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Autonomic Reactivity and Adjustment in Middle Childhood

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AUTONOMIC REACTIVITY AND ADJUSTMENT IN MIDDLE CHILDHOOD

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Abstract

The primary aim of this study was to investigate whether the joint action of the parasympathetic (PNS) and sympathetic nervous system (SNS) influenced three distinct indicators of child adjustment. Although evidence suggests that patterns of reactivity in the PNS and SNS each contribute to adjustment in youth, a paucity of work has examined the interaction between the two systems. Moreover, much of the research on children's autonomic reactivity has overly relied on variable-centered analytic approaches, which aim to predict variance and assume homogeneity in the relations between predictors and outcome. This project also incorporated a person-centered approach to systematically identify individual differences in the interrelation between PNS and SNS reactivity and to classify children into homogeneous autonomic reactivity groups. The person-centered results were then applied to variable-centered analyses to examine how adjustment varied across homogeneous autonomic reactivity groups. Thus, the goal of this study was to apply both variable-centered and person-centered analyses to investigate whether children's autonomic reactivity was related to child adjustment.

Children (*N* = 64, 8-10 years, *M* = 9.06, *SD* = 0.81) and one parent completed a psychophysiological laboratory assessment at Wave 1 during which each child's respiratory sinus arrhythmia reactivity (RSAR; an index of PNS reactivity) and skin conductance level reactivity (SCLR; an index of SNS reactivity) was assessed in response to a mirror tracing challenge task. At both Wave 1 and Wave 2, each parent reported on their child's internalizing symptoms, externalizing symptoms, and social competence.

The variable-centered analyses revealed that, consistent with hypotheses, the two-way RSAR x SCLR interaction was significant predicting internalizing symptoms at Time 1 and at Time 2. In both cases, RSA withdrawal was associated with fewer internalizing symptoms when coupled with low SCLR. When coupled with high SCLR, RSA withdrawal was associated with more internalizing symptoms at Time 1; however, RSAR was unrelated to Time 2 internalizing when coupled with high SCLR. In addition, SCLR was associated with more social competence and (marginally) fewer externalizing problems over time. The person-centered analyses (i.e., a model-based cluster analysis) identified two distinct clusters based on children's RSAR and SCLR. Children in Cluster 1 showed slight RSA withdrawal combined with SCL activation (modest reciprocal SNS activation) and exhibited marginally more internalizing and less social competence, as compared to children in Cluster 2 who, as a group, showed heightened RSAR (either withdrawal or augmentation) and SNS activation. When a 3-cluster model was examined, results indicated that children who showed modest reciprocal SNS activation (Cluster 1) showed marginally more internalizing symptoms then children who showed strong reciprocal SNS activation (Cluster 2A) and marginally less social competence then children who showed coactivation (Cluster 2B).

This study offers important evidence that person-centered analyses can identify differences in autonomic reactivity that are relevant to children's adjustment. Cluster analysis identified only two (i.e., reciprocal SNS activation, coactivation) of the four autonomic profiles assumed to be represented in simple slope analyses in previous work. Thus, incorporating person-centered techniques in future research is an important and likely fruitful approach to investigating how autonomic reactivity contributes to child development.

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Introduction

Adjustment difficulties in childhood represent a prevalent issue; estimates suggest that psychiatric disorders occur in 19.5% of 9-10 year old children, with serious emotional and behavioral problems occurring at rates of 4.6% and 5.7%, respectively (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003). Psychopathology can occur at subclinical levels across childhood, manifesting as more broad adjustment difficulties including problems in the domains of emotional, behavioral, and social functioning. Research supports the idea that there is both homotypic and heterotypic continuity in psychopathology across childhood and adolescence (Costello et al., 2003). Based on their review of existing literature, Costello & Angold (1995) found that 23-61% of children and adolescents with a diagnosed disorder at one wave continued to show mental illness at a subsequent wave, suggesting continuity across childhood and adolescence. Moreover, adjustment difficulties in childhood predict increased adjustment problems both within and across domains of functioning in adolescence (Bornstein, Hahn, & Haynes, 2010) and adulthood (Masten et al., 2005), suggesting that early maladjustment may set the course for long-term problems. Understanding factors that predict child adjustment problems can help inform prevention and intervention work aiming to reduce risk for adjustment problems across development.

Individual characteristics of children may predispose them to demonstrate particular types of adjustment problems (Rothbart & Bates, 1998). One area of functioning that is potentially key to our understanding of children’s adjustment problems is psychophysiology, or the physiological foundations of psychological processes (Cacioppo, Tassinary, & Berntson, 2007). Individual differences in children’s psychophysiology predict variability in a variety of adjustment domains (e.g., Boyce et al., 2001; Gazelle & Druhen, 2009; Hinnant & El-Sheikh, 2009). Thus, children's psychophysiology may help to explain why some children are more likely than others to develop adjustment problems in middle childhood.

Children's psychophysiological responses to stress are of particular interest to attempts to understand the etiology of adjustment problems. Individual differences in physiological responses to stress are important for understanding processes that contribute to the development of psychopathology in children (Calkins & Fox, 2002; Cicchetti & Dawson, 2002). When faced with an environmental stressor, humans experience reactivity in multiple biological stress-response systems, including the autonomic nervous system (ANS) and hypothalamic-pituitary-adrenal (HPA) axis. The development of the stress response system may be influenced by exposure to environmental stressors and adversity (Obradović, 2012; Taylor, Lerner, Sage, Lehman, & Seeman, 2004), and subsequent patterns of physiological stress reactivity may relate to long-term physical and mental health problems when the stress response system becomes dysregulated (e.g., McEwen, 1998; Taylor, et al., 2004). Consequently, stress reactivity is an aspect of psychophysiology that is likely to be particularly relevant to understanding the etiology of adjustment problems.

Activity of the autonomic nervous system (ANS), which operates to maintain homeostasis by carrying out efferent signals from the brain to peripheral organs and tissues, as well as afferent signals from the periphery of the body to the brain (Janig, 2006), appears to have particular relevance to adjustment in middle childhood (Boyce et al., 2001: Cummings, El-Sheikh, Kouros, & Keller, 2007; El-Sheikh et al., 2009; Hinnant,

& El-Sheikh, 2009; Hinnant & El-Sheikh, 2013; Getzler, Santucci, Kovacs, & Fox, 2009; Obradović, Bush, & Boyce, 2011). Although the HPA-axis may also play a role, HPA-axis responding appears to be particularly relevant to stressors that involve threats to the social self (Gunnar, Talge, & Herrera, 2009), which is not the focus of this study. Instead, this dissertation focused on the ANS.

Although a surge of research studies has emerged examining this topic over the past decade, existing research on children's autonomic reactivity remains limited in several ways. First, many studies on children's stress reactivity have examined only one branch of the ANS (i.e., parasympathetic or sympathetic). Because the branches of the ANS work in tandem, examining a single branch does not capture the complete picture of autonomic responding, which may prevent researchers from drawing accurate and specific conclusions about how children's ANS reactivity relates to adjustment. Second, many studies on ANS reactivity have utilized a cross-sectional design. Longitudinal research is needed to investigate whether particular profiles of ANS reactivity precede changes in specific developmental outcomes. Finally, much of the research on children's autonomic reactivity has utilized a variable-centered approach to analysis. Since variable-centered analyses examine aggregate effects, this approach excludes potentially important information about interindividual variability. In contrast, a person-centered approach identifies differences and similarities between individuals, and therefore may be helpful in identifying important heterogeneity in developmental processes (Laursen & Hoff, 2006). This project sought to move this research forward by addressing these limitations.

The goal of my dissertation was to examine whether the joint action of the parasympathetic and sympathetic nervous systems predict concurrent variability and changes across time in three indicators of child adjustment: internalizing symptoms, externalizing symptoms, and social competence. To this end, I conducted both variable-centered and person-centered approaches to investigate whether children's autonomic reactivity predicts individual differences in adjustment concurrently and longitudinally.

The Autonomic Nervous System

The autonomic nervous system (ANS) responds to internal and external demands and provides the physiological resources needed to regulate homeostasis and evaluate risk in the environment. Thus, the ANS is an important element of the physiological stress response system that contributes to emotional and behavioral self-regulation in challenging situations (Porges, 2007, 2011). The ANS is composed of the parasympathetic nervous system (PNS) and sympathetic nervous system (SNS), which operate together in a dynamic manner.

Parasympathetic activity & reactivity

The PNS maintains homeostatic functions and is the first branch of ANS to respond to environmental demands. PNS activity is considered indicative of regulatory processes, including the regulation of emotion and social behavior (Porges, 2007, 2011). The vagus nerve reflects PNS activity and, similar to the function of a brake, acts to inhibit heart rate. Originating in the brain stem, the vagus nerve is the tenth cranial nerve and facilitates a dynamic feedback system between the brain and specific organs through both efferent (i.e., motor) and afferent (i.e., sensory) fibers in order to regulate homeostasis (Porges, 2007; Porges, Doussard-Roosevelt, & Maiti, 1994). Increased vagal input reflects PNS activation, which decelerates heart rate and reduces physiological arousal. In contrast, decreased vagal input reflects decreased PNS activity (or PNS withdrawal), which elicits increased heart rate and increased arousal. When an individual is faced with an environmental challenge or stressor, the vagus nerve typically withdraws input to the heart, thus withdrawing the “vagal brake” and evoking heart rate acceleration and increased arousal. This in turn facilitates increased metabolic and attentional resources in order to manage environmental demands. The “vagal brake” can rapidly be withdrawn or reapplied to generate immediate changes in cardiovascular output in order to manage environmental demands without activating the SNS (Porges, 2007, 2011).

This study examined respiratory sinus arrhythmia (RSA) as a measure of PNS functioning. RSA measures parasympathetic input to the heart and represents the cyclical change in the inter-beat intervals of the heart that occurs in correspondence with respiration. RSA reactivity (RSAR) is an index of PNS responding under conditions of stress or challenge. RSA withdrawal indicates decreased PNS activity in response to stress (i.e., PNS withdrawal); RSA augmentation indicates PNS augmentation, or activation, in response to stress (Porges, 2007).

PNS withdrawal is thought to be an adaptive physiological response to stress (Porges, 2007, 2011) that reflects emotional responsiveness, enables focused attention, and facilitates preparedness for a behavioral response to environmental cues, as well as flexibility in implementing emotional and behavioral self-regulation strategies (Beauchaine, 2001; Calkins, 1997; Porges, 2007, 2011; Thayer & Lane, 2000; Thompson, Lewis, & Calkins, 2008). Thus, insufficient or impaired PNS withdrawal may be relevant to the emergence of internalizing and externalizing problems in children, which involve varying degrees of impairment in emotional and behavioral self-regulation. Moreover, PNS withdrawal in response to challenge has been proposed as a physiological mechanism through which children engage in their social environment in particular (Beauchaine, 2001; Porges, 2011); thus, PNS withdrawal may be also be relevant to children's social competence.

Consistent with these ideas, research supports the link between PNS withdrawal and a variety of beneficial developmental outcomes in children, including better self-regulation (Gentzler, Santucci, Kovacs, & Fox, 2009), fewer internalizing and externalizing problems (Calkins & Keane, 2004; Gentzler et al., 2009) and more social competence (Graziano, Keane, & Calkins, 2007). Moreover, in a recent meta-analysis, Graziano and Derefinko (2013) found that PNS withdrawal was associated with fewer internalizing and externalizing problems in both community and clinical samples, and was associated with fewer social problems in community samples but more social problems in clinical/at-risk sample of children. This discrepancy in the link between PNS withdrawal and social problems across community versus clinical samples may suggest that the processes through which PNS reactivity relates to social functioning are different in children with existing emotional and behavioral problems, as compared to children without clinical symptoms. For example, it may be that children with clinical disorders experience a particularly high degree of PNS withdrawal, which may impair their social functioning by facilitating high emotional arousal coupled with poor self-regulation. In community samples, however, PNS withdrawal appears to have similar beneficial effects for internalizing, externalizing, and social problems. It is also important to note, however, that the meta-analysis described above found only small effect sizes in the associations between PNS withdrawal and internalizing and externalizing problems (Graziano & Derefinko, 2013).

Whereas moderate PNS withdrawal facilitates effective emotional and behavioral self-regulation, extreme PNS withdrawal may indicate hyper-reactivity and emotional lability (Beauchaine, 2001; Thayer & Lane, 2000). Exaggerated PNS withdrawal is linked to both anger and panic, reflecting the negative emotional states characteristic of a “fight or flight” response, and is related to less prosocial behavior and poor emotion regulation in children with ADHD (Beauchaine et al., 2013), as well as more conduct problems and anxiety symptoms in clinical populations (see Beauchaine, 2001). In one community sample, exaggerated PNS withdrawal was associated with more social exclusion and anxious solitude in children (Gazelle & Druhen, 2009). Thus, exaggerated PNS withdrawal may reflect overregulation, which may contribute to emotional and behavioral problems by eliciting extreme states of emotional arousal (Thayer & Lane, 2000). It is important to note that psychophysiology researchers have not identified a cut-off point to mark what should be considered excessive PNS withdrawal, which makes it difficult to compare findings across studies. It may be that excessive PNS withdrawal occurs most often in clinical populations, or that what should be considered an adaptive degree of PNS withdrawal may vary across populations (e.g., clinical versus community populations). Moreover, the magnitude of effect for physiological data will vary across different type of equipment (Quas et al., 2014). Therefore, even if researchers use the same measure (e.g., RSA), when researchers use different equipment to collect physiological data, the raw data cannot simply be compared across studies to identify an “exaggerated” level of reactivity, which makes it very difficult to interpret a true cut-off point at which too much physiological reactivity has occurred.

In response to a stressor, the vagus nerve may withdraw input to the heart to an insufficient extent, which reflects blunted or low PNS withdrawal, or may increase input to the heart, which reflects PNS augmentation or increased PNS activity. Sufficient PNS withdrawal is important for facilitating attentional and behavioral resources relevant to self-regulatory processes and behavioral responding (Porges, 2011). Thus, both blunted PNS withdrawal and PNS augmentation may indicate failure to mobilize the physiological resources necessary for effective engagement with environmental stressors. Consistent with this idea, blunted PNS withdrawal and PNS augmentation have been linked to heightened externalizing problems in children (Beauchaine, 2001; Boyce et al., 2001; Calkins & Dedmon, 2000; Calkins & Keane, 2004; Graziano & Derefinko, 2013; Musser et al., 2011). However, PNS augmentation may not always be harmful. Blair (2003) found that PNS augmentation in response to an executive function task was associated with more social competence in young children. In addition, a study by Hastings and colleagues (2008) found that PNS augmentation in response to a social challenge was associated with fewer internalizing and externalizing problems and greater behavioral self-regulation in children, whereas PNS withdrawal was linked to more adjustment difficulties. However, Graziano and Derefinko's recent meta-analysis of 44 studies suggests that PNS withdrawal is most often associated more adaptive functioning in children across emotional and behavioral domains, and it is linked to better social functioning in non-clinical samples of children (2013). Thus, the majority of available evidence suggests that PNS augmentation is associated with less adaptive functioning across emotional, behavioral, and social domains.

SNS activity & reactivity

The SNS functions in tandem with the PNS and activates in response to environmental stressors. At times, PNS responding may provide sufficient resources to allow the individual to appropriately manage a stressor; however, if the stressor is prolonged or is intense in nature, the SNS will activate, which facilitates a “fight or flight” behavioral response by increasing heart rate, oxygen flow, and perspiration throughout the body. By mobilizing metabolic resources, the SNS facilitates behavioral responding under conditions of perceived threat, extreme challenge, or stress (Boucsein, 2011; Porges, 2011).

This study examined skin conductance level (SCL), which is a common index of SNS activity. SCL assesses electrodermal activity in response to sweat secretion. Sweat glands are innervated only by the sympathetic nervous system; thus electrodermal activity reflects activity of the SNS independent of PNS influence (for a detailed description, see Dawson, Schell, & Filion, 2007). Baseline SCL activity is assessed during times of rest, and SCL reactivity (SCLR) reflects the change from baseline SCL to SCL activity during times of stress or challenge. High SCLR represents increased SNS activity, or SNS activation, in response to stress, whereas low SCLR reflects blunted or impaired SNS activation in response to stress. Thus, in the literature, high SCLR refers to high SNS reactivity and low SCLR refers to low SNS reactivity.

