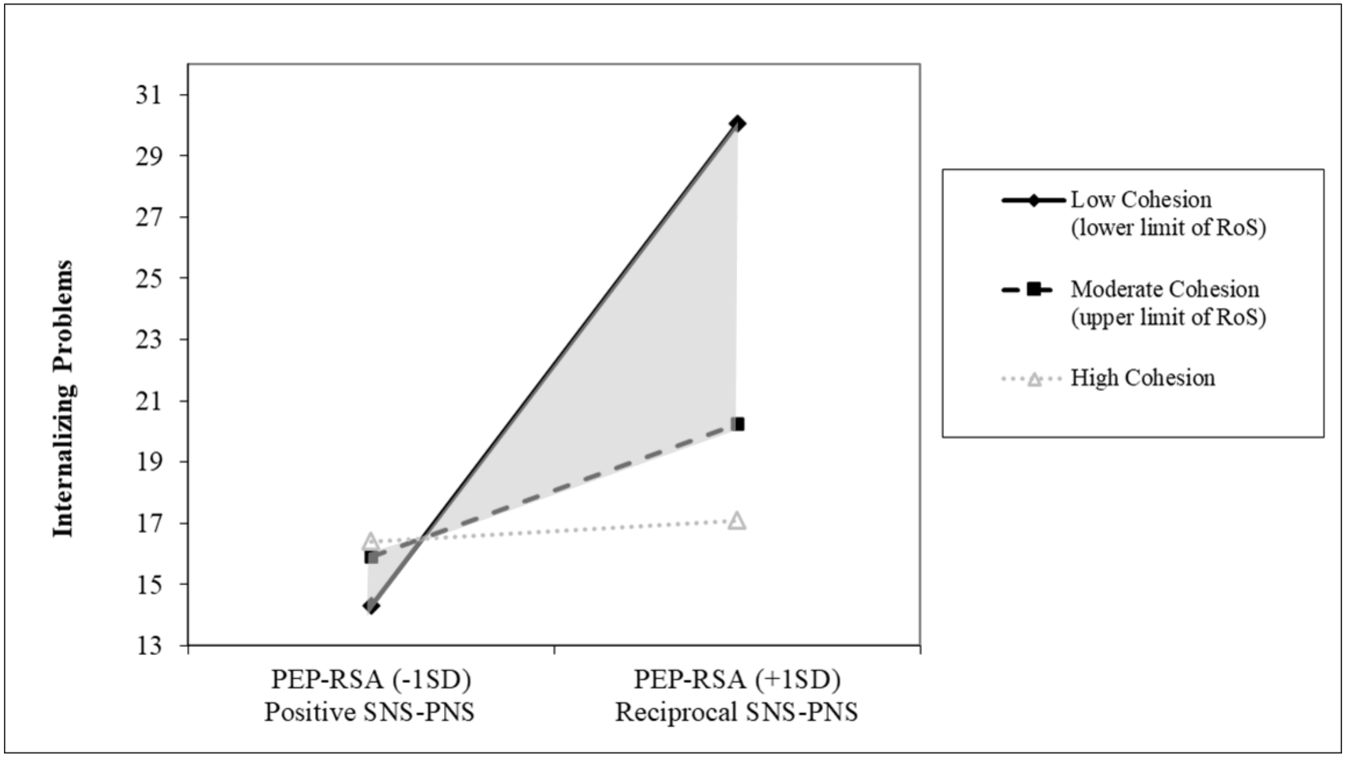
Within-level	**Estimates**	**SE**	**95% CI**	***p*-value**
Intercept	-0.01	0.06	[-0.12, 0.10]	.816
Residual variance	0.87	0.16	[0.56, 1.18]***	.000
Mean	0.04	0.04	[-0.05, 0.12]	.408
Variance	0.08	0.02	[.05, .12]**	.001

	Internalizing Problems T2			**Externalizing Problems T2**		
Between-level	***b* (SE)**	**β**	**95% CI**	***b* (SE)**	**β**	**95% CI**
Covariates						
Internalizing T1	0.56 (0.10)	.64	[0.37, 0.76]	0.10 (0.11)	.11	[-0.12, 0.33]
Externalizing T1	0.01 (0.12)	-.04	[-0.24, 0.23]	0.55 (0.13)	.55	[0.30, 0.81]
Obs child engagement	0.43 (0.70)	.12	[-0.94, 1.81]	0.65 (0.62)	.12	[-0.56, 1.86]
Obs parent positive	0.06 (0.99)	-.07	[-1.89, 2.01]	0.10 (1.06)	.05	[-1.99, 2.18]
Obs parent negative	0.20 (1.02)	.01	[-1.80, 2.20]	0.69 (1.17)	.19	[-1.61, 2.99]
Gender	2.47 (2.06)	.14	[-1.58, 6.52]	3.87 (1.88)	.12	[0.19, 7.54]*
Age	-0.49 (0.82)	-.02	[-2.08, 1.11]	-0.30 (0.76)	.03	[-1.79, 1.19]
Race (black=1)	-0.54 (2.39)	-.02	[-5.30, 4.23]	1.53 (2.27)	.07	[-3.01, 6.08]
Direct effects						
PEP-RSA coordination	34.33 (11.78)	.72	[11.10, 57.42]**	22.60 (7.00)	.43	[8.90, 36.30]**
Family cohesion	-1.39 (0.80)	-.16	[-2.96, 0.17]	-0.75 (0.75)	-.10	[-2.22, 0.73]
Family flexibility	0.91 (1.92)	.05	[-2.86, 4.70]	1.66 (1.62)	.09	[-1.52, 4.83]
Model 1 Interaction						
PEP-RSA x Cohesion	-10.72 (3.93)	-.24	[-18.43, -3.02]**	-13.63 (5.26)	-.28	[-23.94, -3.32] **
Model 2 Interaction						
PEP-RSA x Flexibility	-3.26 (1.80)	-.07	[-6.77, 0.24]	-2.21 (1.16)	-.10	[-4.48, 0.07]

