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The goals of this study were (a) to examine children's normative sympathetic and parasympathetic autonomic nervous system (ANS) responses toward distinct emotional and cognitive laboratory challenges from preschool to grade 1 and to compare the magnitude of ANS responses across these challenges, (b) to examine the associations between sympathetic and parasympathetic ANS responses during laboratory challenges, (c) to examine stability (or instability) and continuity (or change) in ANS functioning from preschool to grade 1, and (d) to examine profiles of children with distinct patterns of sympathetic and parasympathetic functioning in preschool, and to test whether these profiles differ with respect to children's self-regulation outcomes in preschool and one year later.

Two hundred and seventy-eight children and their caregivers (96% mothers) participated in laboratory assessments when children were in preschool, kindergarten, and first grade, and teachers reported on children's behavior when children were in kindergarten. Children's sympathetic and parasympathetic ANS responses were measured during 2 emotionally demanding and 2 cognitively demanding laboratory challenges in preschool, kindergarten, and first grade. Three self-regulation outcomes were assessed: (a) executive functioning, (b) emotional reactivity/regulation, and (c) behavioral regulation in the classroom. In preschool, executive functioning was measured using 3 tasks designed to assess working memory, inhibitory control, and cognitive

flexibility; emotion regulation was observed during frustrating challenges; and mothers reported on children's emotional reactivity. In kindergarten, teachers reported on children's emotional reactivity and behavioral regulation composed of attention control, discipline/persistence, and work habits in the classroom.

Although children, on average, demonstrated parasympathetic inhibition (RSA withdrawal) across all challenges, they showed sympathetic responsivity only during certain challenges. In particular, the cognitively demanding problem-solving Tangrams task, on average, elicited sympathetic activation (PEP shortening) across all time points, whereas the less challenging Go/No-Go task, did not lead to a change in sympathetic activity in preschool or kindergarten but led to sympathetic activation in grade 1. Four blocked-goal frustration tasks (Locked Box, Impossible to Open Gift, Puzzle Box, & Broken Toy) did not lead to a change in sympathetic ANS activity from baseline to task, whereas the two interpersonally upsetting tasks (Toy Removal and Not Sharing) led to sympathetic inhibition (PEP lengthening). There was a positive association between sympathetic and parasympathetic responsivity during only certain challenges (e.g., Tangrams & Locked Box in preschool, Not Sharing & Impossible to Open Gift in kindergarten), such that greater sympathetic activation was associated with greater parasympathetic withdrawal. There was moderate stability in ANS children's responsivity across different tasks within the same assessment. There was modest stability in parasympathetic ANS responses but no stability in sympathetic responses toward laboratory challenges across time. In regards to developmental continuity/change, both baseline sympathetic and parasympathetic ANS activity increased from preschool to

first grade. However, there was no clear pattern of change in children's ANS responsivity toward the cognitively demanding laboratory challenges over time, suggesting that mean-level ANS responsivity scores were mostly continuous over time. Finally, the latent profile analyses yielded four profiles of ANS functioning: (a) a buffered profile with moderate ANS responsivity, (b) a sensitive profile with high ANS responsivity, (c) a coinhibition profile, and (d) a vigilant profile. Children in the sensitive profile demonstrated better executive functioning than children in the buffered and the vigilant groups. The buffered profile showed lower levels of emotional reactivity than the sensitive profile, and better behavioral regulation than the sensitive, coinhibition, and vigilant groups. Profiles did not differ with respect to mothers' report of emotional reactivity or observed emotion regulation.

AUTONOMIC NERVOUS SYSTEM FUNCTIONING IN EARLY CHILDHOOD: RESPONSES TO LABORATORY CHALLENGES, INDIVIDUAL DIFFERENCES, AND RELATIONS TO CHILD SELF-REGULATION

by

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Approved by

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Committee Chair

To my love, Ali Üneri.

Thank you for inspiring me to have big dreams and swimming with me through each wave even from far distances.

APPROVAL PAGE

This dissertation written by SELIN ZEYTINOGLU has been approved by the following committee of the Faculty of The Graduate School at the University of North Carolina at Greensboro.