Activity of the SNS may be a marker of Gray’s neurophysiological motivational systems, known as the behavioral activation system (BAS) and behavioral inhibition system (BIS). According to this theory, functioning of the BAS is facilitated through SNS activity at a broad level, whereas functioning of the BIS is reflected specifically in SCL (see Beauchaine, 2001), a specific indicator of SNS responding. The BAS controls both approach and active avoidance behaviors; approach behaviors aim to maximize reward, whereas active avoidance behaviors aim to minimize punishment in circumstances when a behavioral response is needed. SNS activation is thought to facilitate these active behaviors by mobilizing metabolic resources needed for behavioral activation. In contrast, the BIS facilitates voluntary behavioral inhibition in the face of aversive stimuli or punishment through the production of fear and anxiety. The BAS and BIS are expected to function in opposition, with only one system predominating and influencing behavior at a given time (Beauchaine, 2001; Gray, 1987). Low SCLR reflects low SNS arousal and may be indicative of a weak behavioral inhibition system (BIS) or fearlessness in threatening situations. Since BIS and BAS function in opposition, a weak BIS would also allow the BAS to function without restriction, thus contributing to unrestrained approach behaviors aimed at reward without anxiety or fear of potential consequences. Thus, low SCLR may reflect a weak BIS, which is thought to contribute to behavioral disinhibition, impulsivity, unrestrained behavioral activation behaviors, and sensation-seeking behaviors aimed at increasing an individual's arousal to a normal level (Fowles, Kochanska, and Murray, 2000; Raine, 2002; van Goozen, Fairchild, Snoek, & Harold, 2007).

Consistent with these ideas, extensive research suggests that low SNS arousal is associated with heightened externalizing problems, including aggression (Beauchaine, 2001; Erath, El-Sheikh, Hinnant, & Cummings, 2011; Posthumus, Bocker, Raaijmakers, Van Engeland, & Matthys, 2009) and conduct problems (Gao, Raine, Venables, Dawson, & Mednick, 2010; see Lorber, 2004 for a review). Two recent studies examining the moderating effects of SNS reactivity provide support for the idea that low SNS arousal heightens risk for externalizing problems in children. Gregson, Tu, and Erath (2014) found that peer victimization predicted externalizing problems in children with low but not high SNS reactivity, and Kochanska, Brock, Chen, Aksan, and Anderson (2015) found that negative parenting (high power-assertive control, low mutual responsiveness) was associated with more externalizing problems only for children with low SNS reactivity. Low SNS arousal may be especially problematic for boys. Two additional studies examining the moderating effects of SCLR found that the link between negative parenting (harsh parenting, marital conflict) and externalizing problems was strongest for boys with low SCLR (El-Sheikh, Keller, & Erath, 2007; Erath, El-Sheikh, & Cummings, 2009). In these studies, low SNS reactivity appeared to be related to externalizing behaviors specifically when coupled with environmental risk.

SNS activation is generally considered to be adaptive in the context of stress, as it serves to mobilize metabolic resources needed to manage a stressor through either fight or flight (i.e., escape) behaviors. Higher SNS reactivity is associated with less aggression (Posthumus, et al., 2009). However, if SNS activation is long lasting or is an exaggerated response to stress, this may reflect an overactive BIS, thus contributing to anxiety, fearfulness, behavioral inhibition, and panic (see Beauchaine, 2001 for a review). Indeed, evidence suggests that children with emotional disorders show excessive SNS activation (Garralda, Connell, & Taylor, 1991) and children with higher levels of negative affect have been shown to exhibit higher SNS reactivity in response to emotionally arousing tasks (Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996). It should be noted that higher SNS arousal may also contribute to externalizing problems. In contrast to the studies reviewed above, heightened SNS arousal has also been found to be positively associated with physical aggression (see Lorber, 2004 for a review) and reactive aggression in children (Hubbard et al., 2002).

Three studies examining the moderating effect of SCLR support the idea that exaggerated SNS reactivity may be harmful for youth when coupled with family risk factors. In a community sample, El-Sheikh (2005) found that marital conflict was associated with more internalizing, externalizing, and cognitive problems in girls with heightened SNS reactivity, and more internalizing symptoms in boys with heightened SNS reactivity. In addition, one study found that in the context of high parental depressive symptoms, children with high but not low SNS reactivity exhibited more internalizing, externalizing, and social problems (Cummings, El-Sheikh, Kouros, & Keller, 2007). In a sample of adolescents, Diamond, Fagundes, & Cribbet (2012) observed that living in a single-mother household was associated with greater externalizing problems among boys with high SCLR, but was associated with fewer externalizing problems for boys with low SCLR. In addition, mothers' internalizing problems were associated with greater negative affect amongst girls with high SCLR, but less negative affect for girls with low SCLR (Diamond et al., 2012). As previously discussed in regards to research on parasympathetic reactivity, researchers have not identified a cut off point at which sympathetic reactivity should be considered exaggerated, and raw SCLR values cannot be compared across studies in a meaningful way (Quas et al., 2014). In addition, whereas RSAR is a commonly used measure of PNS reactivity across developmental studies, SNS reactivity can be assessed with distinct measurement procedures (e.g., SCLR, pre-ejection period). Thus, it is difficult to determine if these studies captured sympathetic overarousal or whether extent of SNS reactivity can be compared across studies. It is possible that some studies captured overarousal whereas others did not, which may in part contribute to the discrepancies across findings.

In sum, the literature on the SNS and children's adjustment is more mixed than the literature on the PNS and children's adjustment. SNS activation is thought to mobilize attentional and behavioral resources and thus may be related to adaptive functioning in children. In addition, low SNS arousal may contribute to externalizing behaviors, and exaggerated SNS reactivity may contribute to both internalizing and externalizing symptoms. It is unclear, however, whether SNS arousal is related to children's social competence.

Interactions between PNS and SNS

Most of the research investigating the associations between autonomic reactivity and adjustment has only examined one branch of the ANS. However, physiological systems do not function independently, but instead operate in a dynamic, ongoing manner (Porges, 2007, 2011). According to Beauchaine (2001), impaired PNS reactivity (in the form of excessive PNS withdrawal) generates emotional lability and thus contributes to a variety of emotional and behavioral problems. However, SNS reactivity provides the physiological mechanism by which PNS dysregulation manifests into either approach (i.e., fight) behaviors or more inhibited (i.e., flight) behaviors (Beauchaine, 2001; Beauchaine, et al., 2007). Thus, previous conclusions drawn from studies of only one branch of the ANS are based on only partial information about the processes through which ANS reactivity contributes to child adjustment. To understand the influence of autonomic stress reactivity on child adjustment outcomes with greater specificity, research must examine the joint effects of physiological systems (Beauchaine, 2001; Bauer, Quas, & Boyce, 2002). This approach also represents a key next step in the field; researchers have recently argued for the need to examine interactions between the PNS and SNS when investigating child adjustment (El-Sheikh et al., 2009; Keller & El-Sheikh, 2009; Quas et al., 2014). However, little research has examined the influence of both branches of the ANS on adjustment. Although sparse, studies examining both branches of the ANS are increasing in number and support the importance of examining interactions between the parasympathetic and sympathetic branches of the ANS.

Several theories may be helpful to explain how the PNS and SNS function together to influence children's emotional, behavioral, and social functioning, including Polyvagal theory, the Doctrine of Autonomic Space, and El-Sheikh's biopsychosocial framework.

Polyvagal Theory

The Polyvagal Theory (Porges, 1995, 2007, 2011) proposes that the experience of emotion, emotional expression, and social behavior is directly linked to the neurophysiological system that regulates heart rate. Further, Polyvagal theory proposes that evolutionary development has created a hierarchically organized system that manages sequential responses of the autonomic nervous system under conditions of stress or challenge. According to this theory, the human nervous system has three hierarchically organized neural circuits, which are linked to the behaviors involved in social communication (e.g., facial expression), mobilization (e.g., fight or flight), and immobilization (e.g., freezing, feigning death). The vagus nerve is composed of two distinct branches: a phylogenetically older branch, which promotes abnormally low heart rate and freezing behaviors, and a newer branch which influences heart rate variability and promotes social engagement. The newest circuit of this hierarchical system responds to environmental demands. If the newest circuit fails to sufficiently manage the environmental demands or is overwhelmed with a continued sense of threat, then older neural circuits are activated in sequential order. Importantly, the newest circuit is responsible for parasympathetic activity via the myelinated vagus nerve, whereas the second most recent neural circuit regulates sympathetic activity. Thus, according to Polyvagal Theory, the myelinated vagus nerve provides the first response to environmental conditions via PNS reactivity and only when this circuit is overwhelmed does the SNS activate to manage environmental conditions.

According to Polyvagal Theory, the dorsal vagal complex, referred to as the vegetative vagus, was the first response system to evolve and is composed of nonmyelinated vagal motor fibers originating in the dorsal motor nucleus (DMNX) in the brain. When higher-ordered circuits are overwhelmed or withdrawn in response to extreme threat, the vegetative vagus will activate, which induces extremely low heart rate, reduces oxygen use and energy demands, and increases pain tolerance. When the vegetative vagus is activated, behavioral responses resemble reptilian behavior, such as freezing.

After the vegetative vagus, the SNS was the next evolutionary development. When activated, the SNS is responsible for defensive behaviors, including “fight or flight” behaviors. By increasing cardiac output and sweat gland secretion, the SNS mobilizes resources for a behavioral response, while inhibiting homeostatic activity, including gastrointestinal functioning (Porges, 2011).

The ventral vagal complex is the most recent evolutionary development in the three-tiered neural circuitry of the autonomic nervous system and is composed of the myelinated vagus nerve and other cranial nerves originating in the nucleus ambiguus. According to Polyvagal theory, vagal activity at rest reflects the capacity for self-regulatory processes; effective vagal responding provides an individual with the ability to behaviorally engage in their environment and appropriately manage their emotions and behaviors. Vagal responding involves both withdrawing the vagal brake and reinstating the vagal brake as needed. According to Polyvagal theory, PNS responding varies according to an individual's perception of the environmental conditions. PNS withdrawal facilitates attentional and metabolic resources to enable effective behavioral and social engagement, which would be adaptive in a challenging or stressful scenario in which a behavioral response is needed. PNS activation counteracts the influence of the SNS, thus inhibiting defensive behaviors and promoting a calm behavioral state, which would be adaptive in a safe environment when a behavioral response is not needed. Importantly, vagal influence on the heart can be rapidly withdrawn or reapplied to immediately respond to environmental demands without activating the SNS, but under conditions of perceived threat or prolonged or extreme stress, the SNS will mobilize a fight or flight response.

Polyvagal theory further suggests that humans use primitive neural circuitry to continuously assess risk versus safety in the environment. This process operates without conscious awareness and is referred to as "neuroception." Without cognitive awareness, humans perceive cues of safety or danger, which elicit neurobiologically determined prosocial or defensive behaviors. Polyvagal theory suggests that psychopathology may result when an individual is unable to either (a) inhibit defensive behaviors through PNS activation when the environment is safe or (b) mobilize defensive strategies in a threatening situation, through sufficient PNS withdrawal and SNS activation. In contrast, parasympathetic regulation of the heart contributes to adaptive functioning when the vagus nerve (a) increases the vagal brake to inhibit the defensive behaviors elicited by sympathetic arousal when the environment is safe, or (b) withdraws the vagal brake (i.e., PNS withdrawal) when attentional or metabolic resources are needed to manage environmental demands. Porges (2011) argues that the ability to release the vagal brake (i.e., PNS withdrawal) during a challenging task requiring behavioral and/or attentional resources may represent a physiological strategy that promotes social development and contributes to fewer behavioral problems. Thus, according to Polyvagal theory, human emotion, social communication, and behavior are directly related to the neurophysiological processes that contribute to reactivity of the PNS and SNS. Examining the two branches of the ANS together thus provides a critical avenue for understanding children's emotional, social, and behavioral functioning.

Doctrine of Autonomic Space

To understand how the PNS and SNS function together, it is also useful to consider Berntson's Theory of Autonomic Space (Berntson, Caccioppo, & Quigley, 1991), which proposes a two-dimensional model of autonomic control. The PNS and SNS often respond to stress in a coordinated and reciprocal manner, thus enhancing autonomic functioning; however, in some instances the PNS and SNS may respond in an uncoordinated manner. According to the doctrine of autonomic space (Berntson et al., 1991), the PNS and SNS respond with: a) coupled reciprocal activity, in which PNS and SNS activity is negatively correlated or opposing (either *reciprocal parasympathetic activation* or *reciprocal sympathetic activation*); b) coupled nonreciprocal activity, in which PNS and SNS activity is positively correlated (either *coactivation* or *coinhibition*); or c) an uncoupled response in which only one branch of the ANS shows change. The most commonly studied profiles of autonomic reactivity include the two profiles that involve coupled reciprocal responding and the two profiles that involve coupled nonreciprocal responding (Quas et al., 2014). Thus, according to the doctrine of autonomic space, there are four typical profiles of autonomic stress reactivity: 1) reciprocal parasympathetic activation (PNS augmentation, low SNS reactivity); 2) reciprocal sympathetic activation (PNS withdrawal, high SNS reactivity); 3) coactivation (PNS augmentation, high SNS reactivity); 4) coinhibition (PNS withdrawal, low SNS reactivity).

When the PNS and SNS respond in a coordinated manner, either reciprocal parasympathetic or reciprocal sympathetic activation may occur; both likely reflect a synergistic response between the two branches of the ANS. *Reciprocal parasympathetic activation* involves increased PNS activity combined with low SNS reactivity or SNS withdrawal and therefore reflects enhanced PNS functioning. Thus, reciprocal parasympathetic activation likely elicits increased “rest and digest” processes associated with the PNS. However, PNS augmentation and low SNS reactivity each reflect a physiological response that may provide insufficient resources for managing a stressor; thus, reciprocal parasympathetic activation may also be associated with more adjustment difficulties. In a study that assessed RSAR and salivary alpha-amylase as an indicator of SNS activity, children exhibiting reciprocal parasympathetic activity showed high levels of externalizing problems (Keller & El-Sheikh, 2009).

Recent research on the moderating effects of PNS and SNS reactivity offer contradictory findings regarding reciprocal parasympathetic activation. Two recent studies examined three-way interactions between a relevant environmental stressor, PNS reactivity, and SNS reactivity. One study found that reciprocal parasympathetic activation buffered against the harmful effects of marital conflict (El-Sheikh et al., 2009), whereas the other study (Wagner & Abaied, 2015) suggested that reciprocal parasympathetic activation may be a harmful response to stress. Specifically, I recently found that for college students who showed reciprocal parasympathetic activation, high relational victimization was associated with more reactive relational aggression (Wagner & Abaied, 2015), which suggests that reciprocal parasympathetic activation may impair one's ability to manage environmental stress, thus contributing to adjustment difficulties. It is important to note that the studies described above (El-Sheikh et al., 2009; Wagner & Abaied, 2015) examined a three-way environmental risk x PNS x SNS interaction; findings should be interpreted with caution in relation to this study, as this study investigated the two-way PNS x SNS interaction. Given the limited availability of studies simultaneously considering reactivity within both branches of the autonomic nervous system, however, these findings warrant some consideration regarding the current state of the field on the joint action of the PNS and SNS and their relation to adjustment in children.

Reciprocal sympathetic activation involves PNS withdrawal, which elicits increased heart rate and enables focused attention toward environmental stimuli, combined with SNS activation, which likely elicits increased metabolic resources via a fight or flight response (Berntson et al., 1991; Porges, 2011). Thus, for individuals who exhibit reciprocal sympathetic activation, the action of both the PNS and the SNS will elicit physiological arousal. In the context of stress, moderate levels of both PNS withdrawal and SNS activation may be adaptive responses. Thus the combination of PNS withdrawal and SNS activation may be an adaptive stress response, which would likely contribute to more adaptive functioning. Indeed, moderation studies suggest that reciprocal sympathetic activation buffers against the harmful effects of a variety of environmental stressors, including exposure to marital conflict in children (El-Sheikh et al., 2009) and exposure to relational victimization in college students (Wagner & Abaied, 2015). On the other hand, it is possible that PNS withdrawal combined with SNS activation may lead to over-arousal. Excessive PNS withdrawal is linked to emotional lability including anxiety, panic, and rage; excessive SNS activation may contribute to anxiety, panic, and fearfulness (see Beauchaine, 2001), as well as externalizing symptoms and aggression (Lorber, 2004; Hubbard et al., 2002). One study by Lafko, Murray-Close, and Shoulberg (2015) found that low peer status (peer rejection and unpopularity) was associated with the greatest increases in relational victimization over time for girls who exhibited reciprocal sympathetic activation. Thus, the combination of PNS withdrawal and high SNS reactivity may heighten risk for emotional and behavioral difficulties. Although findings on the correlates of reciprocal sympathetic activation are mixed, the contradiction between these findings may in part be due to the fact that developmental researchers do not currently have cut-off points to mark important distinctions regarding extent of reactivity. It may be that some samples (e.g., Lafko et al., 2015) contain individuals who show excessive or insufficient ANS reactivity, whereas others contain individuals who predominantly show moderate or adaptive levels of PNS withdrawal and SNS activation.