Note. SE = standard error, CI = confidence interval, *b* = unstandardized regression coefficients, β = standardized regression coefficients, Obs = observed behavior during parent-child conflict task, PEP-RSA coordination = correlation between PEP and RSA values over the duration of the 10-minute, parent-child conflict task. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Figure 1

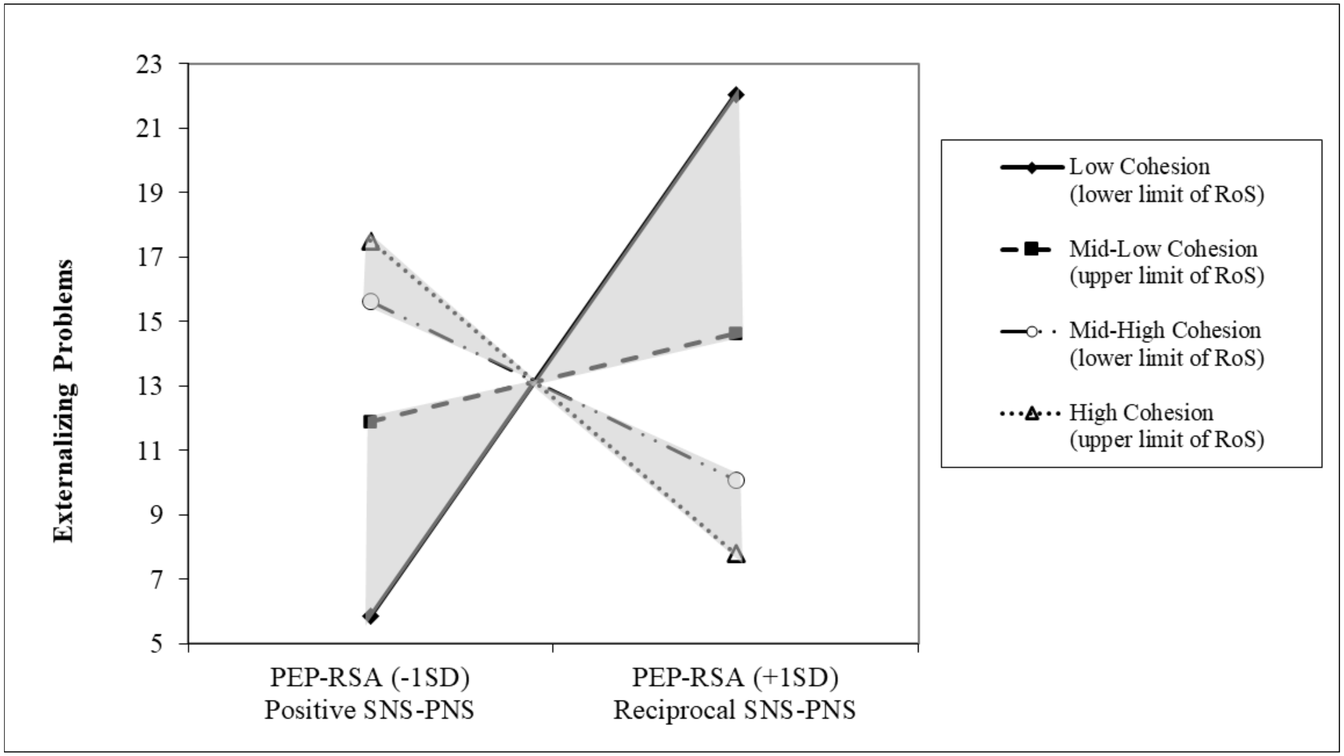
Simple slopes indicating the region of significance (RoS) of the moderating effect of family cohesion



Note. The shadowed area indicates region of significance. The solid line represents the lower limit of the region of significance (Cohesion = 0.6, $b = 41.5$, $p = .003$). The dashed line represents the upper limit of the region of significance (Cohesion = 3.4, $b = 11.5$, $p = .050$). The dotted line represents the effect of ANS coordination on internalizing problems in families reporting high cohesion (Cohesion = 4.3 (+1SD), $b = 1.8$, $p = .742$).

Figure 2

Simple slopes indicating the regions of significance (RoS) of the moderating effect of family cohesion



Note. The shadowed areas indicate regions of significance. The solid line represents the lower limit of the low cohesion region of significance (Cohesion = 0.6, b = 42.6, p = .006). The dashed line represents the upper limit of the low cohesion region of significance (Cohesion = 3.2, b = 7.2, p = .050). The dotted-dashed line represents the lower limit of the high cohesion region of significance (Cohesion = 4.8, b = -15.3, p = .050). The dotted line represents the upper limit of the high cohesion region of significance (Cohesion = 5.7, b = -28.9, p = .023.