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CHAPTER I

INTRODUCTION

The ability to respond effectively to everyday challenges is critical for adaptive functioning. On a typical day, children experience a variety of challenges including those that are emotionally upsetting or frustrating such as a peer taking away a loved toy or not being able to reach a goal, as well as those that are cognitively demanding such as solving difficult problems or concentrating during a prolonged and repetitive task. One prominent approach adopted by developmental researchers for identifying pathways to adaptive and maladaptive functioning has been examining whether ordinary variations in children's responses to distinct types of challenges predict important life outcomes such as social-functioning and academic success. Children's responses to emotional and cognitive challenges have been studied largely separately under the rubrics of emotion regulation or cognitive control, yet findings from both lines of research have demonstrated repeatedly that there are large, early emerging, and relatively enduring individual differences in how children respond to challenges, and that such variations are meaningful predictors of academic achievement (Graziano, Reavis, Keane, & Calkins, 2007), social competence (Masten et al., 2012), behavioral adjustment (Kim, Nordling, Yoon, Boldt, & Kochanska, 2013), and health, wealth and public safety outcomes (Moffitt et al., 2011).

Children respond to challenges at integrated, yet distinct levels, particularly at the biological, psychological, and behavioral levels (Calkins & Marcovitch, 2010). Much of the research on children's responses to emotional and cognitive challenges focused on variations in *behaviors* such as the extent to which one can attend, persist, engage in a task, or display positively or negatively valenced facial expressions. However, a large body of theoretical and empirical work in neuroscience as well as in stress physiology research underscores the importance of examining children's neural and/or peripheral physiological functioning because these processes can often provide novel information regarding the mechanisms and processes that lead to adaptive functioning. For example, examining autonomic nervous system responses can shed light on children's internal physiological regulation to cope with challenges, which may not necessarily be reflected in children's facial expressions or coping behaviors. Likewise, this line of work can demonstrate processes in which the "outside environment," such as the type of caregiving one receives, can "get under the skin" by affecting individuals' neural functioning and/or stress physiology, which can then mediate pathways to adaptive functioning (Gunnar & Quevedo, 2007). Notably, similar to the variations in children's behavioral responses to challenges, there are large individual differences in children's physiological responses to challenges or stressors (Ellis, Jackson, & Boyce, 2006). As such, although some children may show very powerful or elevated physiological responses to quite familiar and mildly stressful challenges, others may show very mild responses to novel and highly stressful challenges. These responses are often referred to as individuals' "stress responsivity" or the characteristic way of responding to challenges physiologically. Understanding the origins of individual differences in children's stress responsivity, as well as the functions of such responses is an important quest for understanding adaptive functioning.

Physiological responses to challenges are supported by an integrated and complex network of systems (i.e., central, autonomic, and endocrine), which together refer to stress response systems (Ellis, Jackson, & Boyce, 2006). One of the stress response systems that most readily and pervasively responds to external challenges is the autonomic nervous system (ANS; Kreibig, 2010). ANS coordinates the rapid communication between the central nervous system, most notably the brain, and the internal organs and muscle tissues, and plays an important role in preparing and energizing the body to deal with external challenges (Berntson, Quigley, & Lozano, 2007). During external challenges, ANS quickly suppresses internal demands to effectively respond to external challenges, whereas during calm states it serves the needs of the internal organs (Porges, 2011). The ANS oversees these functions via the coordination of its two branches, the sympathetic nervous system and parasympathetic nervous system. The sympathetic nervous system mobilizes the body to effectively respond to external challenges, whereas the parasympathetic nervous system down-regulates the body's energy resources to promote the body's growth and restoration (Porges, 2011). As such, both of these branches play an important role in supporting individuals' ability to respond to stressors.

There are at least three reasons why studying individual differences in children's ANS functioning is important. The first reason is that particular indices of ANS functioning may reflect individuals' trait-like or characteristic way of anticipating and/or dealing with stressors or external challenges, which may mediate pathways to adaptive or maladaptive outcomes. In particular, a multitude of contemporary theoretical perspectives posit that certain physiological states, such as basal levels of ANS functioning when individuals are at a resting state (e.g., watching a relaxing video), and/or processes, such as changes in ANS functioning as a response to external challenges (e.g., interpersonal conflict), may contribute to specific adaptive and maladaptive outcomes. For example, both the Polyvagal Theory (Porges, 2011) and the Neurovisceral Integration Model (e.g., Thayer, Hansen, Saus-Rose, & Johnsen, 2009) suggest that basal parasympathetic ANS functioning may index the integration between the heart and the brain and reflect individuals' capacity for self-regulation. A growing body of work provided empirical support for this proposition, showing direct associations between basal parasympathetic ANS activity and emotional and cognitive aspects of self-regulation (for a metaanalysis, see Holzman & Bridgett, 2017). In light of these two theoretical perspectives, researchers have demonstrated empirically that basal levels of sympathetic ANS functioning as well as changes in parasympathetic and sympathetic ANS activity during laboratory challenges may also reflect a range of adaptive and maladaptive processes (e.g., Beauchaine, Gatzke-Kopp, & Mead, 2007; Calkins, Graziano, & Keane, 2007). An important implication of this line of work for the development of prevention and interventions is that if certain aspects of ANS functioning serve as biomarkers of adaptive and maladaptive developmental outcomes, then it may be possible to develop biologically-informed strategies for enhancing children's adaptive functioning; for example, by assessing and improving children's biological capacity for effective self-regulation.