In addition to reciprocal activation, the ANS may sometimes respond to stress in an uncoordinated manner, whereby either dual activation or dual inhibition occurs (Porges, 2011). Dysregulated and uncoordinated physiological responding may contribute to behavioral problems in children, including externalizing problems (Bauer et al., 2002). In instances of *coactivation*, both the PNS and SNS show increased activity. Coactivation involves opposing actions and is analogous to simultaneously using a brake and an accelerator; this may elicit angry, dysregulated stress responses (Berntson, et al., 1991; El-Sheikh, et al., 2009). On the other hand, it may be that SNS activation can to some extent counteract the harmful effect of PNS augmentation, whereby SNS activation mobilizes resources which the PNS failed to provide (due to PNS augmentation rather then withdrawal). Thus, although PNS augmentation may be harmful, if PNS augmentation does occur, it may be helpful for the SNS to activate (i.e., high SNS reactivity) rather then not (i.e., low SNS reactivity). Indeed, Keller & El-Sheikh (2009) examined the two-way SNS x PNS interaction predicting externalizing problems and found that amongst children who showed PNS augmentation, those that showed high SNS activity exhibited fewer externalizing problems then those that showed low SNS activity. Thus, for individuals who exhibit PNS augmentation, those who show higher SNS activity may experience fewer adjustment problems.

Coinhibition involves PNS withdrawal and either low SNS reactivity or decreased SNS activity. When coinhibition occurs, the allocation of physiological resources needed to manage environmental demands is likely facilitated by PNS responding. PNS withdrawal facilitates increased heart rate, increased attention, and preparation for action, and low SNS reactivity may reflect a failure to launch a “fight or flight” response. In circumstances of extreme stress, coinhibition may provide insufficient resources. However, in circumstances in which environmental demands are challenging but minimally stressful, PNS withdrawal may provide a sufficient physiological response without activation of the SNS (Porges, 2011). In these low-stress circumstances, PNS withdrawal may provide sufficient physiological resources for a child to be able to manage environmental challenge and minimal SNS activation may help the child remain relatively calm. Indeed, one study found that children who showed low SNS activity and PNS withdrawal in response to a mirror tracing task had the lowest levels of externalizing behaviors (Keller & El-Sheikh, 2009). Thus, coinhibition may provide sufficient physiological resources in low-stress circumstances; however, coinhibition may be related to adjustment difficulties if PNS withdrawal provides insufficient resources and the SNS fails to activate to mobilize additional resources.

Biopsychosocial framework

A third theoretical framework for conceptualizing the interplay of the PNS and SNS in children’s adjustment was proposed by El-Sheikh and colleagues (2009). These authors have found that within the context of marital conflict, the interactions between children’s PNS and SNS functioning predict externalizing problems in children. Specifically, marital conflict predicted externalizing problems for children with ANS profiles characterized by coupled nonreciprocal responses (i.e., coactivation, coinhibition). In contrast, marital conflict was generally unrelated to externalizing problems for children showing physiological profiles characterized by reciprocal responses of ANS (i.e., reciprocal parasympathetic activation, reciprocal sympathetic activation). Thus, El-Sheikh et al. concluded that children's profiles of autonomic functioning could serve as either protective or vulnerability factors within the context of environmental stressors. From this perspective, children who show either coactivation or coinhibition may become physiologically dysregulated in response to environmental stressors, leaving them vulnerable to future maladjustment. On the other hand, reciprocal responses of the ANS branches may be beneficial and provide children with the physiological resources to appropriately manage an environmental stressor. In turn, these children may fare better across development and experience fewer adjustment difficulties.

Although El-Sheikh et al. (2009) examined the moderating effects of autonomic profiles and my dissertation does not consider children's autonomic profiles within the context of an environmental stressor, El-Sheikh et al.'s conceptualization is still relevant to this study. Many children face everyday stressors (e.g., conflicts with friends, difficult academic tasks) on a regular basis; although these stressors may be less harmful then exposure to marital conflict, children's autonomic responses to everyday stressors may still affect adjustment, either by physiologically equipping children to manage everyday stressors effectively, or by leaving them physiologically dysregulated or ill prepared to manage them. Moreover, I hypothesized that if children are physiologically ill prepared to manage everyday stressors, their autonomic reactivity may continue to influence their adjustment across time. It may be that dysregulated autonomic reactivity has a cumulative effect, thus compounding risk for maladjustment across time. To examine this possibility, I conducted exploratory longitudinal analyses in which I examined whether children's autonomic reactivity predicted changes in internalizing problems, externalizing problems, and social competence.

Person-centered vs. variable centered approach

A small but growing body of research has investigated the joint action of children's parasympathetic and sympathetic nervous systems as a predictor of developmental outcomes. However, contradictions exist across the studies described above, which may in part be due to the fact that researchers have primarily used variable-centered approaches, as is common practice in psychological research. A variable-centered approach to data analysis describes relations between variables. In this approach, hypotheses and research questions are framed in terms of variables and their relation to or ability to predict an outcome (Bergman & Magnusson, 1997). Variable-centered analyses aim to predict variance and therefore are well matched to questions about predictors' relative importance in explaining variance in an outcome. Variable-centered analyses identify processes that to some extent occur across individuals; this approach is therefore important for identifying general principles of how variables relate to each other. Prediction is a noteworthy strength of the variable-centered approach (Laursen & Hoff, 2006). However, this approach focuses on explaining the variance-covariance matrix and assumes homogeneity in the relations between predictors and outcome; therefore, the variable-centered approach is limited because it cannot systematically examine individual differences in how variables are interrelated (Bergman & Magnusson, 1997; Granic & Hollenstein, 2003).

In contrast, person-centered approaches identify individual differences in the relations between variables. Whereas the variable-centered approach assumes population homogeneity, the person-centered approach assumes that there is population heterogeneity (Bergman & Magnusson, 1997; Laursen & Hoff, 2006). Person-centered techniques are designed to identify distinct groups of individuals who share similar characteristics. Classification aims to minimize within-group differences and maximize between-group differences in terms of attributes that characterize the groups. In contrast to variable-centered analyses, person-centered analyses are not limited to analyzing the variance-covariance matrix. Thus, an important strength of the person-centered approach is its ability to describe differences across individuals (Laursen & Hoff, 2006).

Importantly, variable-centered and person-centered approaches can be combined to answer complex questions about processes that relate to development and how developmental outcomes vary across groups. Variable-centered and person-centered approaches each provide a unique perspective on the data: variable-centered analyses can identify how predictors relate to outcomes across homogeneous populations, whereas person-centered analyses can identify systematic differences across individuals (Laursen & Hoff, 2006). Thus, consistent with much of the previous research on children's autonomic reactivity, I first used a variable-centered approach to examine the joint action of the PNS and SNS. Next, I used a person-centered approach to classify children into groups of autonomic reactivity profiles and then applied these results to variable-centered analyses to examine whether there were differences in adjustment across groups.

Incorporating person-centered analyses into the study of psychophysiology is an important step for developmental researchers. This line of research may be helpful for clarifying whether the extent of autonomic reactivity that a child experiences is relevant to adjustment. In addition, person-centered analyses may confirm the existence of distinct profiles of ANS reactivity that have previously been described in the literature (Berntson et al., 1991; El-Sheikh et al., 2009). To my knowledge, only two studies to date have used person-centered techniques to classify children into profiles of physiological reactivity. Muñoz, Kimonis, Frick, & Aucoin (2013) conducted a cluster analysis to identify profiles of autonomic reactivity amongst adolescent boys in a detention center. Cluster analyses identified three groups: “coactivators” (heightened PNS and SNS activation), “sympathetic activators” (heightened SNS activation combined with slightly increased PNS activation), and “low activators” (very low or blunted reactivity in both PNS and SNS branches). Given the unique population of this study, the profiles observed may not generalize to other populations. Nonetheless, Muñoz et al.’s (2013) findings support the idea that it is possible to identify distinct groups based on parasympathetic and sympathetic reactivity. In a recent study, Quas et al. (2014) used latent profile analysis to identify subgroups of children based on their reactivity across multiple physiological systems (PNS, SNS, HPA-axis). In four separate samples, the authors identified meaningful subgroups that were largely consistent across samples, suggesting that distinct patterns of stress reactivity exist across children. In all four samples, a pattern of moderate reactivity across physiological systems was most common; this group showed no hyper- or hypo-arousal and instead demonstrated balance and coordination across systems. In addition, all samples included a subgroup characterized by PNS withdrawal, which offers support for the idea that PNS withdrawal is a typical response to challenge or stress. Exaggerated reactivity across physiological systems was less common, but observed in three of the four samples examined, suggesting that exaggerated reactivity may be an observable but relatively rare response.

An important next step, however, is to investigate how distinct patterns of children's stress reactivity relate to adjustment outcomes. My dissertation addressed this limitation by including a model-based cluster analysis to identify distinct clusters of children based on their profiles of ANS reactivity. I subsequently examined differences in adjustment across clusters.

I examined PNS and SNS reactivity in response to a star-tracing task, which is a laboratory challenge task that has been previously used in several studies with children (e.g., Hinnant & El-Sheikh, 2009; Keller & El-Sheikh, 2009) to elicit a stress response. During this task, children are asked to trace a star while only being able to see their hand through a mirror, which is highly challenging for children and adults. This task requires children to maintain focused attention in order to accurately trace the star; since the participant cannot see his/her hand directly, this task is thought to elicit frustration (Hinnant & El-Sheikh, 2013). Thus, this task requires attentional resources and also likely elicits frustration, which the child must manage while continuing to attend to the task. Importantly, this task has been widely used in the literature to elicit ANS reactivity in middle childhood (e.g., Hinnant & El-Sheikh, 2009; Keller & El-Sheikh, 2009; Obradovic et al., 2011).

It is important to note that previous studies examining ANS reactivity profiles have utilized variable-centered simple slope analyses to approximate groups of individuals based on PNS x SNS profiles. This study extended this research and used both variable-centered and person-centered analyses to examine ANS reactivity groups.

Specific aims and relevant hypotheses are described below. Analyses are described briefly in conjunction with each aim and then described in further detail in the results section.

Aims & Hypotheses

Aim 1: Investigate whether the joint action of children's parasympathetic and sympathetic reactivity predicts individual differences in three outcomes of adjustment (internalizing, externalizing, social competence).

To examine Aim 1, I conducted three cross-sectional multiple regression analyses to investigate whether children's autonomic reactivity was associated with Time 1 adjustment. Separate analyses were conducted for each adjustment outcome (internalizing, externalizing, social competence).

Across adjustment outcomes, I expected that PNS withdrawal would be a beneficial response to stress. Although excessive PNS withdrawal is thought to elicit emotional lability (Beachaine, 2001; Thayer & Lane, 2000), I did not expect my community sample to include children with extreme levels of PNS withdrawal, nor did I have the ability to specifically identify excessive versus moderate PNS withdrawal within this sample, as researchers have not specified a specific cut-off point to indicate excessive versus moderate PNS withdrawal. Thus, I expected that the PNS withdrawal within this sample would be within a range that could be characterized as a beneficial response to stress.

PNS withdrawal is thought to promote effective social engagement, behavioral preparedness, and self-regulatory processes (Beauchaine, 2001) and has been found to predict fewer internalizing problems, externalizing problems, and (in community samples) better social competence (Graziano & Derefinko, 2013). Thus, I expected PNS withdrawal to be associated with better adjustment outcomes in children. However, I expected that the associations between PNS reactivity and each adjustment outcome would vary as a function of SNS reactivity. To test this hypothesis, I examined whether the two-way PNS x SNS reactivity interaction predicted individual differences in each adjustment outcome.

Aim 1 Hypotheses.

Internalizing

I expected a positive main effect of PNS reactivity predicting internalizing problems. Thus, I expected that PNS withdrawal would be associated with fewer internalizing problems in children and PNS augmentation would be associated with more internalizing problems. However, I expected that the relation between PNS reactivity and internalizing problems would vary as a function of SNS reactivity. I expected higher levels of PNS augmentation to be associated with more internalizing symptoms when coupled with both high and low SNS reactivity, but to a greater extent (i.e., a steeper slope) in the context of low SNS reactivity, as high SNS reactivity may compensate for the resources that PNS augmentation fails to provide.

Externalizing

I expected a positive main effect of PNS reactivity predicting externalizing problems, such that PNS withdrawal would be associated with fewer externalizing problems, whereas PNS augmentation would be associated with more externalizing problems. However, I expected that the link between PNS reactivity and externalizing problems would vary across levels of SNS reactivity. Given the evidence linking SNS underarousal with externalizing problems, I expected that children with low SNS reactivity would show overall higher levels of externalizing problems, as compared to children with high SNS reactivity, especially when coupled with PNS augmentation. Thus, I expected that higher levels of PNS augmentation would be associated with heightened externalizing problems in the context of both high and low SNS reactivity, but to a greater extent (i.e., a steeper slope) in the context of low SNS reactivity.

Social competence

I expected a negative main effect of PNS reactivity. Thus, I expected PNS withdrawal to be associated with more social competence and PNS augmentation to be associated with less social competence. I also expected that the association between PNS reactivity and social competence would vary as a function of SNS reactivity. However, given the absence of research on SNS reactivity and social competence, my hypotheses regarding these relations were somewhat more exploratory. I expected that higher levels of PNS augmentation would be associated with less social competence in the context of both high and low SNS reactivity, but to a greater extent (i.e., a steeper slope) in the context of low SNS reactivity.

Aim #2: Conduct exploratory analyses to investigate whether the joint action of children's PNS and SNS reactivity predicts changes in children's adjustment across time.

To investigate whether children's autonomic reactivity predicts changes in adjustment, I conducted three longitudinal regression analyses. In a separate regression for each adjustment outcome, I examined whether RSAR, SCLR, and the 2-way RSAR x

SCLR interaction predicted Time 2 adjustment, when considering Time 1 adjustment levels.

I expected that the effects of children's autonomic reactivity on adjustment would compound over time. For children who respond to stress with dysregulated responses of PNS and/or SNS, the ongoing interactions between the child and their environment (e.g., school, family, peer contexts) may alter their adjustment over time. Thus, I hypothesized that the cross-sectional patterns described above would be replicated longitudinally.

Aim #3: Conduct exploratory analyses using a person-centered approach to identify distinct groups of children based on their autonomic (i.e., PNS and SNS) reactivity. An underlying goal of this analysis was to examine whether a cluster analysis would identify 4 groups that reflect the 4 profiles of ANS reactivity (reciprocal PNS activation, reciprocal SNS activation, coactivation, coinhibition) that are assumed to exist in the variable-centered analyses. In addition, I examined whether there were differences across groups in adjustment (internalizing, externalizing, social competence).

To investigate whether my sample included distinct groups of children based on their ANS reactivity, I conducted a model-based cluster (MBC) analysis using R with children's RSA reactivity and SCL reactivity included as clustering variables. I expected that at least 2 groups would be identified and tentatively hypothesized that 4 groups would be found, with one group mapping onto each of the 4 ANS reactivity profiles described above. In addition, I expected that if at least two distinct clusters exist in the sample, there would be differences in adjustment across identified clusters. Given the exploratory nature of the MBC analysis, I did not make specific hypotheses about how the clusters might align with the theorized ANS reactivity profiles and thus did not make specific hypotheses about differences in adjustment across clusters. However, I expected that if a reciprocal sympathetic activation cluster was identified, children in this cluster would show better adjustment outcomes (i.e., less internalizing and externalizing, more social competence) compared to other groups. In addition, I expected that children who demonstrated PNS augmentation would exhibit the highest levels of adjustment problems compared to other groups.