The second reason why studying children's ANS functioning may be important is because a growing body of theoretical and empirical work support the view that contextual experiences including the quality of the caregiving experiences contribute to the emergence of individual differences in stress responsivity including ANS functioning, which in turn may mediate pathways to adaptive or maladaptive outcomes. Examples of early work in this area include research that supports: (a) the "stress inoculation" hypothesis with evidence showing that early experience of contextual adversity or stress serve as a vaccine to prepare individuals to deal with later stress (e.g., Levine, 1962; see Russo, Murrough, Han, Charney, & Nestler, 2012) and (b) the view that environmental stress alters physiological functioning with evidence showing that exposure to early adversity such as neglectful or abusive caregiving is linked with heightened (e.g., Cicchetti & Rogosch, 2001) or diminished physiological reactions to stressors (e.g., Fernald, Burke, & Gunnar, 2008; for a review see Obradović, 2012). Likewise, contemporary perspectives including the Biological Sensitivity to Context theory (Boyce & Ellis, 2005) and the Adaptive Calibration Model (Del Giudice, Ellis, & Shirtcliff, 2011) offer detailed alternative accounts on how specific contextual experiences may contribute to the emergence of different patterns of stress responsivity. According to the Biological Sensitivity to Context theory, the quality of the environment and children's stress physiology likely has a curvilinear relation, such that both highly nurturing and highly threatening environments lead to heightened sensitivity, whereas environments that are neither sensitive nor insensitive lead to low sensitivity (Boyce & Ellis, 2005). Extending this theory, the Adaptive Calibration Model describes four specific environments differing in stress levels, ranging from low stress to severe/traumatic, that lead to four distinct profiles of stress responsivity: sensitive, buffered, vigilant, and unemotional (Del Giudice, Ellis, & Shirtcliff, 2011). Notably, there are also alternative theoretical propositions that detail the proximal processes through which caregiving may influence the development of children's physiological responses. For example, caregivers' emotional sensitivity and responsiveness to infants' needs and distress have been proposed to contribute to children's ability to build internal capacities for exercising effective physiological regulation (e.g., Perry, Calkins, & Bell, 2016). Overall, these advancements in theory allow researchers to test alternative hypotheses regarding how quality of context may influence individual differences in children's autonomic nervous system functioning. Examining the relations between specific aspects of the context and children's ANS functioning can ultimately help researchers understand the origins of different profiles or patterns of ANS functioning linked with adaptive and maladaptive outcomes.

The third reason why studying children's ANS functioning is important and may help contribute to both basic science and intervention work is because children with distinct patterns of ANS functioning may be influenced by the quality of context differentially. The notion that children's ANS functioning would moderate the influence of contextual influences in leading to different outcomes have been emphasized across a variety of theoretical perspectives. Based on the diathesis-stress model (see Monroe &

Simons, 1991), one can argue that certain patterns of ANS functioning may act as a "vulnerability" factor and therefore predispose children to be affected more negatively by adverse environmental experiences. In contrast, based on the idea that certain aspects of ANS functioning reflect effective physiological regulation, one can expect children who experience such patterns of ANS functioning to be protected against the negative influences of adverse environments because they would physiologically regulate themselves effectively in dealing with adverse circumstances (e.g., Perry, Calkins, Nelson, Leerkes, & Marcovitch, 2012). Moreover, two evolutionary-based perspectives, Differential Susceptibility (Belsky, 2005) and Biological Sensitivity to Context theories (Boyce & Ellis, 2005), suggest that a pattern of heightened ANS responses may reflect susceptibility or sensitivity to contextual influences, and therefore predispose children to be more susceptible than others to the quality of the environmental experiences, such that children with this heightened ANS responses would be affected more negatively by stressful, adverse experiences but also would benefit more from positive experiences, compared to children with dampened physiological responses.