Method

Participants

Sixty-five families participated in this study. Due to problems with the physiological equipment, one child did not have physiological data. Thus, the sample is composed of 64 children, who were predominantly Caucasian (8-10 years, *M* = 9.06, *SD* = 0.81; 36 boys, 28 girls; 95.3% Caucasian, 1.6% Asian American; 1.6% Hispanic; 1.6% reported Other). Each child had one parent participate in this study (93.8% mothers, 6.2% fathers; 95.3% Caucasian, 1.6% Asian American; 1.6% Hispanic; 1.6% reported Other). Reported gross family annual income varied (13.9% under $30,000, 23.1% between $30,000 and $60,000, 18.5% between $60,000 and $90,000; 41.5% above $90,000, 3.1% did not disclose). At Wave 2, 52 families participated. Children with and without data at Wave 2 did not differ in age, *t*(62) = 1.08, *p* = .29; sex, χ^2(N=64, df=1) = 1.12, *p* = .29; Time 1 internalizing, *t*(61) = -.10, *p* = .92; Time 1 externalizing, *t*(61) = -.32, *p* = .75; Time 1 social competence, *t*(60) = 1.39, *p* = .17; RSAR, *t*(62) = .47, *p* = .64; or SCLR, *t*(62) = .36, *p* = .72. Missing data at Wave 2 was estimated using maximum likelihood estimation in Mplus.

Procedure

Families were recruited via flyers, local newspaper ads, and online postings in the northeastern United States. At Wave 1, parent-child dyads completed a 3-hour laboratory visit. In the first phase of the Wave 1 laboratory visit, RSA and SCL were assessed during a series of baseline and challenge tasks. This study examined children's physiological reactivity during one of these challenge tasks. In the second phase of the Wave 1 visit, parents completed a series of questionnaires. Parents were compensated $40 for their laboratory visit plus $0.25 per mile traveled, and children were given a prize or gift card of $10 in value. At Wave 2, parents completed questionnaires and were compensated $15. Wave 2 data was collected six months after Wave 1 participation.

Autonomic Arousal

Children's autonomic arousal was measured with a custom physiological data acquisition system (James Long Company, Inc.), which includes a Pentium computer, Snapmaster software, and a bioamplifier. Respiratory sinus arrhythmia (RSA) was measured using an electrocardiogram (ECG). Parents placed three electrodes on their child's torso: one on each opposing side of their rib cage and one ground lead on their sternum. Respiration was measured with pneumonic bellows that were attached around the child's waist. Cardiac inter-beat intervals (IBI) were measured in milliseconds between consecutive R waves from the electrocardiogram and respiration was sampled at a rate of 1000Hz. ECG data was processed and R waves were identified using James Long Company's IBI Analysis software. Misidentified R waves and any problematic IBI artifacts, including those from physical movement, were manually edited. Consistent with the 'peak-to-valley' method (Berntson et al., 1997), RSA values were calculated in seconds and represent the difference between the minimum IBI during respiratory inspiration and the maximum IBI during exhalation. For each 30-second epoch of IBI data, RSA values were calculated by averaging the variance occurring within the frequency band-pass parameter of .1 to 1000 Hz. RSA values are reported in units of $\ln(\text{ms})^2$.

Skin conductance level (SCL) was assessed using two skin conductance electrodes, which were attached to the volar surfaces of the intermediate phalanges of the second and fourth fingers on the child's non-dominant hand. Prior to measuring skin conductance, each child washed and dried his/her hands. Electrodes were then attached using double-sided adhesive collars. To increase conductivity, a layer of isotonic citrate salt electrode gel was put on the electrodes in the 1-cm diameter hole in the adhesive collars. A .5 volt rms sinusoidal AC excitations signal was used. Electrodermal activity was recorded to disk at 1 kHz but averaged and resampled offline at 1 Hz for the current study.

Physiological data were continuously assessed and recorded throughout baseline and challenge tasks. Baseline RSA and baseline SCL were assessed during a rest period immediately prior to the laboratory challenge task. Baseline values were calculated by averaging the physiological data across the baseline period. RSAR was calculated by subtracting the mean baseline RSA from the mean RSA during the challenge task. Similarly, SCLR was calculated by subtracting the average baseline SCL value from the average SCL value during the challenge task. One RSAR outlier and one SCLR outlier were identified; each was manually edited to be +/- 3 standard deviations from the respective mean.

Mirror tracing task

After a 3-minute resting baseline period, children completed a mirror tracing task (Lafeyette Instrument Company), which is a cognitive task in which they were instructed to trace a star pattern onto a piece of tracing paper while looking only at a reflection of their hand in a mirror. Children were not able to directly see the star pattern or their hand and therefore needed to look at the mirror to see the star and their tracing hand. This task has been used successfully to elicit physiological responses in children (El-Sheikh, Keiley, & Hinnant, 2010; Hinnant & El-Sheikh, 2013).

Questionnaire Measures

Adjustment. Parents reported on child adjustment by completing the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001), which is a 120-item parent-report measure of child behavior across multiple domains of functioning. Internalizing and externalizing symptoms were assessed with the Internalizing problems scale and the Externalizing problems scale, respectively. Social competence was measured with the Social Competence subscale. The CBCL has been demonstrated to have good reliability and validity with high test-retest reliability and strong evidence of content, criterion, and construct validity (Achenbach & Rescorla, 2001).

Results

Preliminary Analyses

Descriptive statistics are displayed in Table 1 and bivariate correlations are displayed in Table 2. RSAR was unrelated to any other variable. SCLR was modestly and positively associated with Time 1 social competence, indicating that SCL activation in response to stress is associated with more concurrent social competence. As expected, each adjustment outcome at Time 1 was moderately or strongly associated with the corresponding adjustment outcome at Time 2. In addition, Time 1 internalizing and Time 2 internalizing symptoms were each moderately and positively associated with both Time 1 externalizing symptoms and Time 2 externalizing symptoms.

Paired sample t tests were conducted to compare mean-level RSA and SCL at rest to mean-levels in response to the mirror-tracing challenge task. Results indicated that the mean RSA during the mirror tracing task (*M* = 0.292, *SD* = 0.456) was not significantly different then the mean-level RSA at baseline (*M* = 0.289, *SD* = 0.341), *t*(63) = -0.07, *p* = .94. This nonsignificant difference is likely to have occurred because subgroups of the sample demonstrated opposite patterns of RSA reactivity: 82.81% of the sample demonstrated RSA withdrawal, whereas 17.19% of the sample demonstrated RSA augmentation. In contrast, results indicated a significant change from mean-level baseline SCL (*M* = 11.81, *SD* = 3.96) to the mean-level SCL during the mirror-tracing task (*M* = 12.67, *SD* = 4.10), *t* (63) = .86, *p* < .001.

Aim 1: Concurrent associations

In order to test whether children's autonomic reactivity predicts differences in concurrent adjustment (Aim 1), I conducted three multiple regression analyses in Mplus (Muthen & Muthen, 1998-2012). Separate models were conducted to examine each of the three adjustment outcomes: internalizing symptoms, externalizing symptoms, and social competence. Missing data was estimated using maximum likelihood estimation in Mplus, and maximum likelihood estimation with robust standard errors was used to accommodate non-normality in the data. Prior to analyses, RSA reactivity (RSAR; indicative of PNS reactivity) and SCL reactivity (SCLR; indicative of SNS reactivity) variables were mean-centered, and a 2-way RSAR x SCLR interaction term was calculated. Each regression included the first order effects of RSAR and SCLR, and the two-way RSAR x SCLR interaction. Sex (male = 0, female = 1) was included as a covariate in each regression. Across models, the correlation between RSAR and SCLR was set to zero, as bivariate correlations indicated that the relation between RSAR and SCLR was negligible ($r = -.005$, *ns*). Standardized regression coefficients and 95% confidence intervals (CI) are reported in Table 3.

Significant interactions were probed following the procedure outlined by Aiken and West (1991) and interactions were graphed using Dawson and Richter's (2006) online template. Simple slopes were calculated at low (-1 *SD*) and high (+1 *SD*) levels of the SCLR. Simple slope statistics for significant interactions are reported in the text. To test whether significant interactions represented crossover interaction effects, procedures recommended by Roisman et al. (2012) were followed. To detect the presence of a crossover interaction, significant interactions were first graphed at 2 standard deviations above and below the mean of RSAR. I subsequently examined the proportion of the interaction (PoI) that is represented on either side of the crossover point (i.e., the point at which the simple slope lines cross over in the interaction plot). PoI values range from 0 to 1; a PoI value close to 0 or 1 suggests an ordinal interaction, whereas a PoI value close to .50 suggests a crossover interaction. Finally, I examined the proportion affected (PA) with respect to RSAR. The PA index assesses the proportion of children differentially affected by high versus low SCLR. A PA value close to 0 suggests an ordinal interaction, whereas a PA value close to .50 indicates a crossover interaction.

Internalizing. Contrary to hypotheses, the regression analysis predicting Time 1 internalizing problems indicated a nonsignificant first order effect of RSAR. In addition, the effects of sex and SCLR were nonsignificant. Consistent with hypotheses, there was a significant 2-way RSAR x SCLR interaction ($\beta = -0.22$, 95% CI = -0.43 to -0.01). The PoI (0.49) and the PA index (0.49) suggest a crossover interaction. Decomposition of the RSAR x SCLR interaction (see Figure 1) revealed that RSAR was positively associated with internalizing symptoms in the context of low SCLR ($\beta = 0.33$, 95% CI = 0.02 to 0.65), but negatively associated with internalizing symptoms in the context of high SCLR ($\beta = -0.16$, 95% CI = -0.30 to -0.02). In other words, consistent with hypotheses, when coupled with low SNS reactivity, PNS withdrawal was associated with fewer internalizing symptoms. Contrary to hypotheses, however, when coupled with high SNS reactivity, PNS withdrawal was associated with more internalizing symptoms.

Externalizing. In the regression analysis predicting Time 1 externalizing symptoms, sex was significantly associated with externalizing symptoms ($\beta = -0.25$, 95% CI = -0.48 to -0.03), such that boys showed significantly more externalizing behaviors as compared to girls. Contrary to hypotheses, the first order effects of RSAR and SCLR were nonsignificant and the 2-way RSAR x SCLR interaction was nonsignificant.

Social Competence. In the regression analysis predicting Time 1 social competence, the first order effect of SCLR was significant ($\beta = 0.26$, 95% CI = 0.01 to 0.50), such that higher SNS arousal was associated with more social competence. Contrary to hypotheses, all other effects were nonsignificant.

Path Model. In order to further explore the relative importance of autonomic reactivity predicting each adjustment outcome, a path model was examined in which the three Time 1 adjustment outcomes (internalizing, externalizing, social competence) were all included. Importantly, the effects reported above held when all adjustment outcomes were included in the model. Sex was significantly associated with externalizing symptoms (β = -0.26, 95% CI = -0.48 to -0.03), SCLR was positively associated with social competence (β = 0.27, 95% CI = .02 to .52), and the two-way RSAR x SCLR interaction was significant predicting internalizing symptoms (β = -0.22, 95% CI = -0.43 to -0.01).

Aim 2: Changes in Adjustment Over Time

In order to test whether children's autonomic reactivity predicts *changes* in adjustment, I conducted three exploratory regression analyses in Mplus (Muthen & Muthen, 1998-2012). All procedures described above were followed; in addition, each longitudinal regression analysis predicting Time 2 adjustment also included Time 1 adjustment as a covariate. Standardized betas and 95% confidence intervals are reported in Table 3. Standardized regression coefficients and confidence intervals for all significant effects and the simple slope analyses are included in the text.

Internalizing. In the regression analysis predicting Time 2 internalizing symptoms, Time 1 internalizing symptoms was significantly associated with Time 2 internalizing (β = 0.62, 95% CI = 0.42 to 0.83), but the effects of sex and SCLR were nonsignificant. Contrary to hypotheses, the first order effect of RSAR was nonsignificant. Consistent with hypotheses, the 2-way RSAR x SCLR interaction was significant (β = -0.35, 95% CI = -0.65 to -0.04) and the PoI (0.46) and the PA index (0.47) suggest a crossover interaction. Decomposition of the RSAR x SCLR interaction (see Figure 2) revealed that RSAR was positively associated with Time 2 internalizing symptoms in the context of low SCLR (β = 0.45, 95% CI = 0.23 to 0.66), but RSAR was not associated with Time 2 internalizing symptoms in the context of high SCLR (β = -0.27, 95% CI = -0.61 to 0.10). In other words, consistent with hypotheses and consistent with the cross-sectional results for internalizing symptoms, when coupled with low SNS reactivity, PNS withdrawal was associated with fewer internalizing symptoms. However, PNS reactivity was unrelated to changes in internalizing symptoms when coupled with high SNS reactivity.

Externalizing. In the regression analysis predicting Time 2 externalizing symptoms, Time 1 externalizing was significantly associated with Time 2 externalizing (β = 0.77, 95% CI = 0.58 to 0.96). The first order effect of SCLR was marginally significant (β = -0.16, 90% CI = -0.31 to -0.02), such that lower SNS reactivity was marginally associated with more externalizing problems. All other effects were nonsignificant.

Social Competence. In the regression predicting Time 2 social competence, Time 1 social competence was significantly associated with Time 2 social competence (β = 0.58, 95% CI = 0.41 to 0.75). All other effects were nonsignificant.

Summary of Variable-Centered Analyses

Contrary to hypotheses, the first order effect of PNS reactivity was nonsignificant across all models. Unexpectedly, more SNS activation was associated with more social competence. In addition, less SNS activation was marginally related to more externalizing symptoms over time. Consistent with hypotheses, the two-way RSAR x SCLR reactivity interaction was significant in the regressions predicting internalizing symptoms at Time 1 and Time 2. In both cases, RSA withdrawal was associated with less internalizing symptoms when coupled with low SCLR. RSA withdrawal was associated with more Time 1 internalizing symptoms when coupled with high SCLR; however, RSAR did not influence Time 2 internalizing symptoms when coupled with high SCLR.

Aim 3: Cluster identification

To test my third aim, I conducted a model-based cluster analysis (MBC), which identified two distinct clusters of children based on their parasympathetic and sympathetic nervous system reactivity. Visual inspection of children's autonomic profiles revealed that Cluster 2 contained children with opposite patterns of PNS reactivity. In an exploratory manner, I identified subgroups within Cluster 2 to create a 3-cluster solution. A detailed explanation for splitting Cluster 2 into subgroups is provided below. Using variable-centered regression analyses, I subsequently examined whether there were adjustment differences across a 2-cluster and 3-cluster solution. The analytic procedure for examining adjustment differences across clusters is described below.

Model-Based Cluster Analysis

To identify distinct groups of children based on their ANS reactivity profile, I conducted a model-based cluster (MBC) analysis using mclust version 5.1 library for R (Fraley, Raftery, Murphy, & Scrucca, 2012). RSAR and SCLR were used as clustering variables and were standardized prior to cluster analysis. Mclust version 5.1 compares the fit of fourteen models based on assumptions of the data's shape, volume, orientation, and number of components. Up to nine components are examined for each model, yielding up to 126 unique possible cluster solutions. Goodness-of-fit was evaluated based on the Bayesian Information Criterion (BIC) value for each model identified. BIC values closest to zero represent the best fit. When comparing fit across models, BIC value differences of ten or greater suggest “very strong” evidence for a superior model, whereas BIC value differences of two or less indicate “weak” evidence for a significant difference across competing models (Raftery, 1995). Previous research suggests that 76 participants would provide adequate power ($1-\beta = .80$) to identify at least two unique groups (Ning & Finch, 2004). Thus the cluster analysis reported here is slightly underpowered.

Results from the MBC analysis indicated that the best fitting model (model 1; BIC = -321.14) was a model with a diagonal distribution, varying volume, varying shape, and two components (i.e., clusters). The next best fitting model (model 2; BIC = -323.54) identified was ellipsoidal in distribution with equal orientation and 2 components. Finally, the third best fitting model (model 3; BIC = -327.66) was ellipsoidal with varying volume, varying shape, varying orientation, and two components. Since the BIC values differed by approximately 2 across model 1 versus model 2, and the BIC values differed by less then 10 across all three models, results suggest that models 1, 2, and 3 are not significantly different from each other (Raftery, 1995). To further explore differences across models, I examined individual classification in each model and visually compared cluster classification across models. Interestingly, model 1, model 2, and model 3 each identified the exact same cluster classification solution. In other words, each child was classified into the same cluster based on his/her ANS reactivity profile in model 1, model 2, and model 3. Taken together, the similar BIC values across models and the identical classification solutions across models lend support for the idea that distinct groups of children exist in this sample.

Theoretically speaking, all three identified models conveyed the same information, as each model identified identical cluster classifications. Model 1 (BIC = -321.14) was chosen because it was the best fitting model (i.e., BIC value closest to zero). MBC results indicate that, on average, Cluster 1 (n = 37) exhibited a level of RSAR that was below the sample average RSAR (Mean = -0.108, variance = 0.007) and below sample-average SCLR (Mean = -.100, variance = 1.039). On average, children in Cluster 2 (n = 27) exhibited RSAR (Mean = 0.120; variance = 2.040) and SCLR (Mean = 0.110, variance = 0.900) levels that were greater then the sample mean. Furthermore, MBC results suggest that the variability in SCLR scores is comparable across clusters, whereas RSAR scores are more variable in Cluster 2 as compared to Cluster 1. It is important to note that RSAR and SCLR scores were standardized prior to the MBC analysis; thus, negative scores cannot be interpreted as withdrawal and positive values cannot be interpreted as augmentation or activation. Based on this 2-cluster model, I created a categorical ANS reactivity group membership variable (Cluster 1 = 1, Cluster 2 = 2), which was subsequently used to examine adjustment differences across clusters.

In order to consider the theoretical implication of the identified cluster model, raw RSAR and SCLR scores were visually inspected and descriptive statistics for each cluster were examined (see Table 4). Examining raw RSAR and SCLR scores revealed that individuals in Cluster 1 (M_{RSAR} = -.03, SD_{RSAR} = .02; M_{SCLR} = .79, SD_{SCLR} = 1.00) exhibited slight RSA withdrawal and less SCL arousal as compared to Cluster 2. On average, Cluster 2 (M_{RSAR} = .03, SD_{RSAR} = .38; M_{SCLR} = .95, SD_{SCLR} = .92) exhibited RSA augmentation and more SCL arousal then Cluster 1. Independent sample t-tests were conducted to examine cluster differences in RSAR and SCLR, and Levene's test was conducted to test for homogeneity of variance across clusters. Results indicated that SCLR scores were not significantly different across clusters, *t* (62) = -0.66, *p* = .51, and the variance in SCLR scores was homogenous across clusters, *F* (62) = 0.32, *p* = .58. Results indicated that RSAR was not significantly different across clusters, *t* (26.13) = -0.85, *p* = .40; however, the variance of RSAR scores was significantly different across clusters, *F* (62) = 83.22, *p* < .001, which indicates that the distribution of RSAR scores was heterogeneous across clusters. Although mean RSAR scores were not significantly different across clusters, this is likely due to the fact that Cluster 2 is comprised of children with opposite responses of the PNS (i.e., either RSA withdrawal or RSA augmentation), which average together to be a value that is similar to the Cluster 1 RSAR mean. Given that SCLR was not significantly different across clusters and that the distribution of SCLR scores is homogeneous across clusters, it appears that RSAR may be the more important factor influencing cluster classification.

To further investigate cluster classification, I visually inspected raw RSAR scores across clusters and generated additional cluster-specific descriptive statistics. Cluster 1 (M_{RSAR} = -.03, SD_{RSAR} = .02) was comprised almost exclusively of children with small negative values for RSAR (range = .086, min = -.07, max = .016). It should be noted that 35 of the 37 children in Cluster 1 showed RSAR scores between -.07 and -.002. Of the two other children in Cluster 1, one child showed an RSAR score of 0.000 (i.e., no change) and one child showed an RSAR score of 0.016 (i.e., slight RSA augmentation). In contrast, Cluster 2 (M_{RSAR} = .03, SD_{RSAR} = .38) showed substantially more variability on RSAR (range = 1.293, min = -.47, max = .823). Interestingly, Cluster 2 appears to have meaningful subgroups. Visual inspection of the raw RSAR scores revealed that

Cluster 2 was comprised of children who either demonstrated substantially larger negative RSAR scores (n = 16; M_{RSAR} = -.238, range = .374, min = -.47, max = -.096) as compared to Cluster 1, or demonstrated substantial RSA augmentation (n = 11; M_{RSAR}= .427, range = .744, min = .079, max = .823). Thus, it appears that Cluster 1 can be characterized as showing slight RSA withdrawal, whereas Cluster 2 can be characterized as demonstrating heightened RSAR; more specifically, Cluster 2 appears to include children with either substantial RSA withdrawal or substantial RSA augmentation.

Since the MBC analysis was slightly underpowered, it may be that children with substantial RSA withdrawal (n = 16) and children with substantial RSA augmentation (n = 11) were classified into the same cluster due to insufficient power. In order to consider whether there are meaningful differences between the subgroups of children in Cluster 2 and how each subgroup may differ from Cluster 1, I created a new ANS reactivity group membership variable in which Cluster 1 membership remained the same and Cluster 2 was split into subgroups: Cluster 2A (n = 16) refers to children originally classified in Cluster 2 who demonstrated RSA withdrawal and Cluster 2B refers to children originally classified in Cluster 2 who showed RSA augmentation. The new ANS reactivity group variable represents these three groups (1 = Cluster 1, 2 = Cluster 2A, 3 = Cluster 2B).

Cluster-specific descriptive statistics for RSAR and SCLR were generated and examined across the three clusters (see Table 4). Cluster 1 showed slight RSA withdrawal and a level of SCLR that is similar to the average SCLR for the entire sample. Similar to Cluster 1, the mean SCLR for children in Cluster 2B was similar to the sample-average SCLR; but in contrast to Cluster 1, Cluster 2B showed RSA augmentation. Children in

Cluster 2A showed greater RSA withdrawal then those in Cluster 1 and also showed above average SCLR.

A one-way ANOVA with planned contrasts was conducted to examine whether mean RSAR and mean SCLR varied across 3 clusters. Homogeneity of variance in RSAR and SCLR scores was tested across clusters and the Brown-Forsythe *F* statistic was generated to provide a robust test of equality of means. Results indicate that there was heterogeneity in the variance of RSAR scores across clusters, F (2, 61) = 57.99, $p < .001$, and RSAR was significantly different across the 3 clusters, F (2, 13.73) = 40.58, $p < .001$. Planned contrasts indicated that RSAR was significantly different between Clusters 1 and 2A ($M_{diff} = 0.21$, $t(15.43) = 6.79$, $p < .001$), between Clusters 1 and 2B ($M_{diff} = 0.46$, $t(10.04) = 5.57$, $p < .001$), and between Clusters 2A and 2B ($M_{diff} = -0.66$, $t(12.78) = -7.60$, $p < .001$). Variability in SCLR scores was homogeneous, F (2, 61) = 0.19, $p = .83$, and mean SCLR was not significantly different across the three clusters, F (2, 61) = 0.50, $p = .61$. All planned contrasts were nonsignificant for SCLR.

Adjustment differences across clusters

Variable-centered analyses were conducted in SPSS to test for concurrent adjustment differences across a 2-cluster solution (Cluster 1 versus Cluster 2), and to test for concurrent adjustment differences across a 3-cluster solution (Cluster 1, Cluster 2A, and Cluster 2B). The analytic procedure and corresponding results are first reported for the 2-cluster model and then for the 3-cluster model. For consistency, the same analytic procedure was followed to test for adjustment differences across the 2- and 3-cluster models.

Two-Cluster Solution. To test for differences in adjustment across Cluster 1 versus Cluster 2, I conducted a one-way ANOVA with a planned contrast for each adjustment outcome, yielding three ANOVAs. Each ANOVA included Levene's test to test for homogeneity of variance in adjustment scores across clusters and the Brown-Forsythe *F* test was conducted to provide a robust test of equality of means. Marginally significant differences are displayed with means plots in Figure 3.

Results indicate that the variability in internalizing scores was significantly different across clusters, $F(1, 61) = 5.09$, $p = 0.03$, and across clusters there was a marginally significant difference in internalizing symptoms, $F(1, 59.95) = 3.06$, $p = .086$, such that children in Cluster 1 ($M = 7.81$, $SD = 6.58$) showed more internalizing symptoms then children in Cluster 2 ($M = 5.41$, $SD = 4.28$). Variability in externalizing scores was significantly different across clusters, $F(1, 61) = 4.79$, $p = 0.03$, but on average externalizing scores were not significantly different, $F(1, 60.02) = 1.33$, $p = .25$ in Cluster 1 ($M = 6.92$, $SD = 6.72$) versus Cluster 2 ($M = 5.30$, $SD = 4.39$). Finally, results indicated that across clusters, there was homogeneity in the variance of social competence scores, $F(1, 60) = 0.22$, $p = .64$, and a marginally significant difference in social competence across clusters $F(1, 59.62) = 3.55$, $p = 0.06$, such that Cluster 2 ($M = 9.63$, $SD = 2.25$) showed more social competence as compared to Cluster 1 ($M = 8.44$, $SD = 2.71$).

3-Cluster Solution. To examine adjustment differences across the 3-cluster solution, I followed the same analytic procedure described above for the 2-cluster solution, except that three planned contrasts were included in each ANOVA. In each ANOVA, contrast 1 tested Cluster 1 versus Cluster 2A, contrast 2 tested Cluster 1 versus

Cluster 2B, and contrast 3 tested Cluster 2A versus Cluster 2B for differences in adjustment. Marginally significant differences are displayed with means plots in Figure 4.

Variability in scores on internalizing symptoms were homogeneous, *F* (2, 60) = 2.49, *p* = 0.09, and not significantly different across the three clusters, *F* (2, 48.56) = 1.97, *p* = .15; however, contrast results showed a marginally significant difference in internalizing symptoms in Clusters 1 versus 2A, (M_{diff} = 2.81, *t*(42.75) = 1.83, *p* = .07), such that Cluster 1 (*M* = 7.81, *SD* = 6.58) showed more internalizing symptoms as compared to Cluster 2A, (*M* = 5.00, *SD* = 4.29). Cluster 2B (*M* = 6.00, *SD* = 4.40) was not significantly on internalizing scores as compared to either Clusters 1 or 2A.

Variability in externalizing scores was homogenous across three clusters, *F* (2, 60) = 3.05, *p* = .06. Externalizing symptoms were not significantly different, *F* (2, 36.64) = 0.93, *p* = .41, across Cluster 1 (*M* = 6.92, *SD* = 6.72), Cluster 2A (*M* = 4.81, *SD* = 3.56), or Cluster 2B (*M* = 6.00, *SD* = 5.50). All contrasts were nonsignificant.

The variability in social competence scores was homogeneous across clusters, *F* (2, 59) = 0.83, *p* = .44. Average social competence was not significantly different across clusters, *F* (2, 44.33) = 1.98, *p* = .15; however, planned contrast results indicated that there was a marginally significant difference in social competence across Clusters 1 versus 2B (M_{diff} = 1.28, *t*(23.55) = 1.74, *p* = .096), such that children in Cluster 2B (*M* = 9.73 , *SD* = 1.93) showed more social competence then children in Cluster 1 (*M* = 8.44, *SD* = 2.71). On average, children in Cluster 2A (*M* = 9.56, *SD* = 2.51) did not differ from either Clusters 1 or 2B on social competence.

Summary of MBC analysis & adjustment differences across clusters

The MBC analysis identified 2 distinct clusters of children based on their parasympathetic and sympathetic reactivity. On average, Cluster 1 showed slight RSA withdrawal combined with a level of SCLR that was less then the sample average. On average, Cluster 2 showed RSA augmentation combined with a level of SCLR that was greater then the sample average SCLR. Marginally significant differences in adjustment were detected across clusters, such that Cluster 1 showed more internalizing symptoms and less social competence as compared to Cluster 2.

As a follow-up set of analyses, adjustment differences were examined across 3 clusters. In the 3-cluster model, Cluster 1 remained the same and Cluster 2 was split into subgroups. On average, children in Cluster 2A showed substantial RSA withdrawal combined with above average SCLR and children in Cluster 2B showed substantial RSA augmentation combined with SCLR scores less then the sample-average SCLR and similar to SCLR scores in Cluster 1. Across these three clusters, RSAR was significantly different, but SCLR was not significantly different. Marginally significant adjustment differences were detected, such that children in Cluster 1 showed more internalizing symptoms then children in Cluster 2A and less social competence then children in Cluster 2B.

Discussion

Limited research has examined the joint action of children's PNS and SNS reactivity as predictors of child adjustment. Although the PNS and SNS operate in a dynamic manner, many studies have considered the influence of either children's PNS or SNS independent of the other branch. However, to formulate a complete picture of how children's autonomic reactivity influences development, it is important to consider both branches of the ANS. The primary objective of this dissertation was to consider both the PNS and SNS in order to more fully understand how children's autonomic reactivity is related to adjustment.

Variable-centered approach

First-order effects

Parasympathetic responding under conditions of stress or challenge has been conceptualized as a physiological mechanism that facilitates emotional responding, focused attention on the challenging situation at hand, and preparedness to launch a behavioral response to engage with one's social environment (Beauchaine, 2001; Calkins, 1997; Porges, 2007, 2011; Thayer & Lane, 2000; Thompson et al., 2008). Polyvagal theory asserts that PNS responding is a psychophysiological marker of the regulation of emotion and social behavior, and that PNS withdrawal is an adaptive response to stress (Porges, 2007). Previous research with children supports the Polyvagal perspective and suggests that greater PNS withdrawal in response to challenge is associated with better self-regulation (Gentzler et al., 2009), fewer internalizing and externalizing symptoms (Calkins & Keane, 2004; Gentzler et al., 2009), and greater social competence (Graziano et al., 2007). Thus, I expected children's PNS reactivity to be relevant to their emotional, behavioral, and social adjustment, and more specifically, I expected greater PNS withdrawal would be related to better adjustment outcomes. Contrary to hypotheses, all first order effects of RSAR were nonsignificant, such that the aggregate effect of RSAR was unrelated to children's internalizing symptoms, externalizing symptoms, and social competence both concurrently and longitudinally. The nonsignificant relation between PNS reactivity and children's adjustment stands in contrast to a recent meta-analysis, which suggests that greater PNS withdrawal is associated with fewer internalizing and externalizing problems and more social competence in community samples of children (see Graziano & Derefinko, 2013). However, there are some discrepancies in the literature. For example, some evidence suggests that RSA augmentation is linked to more social competence (Blair, 2003), fewer internalizing and externalizing symptoms, and greater behavioral self-regulation (Hastings et al., 2008). In addition, some studies (e.g., Hinnant & El-Sheikh, 2009; Keller & El-Sheikh, 2009) have observed nonsignificant relations between children's PNS reactivity and adjustment, including internalizing and externalizing symptoms.

Although the hypothesized link between PNS withdrawal and better adjustment outcomes was not supported, this study does offer support for the idea that PNS withdrawal is a typical physiological response under conditions of challenge or mild stress, as the majority of children (79.69%) showed PNS withdrawal. However, this sample also included children who showed substantial RSA augmentation. These opposing responses were averaged together in the variable-centered analyses, which may at least in part explain why I was unable to detect a first order association between children's PNS reactivity and adjustment. Furthermore, Graziano and Derefinko (2013) noted small effect sizes in the link between PNS withdrawal and both internalizing and externalizing symptoms in children, and the aggregate effect of PNS reactivity on social competence was nonsignificant. Due to the small sample size, this study was likely underpowered to detect small effects.