Despite the richness in testable competing theoretical perspectives and the advancements in methodology for assessing ANS functioning, there are still important gaps within the current state of the literature. The first important gap is that, although both sympathetic and parasympathetic branches of the ANS are implicated in the production of a wide spectrum of responses in dealing with external challenges, the vast majority of research on children's ANS functioning examined children's parasympathetic ANS functioning only, without including assessments of children's sympathetic ANS functioning. Limited work focused on children's sympathetic ANS functioning, and even far less work examined children's sympathetic and parasympathetic ANS functioning simultaneously within the same study. Notably, basic developmental questions that have been answered for children's parasympathetic ANS functioning are yet to be answered for children's sympathetic ANS functioning. For example, less is known about children's normative sympathetic ANS response patterns towards different challenges and whether sympathetic ANS responses are stable and/or continuous over time. Moreover, given the scarcity of work examining children's sympathetic and parasympathetic ANS functioning together, less is known about the relations between children's sympathetic and parasympathetic ANS functioning during challenges. Based on the idea that an association between sympathetic and parasympathetic responsivity to challenge indicates the reciprocal functioning of the two branches of the ANS, this study will examine the associations between sympathetic and parasympathetic responsivity across different tasks to identify contexts that lead to reciprocal functioning of the two branches.

The second important gap in the literature is that although a multitude of prominent theories on ANS functioning, including the Polyvagal Theory (Porges, 2011) and the Neurovisceral Integration Model (Smith, Thayer, Khalsa, & Lane, 2017) propose that ANS responses are context-dependent, less research has been devoted to understanding children's ANS functioning across different laboratory challenges. Examining children's ANS functioning across different laboratory challenges is important for several reasons. First, examining children's ANS functioning across different laboratory challenges would be necessary for understanding whether the associations between children's ANS functioning and particular outcomes related to adaptive functioning depend on the context that ANS functioning has been assessed. For example, it is possible that elevated physiological responses, such as greater sympathetic activation and greater parasympathetic withdrawal, may be adaptive for dealing with certain kinds of challenges that require active mobilization of the body's resources, but may not be adaptive when responding to mildly challenging tasks. Therefore, although heightened ANS responses during one type of challenge may predict adaptive outcomes, the same kind of ANS response during another challenge may predict maladaptive outcomes. The context-dependency of ANS responses may explain the mixed findings regarding the links between particular indices of ANS functioning and children's adjustment. For example, previous research has linked greater parasympathetic inhibition (vagal withdrawal) with both lower and higher levels of externalizing problems (e.g., Calkins & Keane, 2004; Hinnant & El-Sheikh, 2009, respectively). Given that these contradictory findings may be a function of the context during which ANS functioning has been observed, an initial step towards understanding when ANS responsivity is linked with adaptive or maladaptive outcomes would be to investigate systematically the normative ANS responses to distinct laboratory challenges.

Another important reason for examining children's ANS functioning across different laboratory challenges is that children's characteristic way of responding to certain kinds of challenges, but not others, may determine how they are influenced by the context in which they live. For example, it has been shown that children's ANS responses to two different types of laboratory challenges, an interpersonal challenge and a cognitive challenge, moderated the influence of marital conflict on children's adaptive functioning in different ways (Obradović et al., 2010). Specifically, although high ANS responsivity during the interpersonal task acted as a protective factor against marital conflict, high ANS responsivity during the cognitive task acted as biological sensitivity to context factor such that it led to better outcomes in low conflict and worse outcomes in high conflict. One explanation provided for these findings was that greater ANS responsivity to laboratory challenges that are more similar to the real-life adversities that children encounter may serve as a buffer against the negative influences of such adversities; whereas greater ANS responsivity to non-interpersonal, cognitive challenges may reflect overall biological openness or proneness to contextual influences. Given the importance of this line of work, advancing our understanding of whether children's ANS responses to different challenges moderate certain contextual influences requires a better understanding on how distinct challenges influence children's ANS functioning.