Activity of the SNS is thought to be particularly relevant to behavioral processes. Sympathetic activation elicits increased heart rate, oxygen flow, and perspiration, which generate the metabolic resources needed to launch an active behavioral response to stress (Beauchaine, 2001; Boucsein, 2011). Moreover, the SNS is also implicated in regulatory processes that contribute to effective behavioral control. Thus, it was surprising that SNS reactivity was unrelated to concurrent externalizing symptoms. In this study, SNS reactivity was measured in response to a problem-solving task. Perhaps the mirror tracing task did not elicit sufficient variability in SNS arousal to detect an overall effect of SCLR. It is also possible that SCLR was unrelated to Time 1 externalizing symptoms due to the low frequency of problems in this sample. Consistent with this view, Boyce et al. (2001) found that only children showing high externalizing symptoms demonstrated a blunted response of the SNS. There was, however, a marginal negative effect of SNS reactivity on Time 2 externalizing problems. After accounting for externalizing problems at Time 1, lower SNS reactivity was marginally associated with increased externalizing problems at Time 2. Although the sample-wide mean of externalizing problems decreased from Time 1 to Time 2, it seems more likely to have occurred for children who showed higher levels of SNS arousal. Extensive evidence suggests that blunted reactivity of the SNS heightens risk for externalizing problems, including more aggression and conduct problems (e.g., Erath et al., 2011; Posthumus et al., 2009; Gao et al., 2010). Blunted SNS reactivity may be a marker of a weak behavioral inhibition system (BIS), which may contribute to impulsivity, an inability to appropriately inhibit behavior, or fearlessness in circumstances in which punishment is possible (Beauchaine, 2001, Fowles et al., 2000; Raine, 2002; van Goozen et al., 2007).

Interestingly, children's SNS arousal was also relevant to concurrent social competence, such that more SNS activation in response to challenge was associated with more social competence. Since there is a relative absence of research on children's SNS reactivity and social competence, it is particularly interesting that on average SNS reactivity, but not PNS reactivity, was relevant to children's social competence. SNS arousal facilitates behavioral preparedness and provides metabolic resources to manage challenging environmental circumstances (Beauchaine, 2001). Thus, children with less SNS arousal may be less physiologically prepared to behaviorally respond to stress or challenge, in turn leaving them less competent in managing their social environment. Alternatively, children who experience more SNS arousal likely maintain more physiological resources during times of challenge, facilitating active engagement behaviors and effective behavioral control (Beauchaine, 2001), both of which may be beneficial to children's social adjustment. Since the children who participated in this study constitute what is considered to be a community sample, it is likely that the extent of SNS activation observed in this study is within a range that could be characterized as typical, rather then reflecting over-arousal, which would theoretically be harmful to children's adjustment. It is important to note however, that the association between SNS reactivity and social competence was somewhat weak and was not replicated longitudinally. Nonetheless, this finding provides novel information about how SNS responding can contribute to children's social functioning.

Given that activity of the SNS is considered to be especially relevant to behavioral processes (Beauchaine, 2001; Boucsein, 2011), it is not surprising that in this study, the aggregate effect of SNS reactivity was unrelated to children's internalizing problems at both Time 1 and Time 2. Although exaggerated SNS reactivity may contribute to extreme emotional states (see Beauchaine, 2001), it is unlikely that children in this community sample demonstrated exaggerated SNS reactivity. Three moderation studies suggest that family risk factors are associated with more internalizing symptoms for youth who show heightened or exaggerated SNS reactivity (El-Sheikh, 2005; Cummings et al., 2007; Diamond et al., 2012), but in this study, children's autonomic reactivity was not considered in the context of a known family risk factor. Thus, although there is some evidence suggesting that the SNS may contribute to emotional processes in youth, this may be more likely when known environmental risk factors are present or when SNS activation is exaggerated, which may contribute to physiological and emotional dysregulation.

PNS x SNS interactions

The primary goal of this dissertation was to investigate whether the joint action of the parasympathetic and sympathetic branches of the ANS contribute to children's adjustment. I hypothesized that the associations between children's PNS reactivity and adjustment would vary as a function of SNS reactivity. Consistent with hypotheses, the joint action of children's PNS and SNS reactivity was relevant to children's concurrent internalizing symptoms, as well as changes in internalizing symptoms across six months. Thus, although PNS reactivity was on average unrelated to children's internalizing symptoms, PNS reactivity was relevant to children's internalizing symptoms when considered in conjunction with SNS reactivity. Consistent with hypotheses, the association between PNS reactivity and internalizing symptoms varied across levels of SNS reactivity. However, the hypothesized nature of the interaction effect was only partially supported across models. As expected, in relation to internalizing symptoms at both Time 1 and Time 2, PNS withdrawal was beneficial when combined with low SNS reactivity. It appears that PNS withdrawal combined with low SNS reactivity may provide children with sufficient resources to successfully manage environmental demands (via PNS withdrawal) while potentially maintaining a lower level of arousal through low SNS reactivity. Together, PNS withdrawal and low SNS reactivity may provide children with an adaptive level of arousal and sufficient internal resources to engage with environmental demands, thus enabling children to effectively regulate their emotional functioning. Since low SNS arousal mobilizes minimal physiological resources for managing a challenging circumstance, sufficient PNS withdrawal may be especially important for children who experience lower SNS arousal.

Contrary to hypotheses, however, PNS withdrawal was linked to more concurrent internalizing problems when combined with high SNS reactivity, whereas PNS augmentation was beneficial. Both PNS withdrawal and high SNS reactivity promote physiological arousal. When coupled with high SNS reactivity, PNS withdrawal may leave a child too aroused in response to stress, thus enhancing emotional difficulties. PNS activation counteracts SNS arousal and therefore inhibits a “fight or flight” response and promotes a sense a calm, which according to Polyvagal theory would be beneficial in a safe environment (Porges, 2011). For children who experience high SNS reactivity, PNS augmentation may be helpful for managing one’s emotional experience in response to challenging environmental demands.

However, the effect of PNS reactivity on internalizing symptoms given high SNS reactivity was not replicated across time. For those exhibiting high SNS reactivity (a response which provides physiological resources in times of stress), the effect of PNS reactivity was not strong enough to influence change in internalizing symptoms across six months. Whereas low SNS arousal likely provides minimal resources during times of stress, higher SNS arousal may provide adequate physiological resources regardless of PNS responding. It may be that children who experience heightened SNS arousal (that is within an adaptive range) receive adequate physiological resources via the SNS and are thus less sensitive to the extent of resources provided by PNS responding. In contrast, children who experience low SNS arousal receive minimal resources from their sympathetic nervous system and thus may be more in need of the physiological resources provided by PNS withdrawal.

Although RSAR and SCLR are both continuous variables, which were examined in a two-way interaction, the simple slope analyses (Figures 1 and 2) can be tentatively compared to previous literature on the autonomic profiles proposed by Bertson et al. (1991). Keller and El-Sheikh (2009) made a similar attempt when interpreting interactions between children's SNS and PNS activity. Reciprocal PNS activation includes PNS augmentation (individuals on the right side of Figures 1 & 2) and low SNS reactivity (individuals on the solid line in Figures 1 & 2). Coinhibition would be depicted by PNS withdrawal (individuals on the left side of Figures 1 & 2) and low SCLR (individuals on the solid line in Figures 1 & 2). Reciprocal SNS activation involves PNS withdrawal (individuals on the left side of Figures 1 & 2) and high SCLR (individuals on the dotted line in Figures 1 and 2). Finally, coactivation is characterized by PNS augmentation (individuals on the right side of Figures 1 & 2) and high SCLR (individuals on the dotted line in Figures 1 & 2).

Although El-Sheikh et al. (2009) examined PNS x SNS profiles within the context of marital conflict, whereas this study examined the effect of the two-way PNS x SNS interaction, I believe it is still appropriate to consider whether my findings conceptually align with El-Sheikh et al.'s biopsychosocial framework. Somewhat more comparable to this study, Keller and El-Sheikh (2009) examined whether children's PNS reactivity moderated the link between baseline SNS activity and externalizing symptoms. Keller & El-Sheikh (2009) concluded that children who demonstrated characteristics of coinhibition (PNS withdrawal combined with low SNS activity) exhibited the fewest externalizing symptoms, whereas children who exhibited characteristics of reciprocal PNS activation (PNS augmentation coupled with low SNS activity) showed higher levels of externalizing symptoms. Although Keller & El-Sheikh (2009) examined SNS activity at rest and examined externalizing symptoms as the outcome, their findings provide some support for the idea that coinhibition may be a more beneficial autonomic response then reciprocal PNS activation.

El-Sheikh and colleagues (2009) conceptualized reciprocal autonomic profiles as beneficial, whereby the coordinated response of the PNS and SNS provides a child with important physiological resources needed to manage environmental stressors. In contrast, El-Sheikh et al. (2009) argued that autonomic responses that mark dual activation (i.e., coactivation) or dual inhibition (i.e., coinhibition) both reflect physiological dysregulation, which they argued leaves a child physiologically ill-equipped to effectively manage environmental stressors and thus vulnerable to maladjustment. Results from my variable-centered analyses predicting children's internalizing symptoms do not support El-Sheikh et al.'s biopsychosocial framework (2009); instead, I found that those with reciprocal responses of the ANS were at the highest risk for internalizing symptoms.

Contrary to hypotheses, the two-way PNS x SNS reactivity interaction was not relevant to children's concurrent externalizing symptoms or social competence, or to changes in externalizing symptoms and social competence. It is particularly surprising that the interaction between PNS and SNS reactivity did not influence children's externalizing symptoms. Previous studies that have considered both the PNS and SNS suggest that the joint action of the PNS and SNS is relevant to children's externalizing problems (El-Sheikh et al., 2009; Keller & El-Sheikh, 2009). It may be that the community sample of children in this study included levels of externalizing symptoms too low or with too little variability to detect effects. Moreover, this sample was relatively small, which limited statistical power to detect what is likely a small effect in the population.

Person-centered approach

Conducting a Model Based Cluster (MBC) analysis based on children's autonomic reactivity and applying the results to investigate differences in adjustment across groups represents a novel approach to examining how autonomic reactivity is related to children's functioning. Although the MBC analysis was likely underpowered, results from the MBC analysis offer support for the idea that it is possible to identify distinct profiles of autonomic reactivity in children. This study adds to previous research (Muñoz et al., 2013; Quas et al., 2014) that has utilized a person-centered approach to classify youth into physiological reactivity profile groups and extends this literature by considering whether particular developmental outcomes vary across autonomic profile groups.

The MBC analysis identified 2 distinct clusters of children based on their PNS and SNS reactivity in response to a laboratory challenge task. Cluster 1 included 37 children, who, on average, showed slight RSA withdrawal and SCL activation at a level similar to but slightly less then the sample-wide mean SCLR, reflecting an autonomic profile that can be characterized as modest reciprocal SNS activation. Cluster 2 included 27 children who, on average, demonstrated slight RSA augmentation and SCLR at a level that was slightly higher than the sample-wide average SCLR. Thus, on average, Cluster 2 can be characterized as showing coactivation of the PNS and SNS.

To further interpret the patterns of autonomic reactivity across clusters, it was important to consider whether PNS and SNS reactivity were different across the two clusters. Across the two clusters, mean-level SNS reactivity was not significantly different, and the variability in SCLR scores was homogeneous. On average, Cluster 1 (modest reciprocal SNS activation group) and Cluster 2 (coactivation group) showed opposite responses of the PNS (withdrawal versus augmentation); however, RSAR was not significantly different across these groups. Importantly, the variability in RSAR scores was significantly different across the two clusters, with Cluster 2 showing substantially more variability in RSAR scores. By further inspecting RSAR scores in Cluster 2, it became apparent that children in Cluster 2 either showed substantial RSA withdrawal or substantial RSA augmentation. Therefore, children in Cluster 2 can more accurately be characterized as showing heightened PNS reactivity, which includes heightened PNS withdrawal and heightened PNS augmentation, combined with SNS activation. It may be that low power prevented the MBC analysis from identifying a 3-

cluster solution in which children in Cluster 2 were classified into separate clusters based on the direction (i.e., withdrawal vs. augmentation) of PNS reactivity.

Children in the modest reciprocal SNS activation group (Cluster 1) showed more internalizing symptoms and less social competence as compared to children in the heightened PNS reactivity group (Cluster 2). Although these differences were only marginally significant, these trends suggest that it is possible to detect meaningful differences in children's autonomic processes via person-centered analyses, and these differences appear to be relevant to children's emotional and social functioning. Specifically, children who showed modest PNS withdrawal combined with an average level of SNS activation (Cluster 1) appear to be at a disadvantage, as these children exhibited marginally higher internalizing problems and less social competence than children who showed heightened PNS reactivity combined with SNS activation (Cluster 2).

As an exploratory set of analyses, I chose to split Cluster 2 into subgroups based on the direction of heightened PNS reactivity. Thus, children who showed heighted PNS withdrawal were classified into Cluster 2A and children who showed heightened PNS augmentation were classified into Cluster 2B. On average, Cluster 2B showed SNS activation combined with PNS augmentation and can thus be characterized as showing coactivation. Importantly, 14 children in Cluster 2 showed reciprocal SNS activation and 29 out of 37 children in Cluster 1 showed reciprocal SNS activation, yet these children were not classified into the same cluster, which suggests that although they all showed reciprocal SNS activation, these children are inherently different. SCLR did not vary across Cluster 1 versus 2A, but RSAR was significantly different across these groups of children. As previously described, most children in the modest reciprocal SNS activation group (Cluster 1) showed slight PNS withdrawal, whereas the reciprocal SNS activators who were originally classified into Cluster 2 (i.e., those in Cluster 2A) showed substantially more PNS withdrawal then children in Cluster 1. Thus, children in Cluster 2A can be characterized as showing strong reciprocal SNS activation. I had tentatively hypothesized that the MBC analysis would identify four clusters, with one cluster representing each of the four ANS profiles previously identified in the literature (see Berntson et al., 1991; El-Sheikh, et al., 2009). Contrary to this hypothesis, the exploratory 3-cluster model included two distinct reciprocal SNS activation groups and one coactivation group. The MBC analysis did not identify a reciprocal PNS activation group or a coinhibition group.

When mean differences in adjustment were tested across three clusters, differences in internalizing symptoms and social competence were detected. It is important to note that all adjustment differences found across clusters are marginal effects and should be interpreted with caution. Given the small sample size, it is nonetheless noteworthy that adjustment differences emerged across three groups. I expected that if the MBC analysis identified a reciprocal SNS activation cluster, children in this cluster would show the best adjustment outcomes. Examining adjustment differences across the 3-cluster model does not support this hypothesis, however, as children in the modest reciprocal SNS activation group (Cluster 1) showed the most internalizing problems across clusters. In addition, there was a marginally significant difference in internalizing symptoms between modest reciprocal SNS activators (Cluster 1) versus strong reciprocal activators (Cluster 2A), suggesting that extent of ANS reactivity is important to consider. It may be that simply showing a reciprocal response of the ANS is not enough, and a greater degree of PNS withdrawal is key to providing the physiological resources to effectively manage one's emotional experience. To my knowledge, no study using a person-centered approach has identified groups that reflect varying degrees of the same autonomic reactivity profile. However, this study can be contextualized within previous work that has considered a single branch of the ANS. Children in the modest reciprocal SNS activation group (Cluster 1) appear to have shown blunted PNS withdrawal, whereas those in the strong reciprocal activation group (Cluster 2A) showed heightened PNS withdrawal. Adequate PNS withdrawal is critical for the self-regulatory processes that support effective emotional and behavioral regulation in response to stress or challenge (Porges, 2011). In a study of young children, Calkins and Dedmond (2000) found that children identified as high-risk for future behavioral problems showed significantly less PNS withdrawal and more emotional and behavioral dysregulation, as compared to other children. Calkins and Keane (2004) measured children's PNS reactivity at two time points (2.5 and 4 years of age) and classified children into groups using a k-means cluster analysis. These authors found that, as compared to children who showed blunted PNS withdrawal at both time points, children who showed greater PNS withdrawal at both time points were significantly more socially skilled and showed significantly less negative affect and fewer externalizing behaviors. Taken together, these studies support the idea that children who experience blunted PNS withdrawal exhibit more adjustment difficulties then children who show a greater extent of PNS withdrawal.

In regards to social competence, there was a marginally significant difference between modest reciprocal SNS activators (Cluster 1) and coactivators (Cluster 2B). Contrary to hypotheses, children who showed PNS augmentation exhibited better social adjustment then other children. Children in the modest reciprocal SNS activation (Cluster 1) group showed the lowest level of social competence, whereas coactivators (Cluster 2B) exhibited the highest social competence. This finding contradicts El-Sheikh et al.'s (2009) framework, which holds that reciprocal SNS activation is advantageous and physiologically equips a child to manage environmental demands, whereas coactivation reflects physiological dysregulation and thus marks a vulnerability to maladjustment. Instead, these findings suggest that children who exhibit a modest degree of reciprocal SNS activation are at a disadvantage as compared to those that show coactivation. Children in the coactivation and modest reciprocal SNS activation groups showed similar levels of SNS activation, which suggests that differences in patterns of PNS responding, rather then SNS responding, may be most relevant to children's social functioning. Moreover, coactivators and modest reciprocal SNS activators showed levels of SNS activation that were similar to the sample-wide average of SNS reactivity, suggesting that these children showed a typical degree of SNS activation compared to the overall sample. Thus, it appears that for children with an average level of SNS activation, PNS augmentation may be more beneficial to social functioning then insufficient or blunted PNS withdrawal. This finding is especially interesting given that the majority of research (see Graziano & Derefinko, 2013) suggests that in community samples PNS withdrawal is beneficial to children's functioning. Although children in the modest reciprocal SNS activation group (Cluster 1) did show PNS withdrawal, it is possible that the degree of

PNS withdrawal was insufficient and thus more harmful then PNS activation. PNS augmentation involves applying the "vagal brake" which inhibits SNS arousal and functions to increase rest and digest processes facilitated by the PNS (Porges, 2011). PNS augmentation may be helpful for maintaining a subjective sense of feeling calm through PNS activation, and for some children this may be helpful for successful social engagement. Indeed, some evidence suggests that PNS augmentation is associated with better adjustment outcomes in children. PNS augmentation has been linked to more social competence (Blair, 2003) and fewer internalizing and externalizing problems and better behavioral self-regulation in children (Hastings et al., 2008). Consistent with these studies, this research suggests that PNS augmentation may be beneficial to children's social functioning, as children who showed PNS augmentation (combined with average SNS activation) exhibited the highest social competence across three clusters. According to Polyvagal theory, applying the vagal brake facilitates social engagement in circumstances in which the environment is perceived as safe (Porges, 2007, 2011). In this study, the person-centered analyses suggest the most socially competent children were those children whose physiological response involved applying the vagal brake in response to the mirror-tracing task. Consistent with Polyvagal theory, this research suggests that PNS activation may be beneficial when a child is faced with a challenging yet safe situation.

Examining adjustment differences across the 3-cluster solution raises questions about the utility of conceptualizing children's autonomic reactivity in terms of El-Sheikh et al.'s (2009) theoretical perspective. In their 2009 monograph, El-Sheikh and colleagues proposed the notion that ANS profiles characterized by reciprocal responding (i.e., reciprocal PNS activation and reciprocal SNS activation) are beneficial, whereas uncoordinated responding (i.e., coactivation or coinhibition) is harmful for child development. Interestingly, my findings suggest that understanding how children's autonomic reactivity influences their adjustment may require a more nuanced conceptualization of how the parasympathetic and sympathetic branches of the ANS respond together. Specifically, the extent or degree of reactivity may be important to consider. My dissertation provides preliminary evidence that there may be meaningful differences in autonomic reactivity across children who demonstrate the same autonomic profile, as defined by El-Sheikh et al. (2009). In this sample, children who showed modest reciprocal SNS activation (Cluster 1) exhibited marginally more internalizing symptoms then children who showed strong reciprocal SNS activation (Cluster 2A). Children who showed strong reciprocal SNS activation showed greater PNS withdrawal then children in the modest reciprocal SNS activation, and a greater degree of PNS withdrawal appears to be advantageous to children's emotional functioning. Rather then considering all children who showed reciprocal SNS activation to be similar, I distinguished between groups of children who showed different degrees of reciprocal SNS activation and was able to detect marginal, yet meaningful, differences across groups. This finding should be interpreted with caution, however, and should be replicated in a larger sample in the future.

Overall, the MBC results suggest that the degree or extent of PNS reactivity that children experience is important and relevant to adjustment. Children in Cluster 1 can be described as showing minimal or blunted PNS reactivity. Thirty-five children in Cluster 1 showed slight PNS withdrawal, one child showed slight PNS augmentation, and one child showed no change in PNS activity from rest to the challenge condition. Thus, every child in Cluster 1 showed a small degree of PNS response, and these children were identified as inherently different then children in Cluster 2. Much of the developmental literature on children's PNS reactivity has emphasized the distinction between PNS withdrawal versus augmentation. However, the 2-cluster model suggests that extent of PNS reactivity (e.g., blunted versus heightened) is important to consider when conceptualizing children's autonomic reactivity. Children who showed blunted PNS responding (including slight PNS withdrawal, no change, and slight PNS augmentation) were most similar to each other and thus classified into Cluster 1, whereas children in Cluster 2, who all showed heightened PNS reactivity (either heightened PNS withdrawal or heighted PNS augmentation) were most similar to each other in the model-based cluster results. Furthermore, children in all clusters showed SNS activation, and SNS reactivity did not vary across clusters in either the 2- or 3-cluster model. Thus, in this sample, differences in extent of PNS reactivity appear to be important in distinguishing groups of children based on their autonomic reactivity profiles.

Integrating variable-centered versus person-centered approaches

An important aim of this study was to consider whether variable-centered and person-centered analyses would yield similar results and by doing so consider whether these distinct analytic procedures offer a similar message about how children's autonomic reactivity is related to their adjustment. Importantly, a variable-centered analytic procedure is commonplace in research on children's autonomic reactivity. Decomposition of variable-centered interaction effects involves plotting simple slopes to estimate an average effect across approximated groups. By conducting person-centered analyses to identify ANS reactivity profile groups and applying this information to variable-centered analyses to examine adjustment differences, I was able to examine whether these distinct analytic procedures conveyed a similar message regarding how children's autonomic reactivity is related to their adjustment. For simplicity, I use the term person-centered analyses to refer to the set of analyses in which I conducted person-centered analyses and applied these results to variable-centered analyses to examine adjustment differences across clusters.

Based on my results, conceptualizing children's PNS x SNS reactivity in terms of profiles of autonomic reactivity seems to be most appropriate when distinct clusters or groups have been identified. Variable-centered analyses that consider the joint action of the PNS and SNS approximate groups based on levels of PNS and SNS reactivity. Although this technique is common in research on children's autonomic reactivity, the interpretation of such analyses may emphasize effects of autonomic profiles that are uncommon in the observed data. It may be helpful for future studies to incorporate a person-centered approach to confirm the presence of autonomic reactivity profile groups and to use this information when interpreting variable-centered interaction effects. Moreover, effects may not necessarily be linear, and simple slope analyses often assume an overall linear effect.

Overall, the two analytic approaches yielded somewhat different information. First, the findings regarding children's social competence convey different information. In the variable-centered results, children's PNS reactivity was unrelated to social competence, and higher SNS arousal was linked to more social competence. In contrast, the person-centered analyses suggest that differences in PNS responding are relevant to children social competence. Across the 2-cluster model, children in the heightened PNS reactivity group (Cluster 2) showed marginally more social competence then children who showed modest reciprocal SNS activation (Cluster 1), but SCLR was not significantly different across these groups. When social competence was compared across 3 clusters, children who showed coactivation (Cluster 2B) were more socially competent then those who showed modest reciprocal SNS activation (Cluster 1). These groups (Clusters 1 and 2B) showed very similar levels of SNS reactivity, which points to PNS reactivity as the factor weighing more heavily in distinguishing between these groups. Whereas the person-centered analyses suggest that differences in PNS reactivity are relevant to social competence, the variable-centered regression analysis did not identify PNS reactivity as relevant to children's social competence. Thus, the two approaches seem to provide different information about the autonomic processes that are most important for children's social competence. Since this sample included children who exhibited PNS withdrawal and augmentation, it is possible that examining the aggregate effect of PNS reactivity clouded the nature of how PNS responding is related to child adjustment in this sample.

Second, both the variable-centered and the person-centered results suggest that ANS functioning has implications for children's internalizing symptoms. In the variable-centered analyses, PNS withdrawal was associated with more concurrent internalizing symptoms when coupled with high SNS reactivity (see Figure 1). Although the variable-centered regression analyses used continuous measures of PNS and SNS reactivity, an attempt can be made to identify how the simple slope analyses map onto the autonomic profiles identified in the Doctrine of Autonomic Space (Berntson et al., 1991). This strategy has been used in previous research on children's PNS and SNS activity (e.g., Keller & El-Sheikh, 2009). According to the variable-centered regression results, for children who experience high SNS reactivity (i.e., SNS activation), PNS withdrawal is harmful and thus linked to more internalizing symptoms. PNS withdrawal combined with SNS activation maps onto reciprocal SNS activation (Berntson et al., 1991). Interestingly, this finding aligns with the person-centered analyses with a 2-cluster model. When only 2 clusters were considered, I examined adjustment differences between children in Cluster 1, who on average showed modest reciprocal SNS activation, and children in Cluster 2, who on average showed coactivation (i.e., PNS augmentation and SNS activation). Results indicated that children in the modest reciprocal SNS activation group (Cluster 1) showed more internalizing symptoms then coactivators (Cluster 2). In other words, across the variable- and person-centered results, findings suggest that the combination of PNS withdrawal and SNS activation (reciprocal SNS activation) is associated with more internalizing symptoms.

However, when internalizing symptoms were examined across 3 clusters, the results did not align with the simple slope analyses predicting Time 1 internalizing symptoms. When 3 clusters were considered, the largest difference in internalizing symptoms was detected between Cluster 1 (modest reciprocal SNS activation) and Cluster 2A (strong reciprocal SNS activation), which suggests that it is important to consider the extent of ANS reactivity. Importantly, the variable-centered simple slope analyses portray a linear relation between children's PNS reactivity and internalizing symptoms, whereas the person-centered results suggest a more complicated picture of how the joint action of the PNS and SNS is related to children's internalizing symptoms.

The variable-centered simple slope analyses suggest that at high SCLR, there is a linear effect of PNS reactivity such that more PNS withdrawal is harmful (see Figure 1). However, children in Cluster 2A showed greater PNS withdrawal and fewer internalizing symptoms then children in Cluster 1. Given that the simple slope analysis suggests a linear effect of PNS reactivity, this effect theoretically would continue along a linear path beyond the low RSAR plotted in Figure 1, meaning that for children who exhibit higher SNS activation, greater PNS withdrawal would be related to more internalizing symptoms. However, the person-centered analysis with three clusters suggests that greater PNS withdrawal is beneficial. In this community sample of children, greater levels of PNS withdrawal appear to protect youth from internalizing symptoms; however, it is possible that the vagus nerve may withdraw too much. Indeed, exaggerated PNS withdrawal is associated with problems related to emotional and behavioral functioning (Beauchaine, 2001; Gazelle & Druhen, 2009) and children with high internalizing problems have been shown to exhibit greater RSA withdrawal then children without internalizing problems (Boyce et al., 2001). Thus, it may be useful to consider curvilinear effects of autonomic reactivity. Examining curvilinear effects was beyond the scope of this dissertation, but my person-centered analysis with 3 clusters lend tentative support for the idea that the relations autonomic reactivity and adjustment may not be linear. Indeed, Keller and El-Sheikh (2009) have documented nonlinear effects of autonomic reactivity in children, and others have observed nonlinear effects of autonomic functioning in adults (Kogan, Gruber, Shallcross, Ford, & Mauss, 2013).

Furthermore, the person-centered results (for both the 2- and 3-cluster models) do not confirm the information that is conveyed by the low SCLR slope in the variable-centered model of concurrent internalizing symptoms (see Figure 1). The MBC analysis did not identify a cluster of children who on average showed coinhibition (PNS withdrawal and low SNS reactivity) or a cluster of children who exhibited reciprocal PNS activation (PNS augmentation and low SNS reactivity). Thus, the simple slope analyses convey effects for approximated groups of children that do not seem to exist in the data. This discrepancy presents a conundrum for considering how to best conceptualize this study in the context of previous research on children's autonomic reactivity, which has largely included variable-centered analyses. It appears that variable-centered analyses of autonomic reactivity may suggest effects at levels of reactivity, or profiles of reactivity, that are uncommon in the sample observed and potentially in the true population of children. Finally, the simple slope analyses estimate the effect of PNS reactivity on internalizing symptoms at low and high levels of SCLR, which again suggests the presence of approximated groups, but SCLR was not significantly different across clusters in either the 2-cluster or 3-cluster model. Thus, in this instance, the very nature of plotting an effect at high and low levels of autonomic reactivity, which is common in developmental research, seems to emphasize a distinction that was not supported by the person-centered analysis. Since SCLR did not vary across clusters, the variable-centered simple slope analyses, which suggest an effect of PNS reactivity at high and low levels of SCLR, seem to convey a message that was not confirmed by the person-centered analyses.

Based on the results of this study, I consider person-centered analyses to be a useful and important approach to examining children's autonomic reactivity profiles. Researchers aiming to conceptualize the relations between children's autonomic reactivity profiles and specific developmental outcomes would likely benefit from incorporating person-centered techniques. A conservative approach would be to include a person-centered analysis to confirm the existence of distinct autonomic profile groups within the sample, and to also conduct variable-centered analyses. Without a person-centered approach, researchers may want to be cautious in interpreting effects for each of the four autonomic profiles previously identified in the literature (see Berntson et al., 1991; El-Sheikh et al., 2009).

Limitations

It is important to consider the most notable limitations of this study. First, a small sample size limited my statistical power. More statistical power would have increased the likelihood that I could detect effects of autonomic reactivity that truly exist. In addition, with a larger sample, I would expect that a cluster analysis might have identified more clusters based on children's ANS reactivity profiles. With larger clusters, group differences in adjustment may have been more apparent and statistically detectable. Although adjustment differences were only marginally significant across clusters, this may be due to low power. Nonetheless, it is useful to consider how adjustment varied across clusters and the potential practical and theoretical implications of this study, while keeping in mind that these findings are very tentative and should be replicated in larger, more diverse samples.

The small sample size also limited the number of factors that could be considered in the analyses in this study. Clearly, a child's PNS and SNS reactivity are not the only factors that contribute to adjustment outcomes. Future research should build upon these findings and investigate how the joint action of children's PNS and SNS may interact with additional factors (e.g., environmental factors) to influence adjustment in middle childhood. In addition, future work should consider how autonomic reactivity profiles vary across gender. Previous research (e.g., Erath et al., 2011) has identified gender differences in the effects of autonomic reactivity; however, the small sample size prevented me from considering gender as a moderator. This sample was predominately Caucasian, which limits the generalizability of these findings. For example, racial differences exist in SCL activity and this is thought to be a result of the inverse relation between darker skin pigmentation and number of sweat glands (Boucsein, 2011).

An additional potential limitation of this study is that variable-centered analyses were used to examine differences across autonomic profile clusters. Though person-centered analyses were used to classify children, I then considered average differences in adjustment across groups of children. An important next step will be to use a person-centered technique to consider how autonomic profile clusters differ on specific developmental outcomes. For example, along with autonomic reactivity scores, one or more indicators of adjustment could be included in the set of clustering variables in a MBC analysis.

Finally, this study examined ANS reactivity in response to a single type of task. Previous research (e.g., Obradović et al., 2011) has documented differences in patterns of reactivity across distinct types of laboratory challenge tasks. Thus, a potentially fruitful next step would be to use person-centered techniques to identify autonomic reactivity profile groups in response to distinct types of tasks, and to examine patterns of reactivity across these contexts.

Conclusion

This study extends research on children’s autonomic reactivity and provides new information about the physiological processes that contribute to child adjustment. Incorporating both variable-centered and person-centered analytic approaches, this study suggests that the joint action of children’s parasympathetic and sympathetic nervous systems is relevant to children’s emotional and social functioning. Importantly, the person-centered model-based cluster analysis identified distinct groups of children based on their autonomic reactivity profiles. However, this study identified only two (i.e., reciprocal SNS activation, coactivation) of four autonomic profiles that have been previously identified in the literature and are assumed to be represented in the variable-centered simple slope analyses. Thus, this research confirms that it is possible to identify distinct profiles of autonomic reactivity in children and suggests that in the future, it may be helpful to confirm the presence of distinct autonomic profile groups when investigating the effects of children’s autonomic reactivity profiles based on variable-centered analyses.