Given that understanding children's sympathetic and parasympathetic ANS responses to different types of everyday challenges would be important for identifying the pathways towards adaptive functioning, the overarching goal of this dissertation is to systematically investigate children's sympathetic and parasympathetic ANS responses to laboratory challenges from 4 to 6 years of age, corresponding to the window of time between preschool and first grade. Towards this goal, the first aim of this study is to examine children's ANS responses to two distinct categories of laboratory challenges, emotion regulation and cognitive control tasks, across the early childhood period. Within each of these categories of challenges, children's responses will further be examined across 2 distinct types of tasks. The two types of emotion regulation tasks will include: frustrating obstacles that are either too difficult or impossible to resolve, and interpersonally upsetting tasks. The two types of cognitive tasks will include: a spatial problem-solving tangrams task, and an inhibitory control Go/No-Go task. This study design, particularly the inclusion of two distinct types of emotion regulation and cognitive control challenges, will be advantageous for understanding children's sympathetic and parasympathetic ANS responses toward different types of emotional and cognitive challenges. Obrist's (1981) active and passive coping approach and the Motivational Intensity Theory (see Wright & Kirby, 2001) are used to guide predictions regarding children's sympathetic responses to laboratory challenges, whereas the Polyvagal Theory (Porges, 2011) and the Neurovisceral Integration Model (Thayer et al., 2009) guide the hypotheses on children's parasympathetic responses to challenges. Overall, this line of investigation has potential for advancing our understanding regarding (a) which challenges lead to the activation or inhibition of the sympathetic and parasympathetic systems, and (b) whether laboratory challenges differ with respect to the magnitude of physiological responses they elicit.

The second goal of this study is to examine the associations between children's sympathetic and parasympathetic ANS responses across different laboratory challenges. An early assumption on ANS was that its two branches are regulated reciprocally by the central nervous system, such that increases in the activation of one branch would correspond to increases in the inhibition of the other branch (Fulton, 1949). This view likely gained popularity because the influence of the two branches of the ANS on internal organs and muscles, especially those controlled by lower-level reflex systems, are often antagonistic (Porges, 2011). For example, the sympathetic branch accelerates the heart, whereas the parasympathetic nervous system slows it. However, there is ample evidence suggesting that higher level neural systems control these two branches in a rather flexible way leading to reciprocal, coactivational, coinhibitional, or independent patterns of activities (Berntson, Quigley & Lozano, 2007). Although the functioning of the two branches are orthogonal, during certain types of challenges that may require active engagement or mobilization, these two branches may function reciprocally with one another with increases in sympathetic activation paralleling parasympathetic inhibition. In order to gain a greater understanding on when these two systems work reciprocally, the associations between children's sympathetic and parasympathetic responses will be examined across distinct tasks.

The third goal of this study is to examine the stability (instability) and continuity (or change) in children's sympathetic and parasympathetic responses to different laboratory challenges from 4 to 6 years of age. Examining the stability in children's ANS responses to different types of challenges is important for two reasons. First, examining stability is critical for understanding the reliability of different laboratory measures. Evidence of longitudinal stability in individuals' responses to laboratory tasks may suggest that the measures show some degree of reliability. As such, this line of investigation can help identify laboratory tasks that allow for measuring ANS responsivity more consistently across time. Second, examining stability is also important for understanding development. For example, individual differences to certain laboratory tasks may be stable early in development (from age 4 to age 5), whereas for others, they may become stable only later in early childhood (from age 5 to age 6). Thus, examining when individual differences become more stable across time can advance our understanding on when during development children start to show more trait-like, characteristic way of dealing with certain types of challenges.

In regards to the continuity and discontinuity in children's ANS functioning, more work has examined change in baseline sympathetic and parasympathetic functioning (e.g., Esposito, Koss, Donzella, & Gunnar, 2016), but few studies examined the development of children's ANS responses across different tasks. One of the advantages of the design of this study is that two of the laboratory challenges (i.e., Tangrams and Go/No-Go) have been used across the 3 assessments, and therefore results showing continuity or change in ANS responses during these challenges would likely be attributable to the actual developmental changes children's physiological responses rather than to the differences in the nature of the tasks. Previous research conducted to answer this question frequently assessed ANS responses across different tasks over time (e.g., Perry et al., 2013) or created composite scores derived from children's ANS responses to a range of laboratory tasks (e.g., Alkon et al., 2003; Boyce et al., 2001). Based on the assumption that ANS responses may be context specific, examining children's ANS responses during the same task across time can inform us about the development of ANS responsivity over time.