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Table 1

Descriptive statistics for study variables

	Mean	Standard Deviation	Minimum	Maximum
RSAR	-0.004	0.25	-0.47	0.82
SCLR	0.86	0.97	-1.02	3.82
Time 1 Internalizing	6.78	5.75	0.00	28.00
Time 1 Externalizing	6.17	5.82	0.00	26.00
Time 1 Social Competence	8.98	2.55	0.00	14.00
Time 2 Internalizing	4.79	4.24	0.00	20.00
Time 2 Externalizing	4.62	4.40	0.00	16.00
Time 2 Social Competence	9.09	2.01	5.00	14.00

Note. RSAR = Respiratory Sinus Arrhythmia Reactivity. SCLR = Skin conductance Level Reactivity.

Table 2

Bivariate correlations

Variable	1	2	3	4	5	6	7	8
1. RSAR	—	-.01	.01	.03	.07	.07	-.01	-.13
2. SCLR		—	.03	-.02	.27*	.06	-.09	-.03
3. Time 1 Internalizing			—	.60***	-.01	.66***	.38**	-.08
4. Time 1 Externalizing				—	-.11	.39**	.72***	-.22
5. Time 1 Social Competence					—	.09	-.04	.50***
6. Time 2 Internalizing						—	.58***	-.12
7. Time 2 Externalizing							—	-.20
8. Time 2 Social Competence								—

Note. RSAR = Respiratory Sinus Arrhythmia Reactivity. SCLR = Skin Conductance Level Reactivity.
* *p* < .05, ** *p* < .01, *** *p* <.001

Table 3

Regression Coefficients for Child Autonomic Reactivity Predicting Adjustment

	T1 Internalizing Symptoms		T1 Externalizing Symptoms		T1 Social Competence	
	β [95% CI]	R^2	β [95% CI]	R^2	β [95% CI]	R^2
Sex	-.19 [-.44, .06]	.10, *p* = .22	-.25* [-.48, -.03]	.08, *p* = .22	-.01 [-.25, .23]	.08, *p* = .18
RSAR	.11 [-.11, .33]		.07 [-.14, .29]		.10 [-.13, .33]	
SCLR	.00 [-.39, .40]		.00 [-.29, .29]		.26* [.01, .50]	
RSAR x SCLR	-.22* [-.43, -.01]		-.11 [-.32, .10]		-.06 [-.28, .15]	
	T2 Internalizing Symptoms		T2 Externalizing Symptoms		T2 Social Competence	
T1 adjustment	.62* [.42, .83]	.53, *p* < .001	.77* [.58, .96]	.59, *p* < .001	.58* [.41, .75]	.34, *p* = .002
Sex	.02 [-.17, .20]		.10 [-.07, .26]		.04 [-.19, .26]	
RSAR	.15 [-.05, .35]		-.01 [-.14, .13]		-.19 [-.48, .10]	
SCLR	.03 [-.16, .22]		-.16^ [-.33, .01]		-.21 [-.46, .04]	
RSAR x SCLR	-.35* [-.65, -.04]		-.05 [-.29, .19]		.05 [-.37, .47]	

Note. RSAR = Respiratory Sinus Arrhythmia Reactivity. SCLR = Skin Conductance Level Reactivity
* 95% CI does not contain zero. ^ 90% CI does not contain zero.

Table 4

Descriptive statistics for autonomic reactivity

<table>
<tr><td></td><td colspan="6">Total Sample (N = 64)</td></tr>
<tr><td>RSAR</td><td colspan="6">M = -.004, SD = .25</td></tr>
<tr><td>SCLR</td><td colspan="6">M = .86, SD = .97</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td></td><td colspan="6">2-Cluster Solution</td></tr>
<tr><td></td><td colspan="3">Cluster 1 (n = 37)</td><td colspan="3">Cluster 2 (n = 27)</td></tr>
<tr><td>RSAR</td><td colspan="3">M = -.030, SD = .022</td><td colspan="3">M = .033, SD = .38</td></tr>
<tr><td>SCLR</td><td colspan="3">M = .788, SD = 1.00</td><td colspan="3">M = .951, SD = .92</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td></td><td colspan="6">3-Cluster Solution</td></tr>
<tr><td></td><td colspan="2">Cluster 1 (n = 37)</td><td colspan="2">Cluster 2A (n = 16)</td><td colspan="2">Cluster 2B (n = 11)</td></tr>
<tr><td>RSAR</td><td colspan="2">M = -.03[a], SD = .022</td><td colspan="2">M = -.24[a], SD = .12</td><td colspan="2">M = .43[a], SD = .27</td></tr>
<tr><td>SCLR</td><td colspan="2">M = .79, SD = 1.00</td><td colspan="2">M = 1.07, SD = 1.04</td><td colspan="2">M = .78, SD = .72</td></tr>
</table>

Note. RSAR = Respiratory Sinus Arrhythmia Reactivity. SCLR = Skin Conductance Level Reactivity. [a] significant difference at $p < .05$ level.

RSAR x SCLR 2-way Interaction Predicting Time 1 Internalizing Symptoms

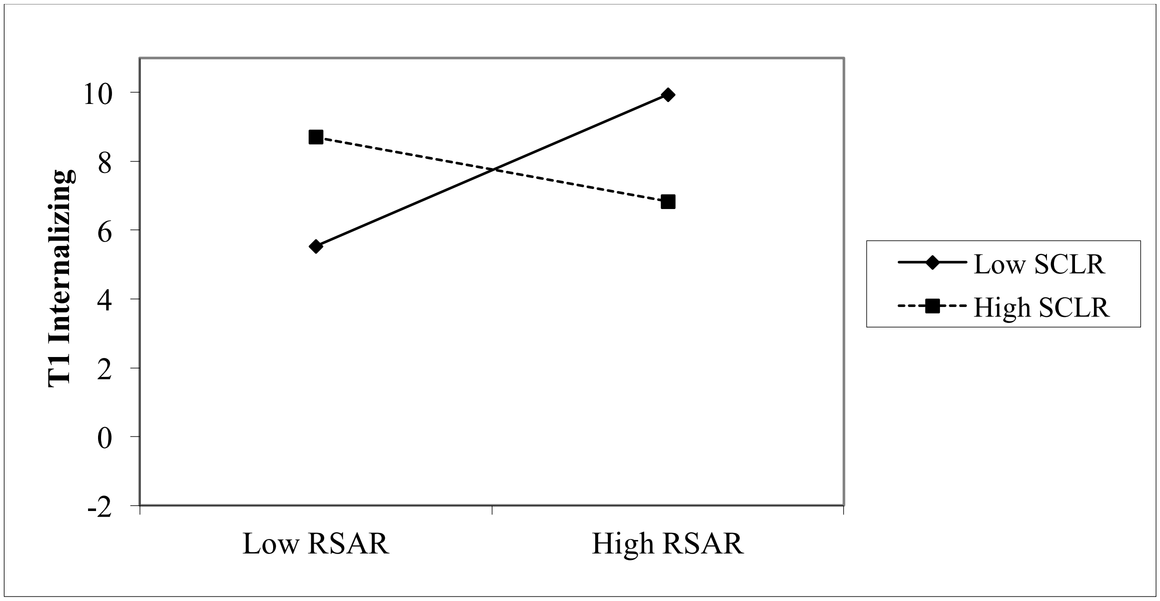

Figure 1. Concurrent internalizing symptoms as a function of respiratory sinus arrhythmia reactivity (RSAR) and skin conductance level reactivity (SCLR). Low and high RSAR are graphed at 1 *SD* below and above the mean, respectively. Low RSAR represents RSA withdrawal, whereas high RSA represents RSA augmentation. Low and high SCLR are graphed at 1 *SD* below and above the mean, respectively.

RSAR x SCLR 2-way Interaction Predicting Time 2 Internalizing Symptoms

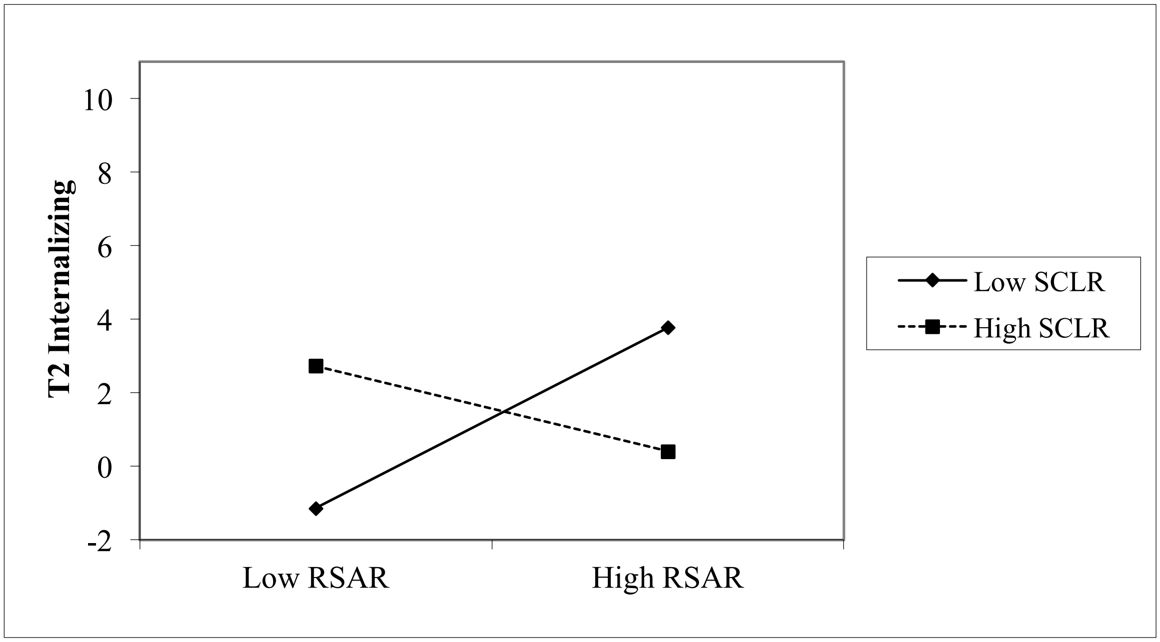

Figure 2. Change in internalizing symptoms as a function of respiratory sinus arrhythmia reactivity (RSAR) and skin conductance level reactivity (SCLR). Low and high RSAR are graphed at 1 *SD* below and above the mean, respectively. Low RSAR represents RSA withdrawal, whereas high RSA represents RSA augmentation. Low and high SCLR are graphed at 1 *SD* below and above the mean, respectively.

Adjustment differences across 2-cluster model

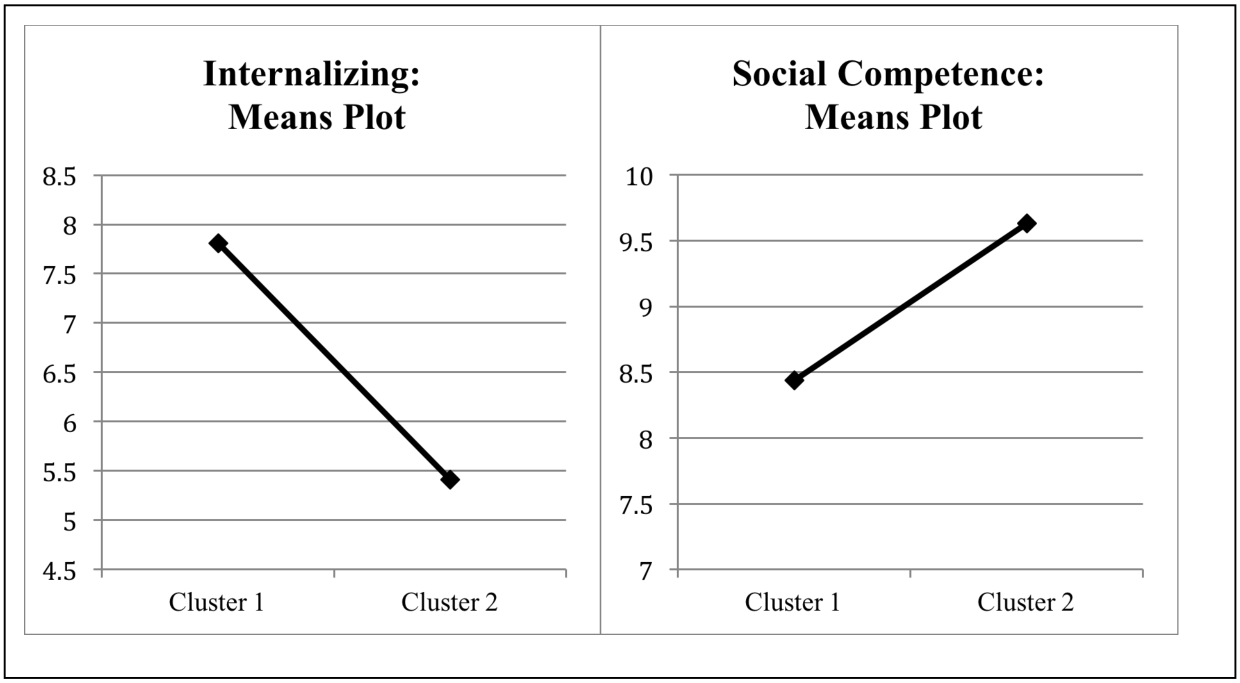

Figure 3. Marginally significant differences in internalizing symptoms and social competence across 2 clusters. Cluster 1: Modest reciprocal SNS activation. Cluster 2: Heightened PNS reactivity combined with SNS activation.

Adjustment across 3-cluster model

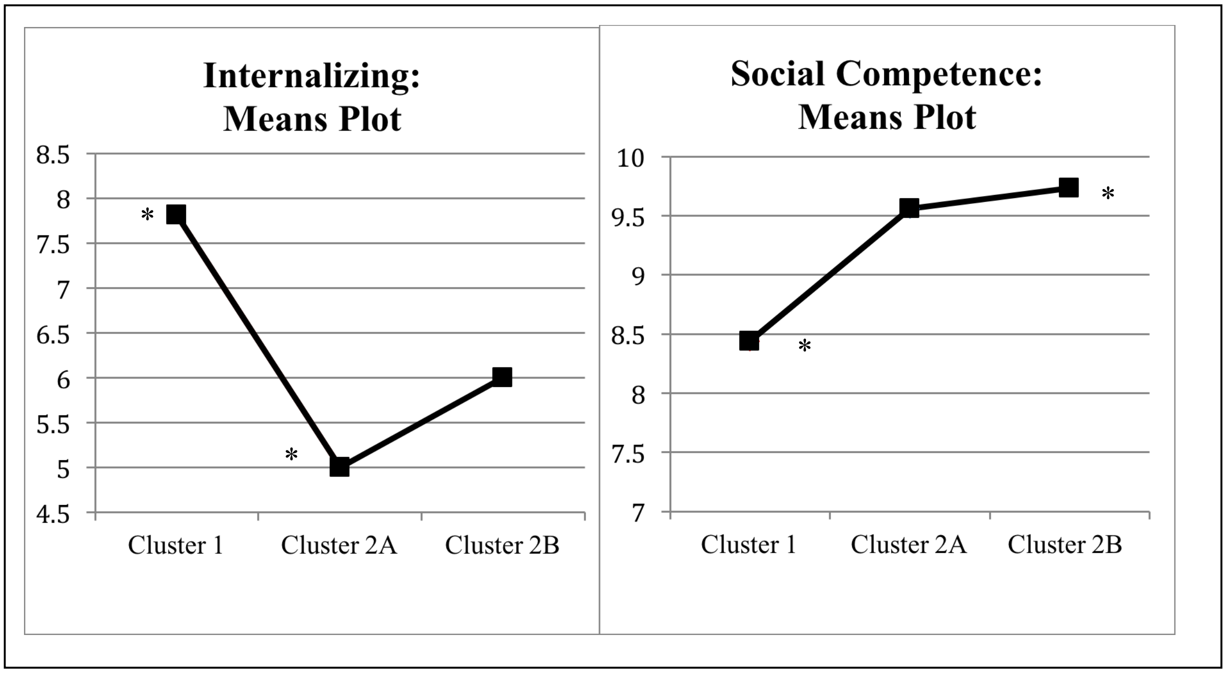

Figure 4. Marginally significant differences in internalizing symptoms and social competence are denoted with an asterik. Cluster 1: Modest reciprocal SNS activation group. Cluster 2A: Strong reciprocal SNS activation group. Cluster 2B: Coactivation group.