The fourth goal of this study is to examine whether there are profiles of children with qualitatively distinct sympathetic and parasympathetic functioning at 4 years of age corresponding to the preschool year, and if so, whether these profiles differ with respect to children's self-regulation outcomes in preschool and one year later. Adopting a person-centered methodological approach for investigating children's ANS functioning has several unique advantages over using a variable-based approach. First, this line of investigation can help examine patterns of within-person functioning of the sympathetic and parasympathetic systems. Although some children may typically experience reciprocal sympathetic activation and parasympathetic inhibition, others may typically experience parasympathetic inhibition but no change in the sympathetic branch. Second, based on the idea that sympathetic and parasympathetic activity during calming states and during challenges provide unique information about children's ANS functioning, several scholars have advocated for examining these two aspects of ANS activity together (e.g., (Del Giudice et al., 2011; Hinnant & El-Sheikh, 2009; Quas et al., 2014). Adopting a person-centered approach would also allow for examining physiological activity during baseline and challenge together. Third, adopting a person-centered approach would allow for testing models, such as the Adaptive Calibration Model (Del Giudice, Ellis, & Shirtcliff, 2011), that propose non-linear relations between context, ANS functioning, and adaptive functioning. If there are profiles of distinct patterns of ANS functioning, then groups will be compared with respect to self-regulation outcomes.

CHAPTER II

THEORETICAL FRAMEWORK

The ability to cope with challenges effectively is key for leading a healthy and successful life. Early childhood is a period during which children become increasingly more adept at responding effectively to distinct forms of challenges. For example, during emotionally challenging experiences, rather than bursting into tears, most young children regulate their arousal and negative affect successfully and solve problems in a proactive manner. Likewise, during cognitive challenges, young children become increasingly more competent at sustaining their attention and using higher-order cognitive skills that fall under the rubric of executive functions. For example, children become better at holding rules and goals in their memory (i.e., working memory), inhibiting prepotent responses in favor of alternative responses (i.e., inhibitory control), or switching across rules, tasks, or strategies flexibly (i.e., cognitive flexibility; Carlson, Zelazo, & Faja, 2013). Finally, in classroom contexts that present a variety of emotional and cognitive challenges, young children show increasing competence at regulating their behaviors, particularly when they need to concentrate on instructions or tasks, work independently, or transition across different tasks (Morrison, Ponitz, & McClelland, 2010). The improvements in children's ability regulate their emotions, thoughts, and behaviors to cope with external challenges have been proposed to contribute to a range of psychological adjustment outcomes including greater ability to engage in prosocial behaviors and decreases in externalizing behaviors such as hitting or hurting others that are normative during toddlerhood years. As such, given the improvements in children's ability to cope effectively with challenges, it is important to understand the processes that support or mediate effective coping responses during this period.

One key biological system that supports individuals' ability to coordinate their moment-to-moment responses to various types of external challenges is the autonomic nervous system (ANS; Janig, 2008). Several theoretical perspectives support the view that, as one of the fastest responding biological systems, the ANS mediates pathways to adaptive functioning by supporting individuals' emotional, cognitive, and behavioral responses to cope with everyday challenges (Porges, 2011; Thayer et al., 2009). Given that variations in the functioning of the ANS may be linked with distinct pathways to adaptive and maladaptive outcomes, understanding the development and functioning of this system during early childhood may be important for identifying ways to promote children's adaptive functioning. Towards this end, the overarching goal of this study is to examine the functioning of the two branches of the ANS – the sympathetic and parasympathetic systems – across ordinary emotional and cognitive challenges during early childhood to address four main goals: (1) to understand normative ANS responses to emotional and cognitive challenges, (2) to identify challenges that demand the two branches of ANS to work reciprocally, (3) to understand the stability and continuity in indices of ANS functioning over time, and (4) to examine whether there are distinct profiles of ANS functioning, and whether these profiles differ with respect to child self-regulation outcomes. To review the major theoretical perspectives relevant for these goals, I will (a) provide an overview of the functioning of the ANS and introduce the measures of cardiac ANS functioning, (b) describe theories that explain how the two branches of the ANS may respond to distinct challenges, (c) review theoretical work on the role of the ANS for adaptive functioning, (d) discuss the relations between the ANS and specific self-regulation outcomes.

The Functioning of the Autonomic Nervous System

In order to understand how the ANS responds to everyday challenges and may contribute to adaptive outcomes, a basic understanding of this system's functions as well as functioning is necessary. Although the ANS has traditionally been viewed as a vegetative peripheral system that awaits passively to respond to external challenges, contemporary theories describe it as a complex system that works in conjunction with other neurophysiological and neuroanatomical systems to actively regulate behavioral responses (Janig, 2008; Porges, 2011; Smith et al., 2017). The ANS coordinates the rapid communication between the central nervous system, and the internal organs and muscle tissues via the afferent pathways that relay external stimuli from sensory organs to the brain and the efferent pathways that control effector organs such as the muscles to generate bodily responses (Kandel, Schwartz, & Jessell, 2013). These pathways allow the central nervous system, particularly the brain, to modulate both the autonomic nervous system and the neuroendocrine stress systems (Porges, 2011; Ulrich-Lai & Herman, 2009). By using the information distributed by the central system, the ANS plays a central role in coordinating individuals' responses to various types of challenges.

One main reason why the ANS plays such a central role in supporting individuals' responses to challenges is because of its core function of regulating the homeostatic function of the body. Homeostasis, which refers to the organisms' tendency to maintain a stable internal environment, is not only a key concept in most contemporary theories on autonomic nervous system functioning, but also "a dominant explanatory framework" for understanding autonomic physiological regulation (Cannon, 1929, 1939; Ramsay & Woods, 2014). Homeostasis, described as the *wisdom of the body* (Cannon, 1932), encompasses the self-regulatory processes of maintaining physiological parameters such as blood glucose or body pressure in a tenable range that allows for the capacity to shift the internal state of the organism from being upset to a normal state (see Janig 2008; Ramsay & Woods, 2014). Although the idea of homeostasis is at the core of many contemporary theories on ANS, the term, allostasis, which refers to achieving stability through change (Sterling & Eyer, 1988), has been developed to with an attempt to emphasize that the goal of physiological regulation is not to preserve the internal state at a particular "set-point" but to promote fitness through adjusting internal parameters to adapt to changing circumstances (Sterling 2004, 2011). The notion of allostasis has gained much popularity; though notably, many proponents of allostasis did not abandon the homeostasis framework but use the term allostasis to describe the regulatory processes through which homeostasis is maintained (e.g., McEwen, 2010; Schulkin, 2004; also see Sterling, 2004). Thus, one shared notion across both approaches is that, the regulation of the internal state of the organism is critical for the body's ability to produce behavioral responses.

The ANS regulates homeostatic functions and responds to external challenges via the orthogonal and synergistic coordination of its two anatomically distinct branches, the sympathetic and parasympathetic systems. The sympathetic nervous system promotes increased metabolic output to effectively mobilize the individual to produce defense responses (i.e., fight, flight), whereas the parasympathetic nervous system down-regulates the body's energy resources to promote the body's growth and restoration. The influence of these two branches on internal organs and muscles are often antagonistic. For example, the sympathetic nervous system accelerates the heart, dilates the pupil, and inhibits intestinal movements, whereas the parasympathetic nervous system slows the heart, constrict the pupil and relaxes internal movements. The two systems influence the heart differentially; the sympathetic system has a larger influence on cardiac contractility, whereas the parasympathetic system has a greater influence over heart rate. These opposing effects on the heart are mediated by distinct cardiac neurons: the beta-adrenergic neurons of the sympathetic system and cholinergic neurons of the vagal system (Smith et al., 2017).

In order to understand the unique responses of the two branches of ANS to distinct types of external challenges, it is important to consider the differences in their response timescales. Compared to the parasympathetic system, the sympathetic system has a slower timescale; a shorter latency of action, a slower rise time, and a lower frequency capacity (Berntson, Cacioppo, & Quigley, 1991). Specifically, the sympathetic nerves exert their influence within few seconds, whereas the parasympathetic nerves lead to changes within milliseconds (Nunan, Sandercock, & Brodie, 2010). Given that the sympathetic system has a slower response to challenges, it has been proposed that the moment-to-moment changes in autonomic responses that support flexible behavioral responses are largely supported by the parasympathetic system (Saul, 1990; Smith et al., 2017). Overall, the two branches of the ANS are supported largely by distinct neural processes and anatomical structures, exert orthogonal influences on the body organs, and serve different roles in supporting the organism's functioning via distinct response timelines.

Sympathetic and parasympathetic responses can be measured via a multitude of measurement strategies. Although sympathetic nervous system functioning can be indexed by measures such as salivary alpha-amylase or skin conductance (Nater & Rohleder, 2009), an alternative index that offers a more fine-tuned time resolution is a cardiac indicator: pre-ejection period (PEP). PEP refers to the time interval in milliseconds between the onset of ventricular depolarization (Q wave of the ECG) and onset of left ventricular ejection. This measure is thought to reflect the force of myocardial contraction via beta-adrenergic influences and index the overall sympathetic influence on the heart. PEP shortening (i.e., decreases in PEP from baseline to task) reflects sympathetic activation, whereas PEP lengthening (i.e., increases in PEP from baseline to task) reflects sympathetic inhibition. Similarly, although there are alternative ways of measuring parasympathetic activity, Porges (1985) developed a method that quantifies the amplitude of respiratory sinus arrhythmia (RSA), a special heart rate pattern that emerges as a function of the influences of the smart vagus on the heart. In particular, RSA is the rhythmic oscillations in heart rate observed at the frequency of spontaneous breathing (Porges, 2003). RSA withdrawal (i.e., decreases in RSA from baseline to task) reflects parasympathetic inhibition, whereas RSA augmentation (i.e., increases in RSA from baseline to task) reflects parasympathetic augmentation.

Sympathetic and Parasympathetic ANS Responses to Distinct Challenges

Given the distinct functions of the sympathetic and parasympathetic ANS, an important question is how these two branches of the ANS respond to different contexts or types of challenges. Answering this question has several important implications. First, understanding which laboratory challenges lead to changes in the activity of the branches of the ANS may help identify the type of challenges that are more appropriate for studying the responsivity patterns of a specific branch or both branches. Second, this line of work can help identify the type of challenges are more challenging or lead to more intense coping responses. Third, this work can help understand whether ANS response patterns to challenges differ based on the domain (i.e., emotional vs. cognitive) or type of challenge within the same domain (i.e., frustrating tasks vs. interpersonally upsetting emotional tasks).

One theory that explains how the sympathetic and parasympathetic branches of ANS may respond to external challenges is the Polyvagal Theory (Porges, 1995, 2001, 2011). According to the Polyvagal Theory, individuals respond to external challenges via the support of three hierarchically organized circuits or systems, which have evolved across three phylogenetic stages. These systems are: (a) the unmyelinated vegetative vagal system of the parasympathetic branch, shared with most vertebrates, that support behaviors related to immobilization such as freezing, behavioral shutdown, or feigning death, (b) the sympathetic nervous system responsible for mobilizing the organism and engaging in defense behaviors, and (c) the uniquely mammalian myelinated vagal system of the parasympathetic branch responsible for promoting social communication and engagement with the environment. The Polyvagal Theory proposes that, when confronted with a challenge, the phylogenetically newer circuits are recruited first, but if they are rendered functionless, the phylogenetically older circuits are recruited. Based on the hierarchical functioning of these systems, the phylogenetically newer circuits, such as the myelinated vagal system, inhibit or disinhibit the activity of the phylogenetically older circuits, such as the sympathetic system, to promote effective responding to external challenges. Based on this theory, the recruitment these systems do not occur in an all-or-none fashion, but that there are transitional blends in their functioning, such that more than one system may be recruited depending on the demands posed by the challenge.

Thus, based on the Polyvagal Theory, individuals first respond to a challenge via the myelinated vagal system. Specifically, the special efferent pathways of the myelinated vagus nerve ("smart vagus"), originating from the brainstem nucleus ambiguous, send input to heart to produce changes in cardiac activity that allow the organism to switch between servicing metabolic demands and responding to external challenges. During a challenge, the smart vagus increases the heart rate by disinhibiting vagal influence on the heart – a phenomenon referred to as vagal withdrawal or parasympathetic inhibition – to promote active coping, whereas during calm states, it slows the heart rate by increasing vagal influence on the heart – a process referred to as vagal augmentation or parasympathetic activation – to calm the organism. On the other hand, during more chronic challenges that pose threat to one's safety, the vagal system withdraws its inhibitory influence on the sympathetic system to facilitate active mobilization or defense responses. Notably, this perspective suggests that the state of the myelinated vagal system is the defining characteristic of stress given that this system responds to external challenges more frequently and ubiquitously, mostly in the absence of major shifts in the sympathetic ANS (Porges, 2011). Based on this approach, greater vagal withdrawal indicates greater engagement in coping responses, and thus, it is reasonable to assume that laboratory challenges that require greater active coping would lead to greater vagal withdrawal.

Another theoretical perspective useful for understanding how ANS may respond to distinct types of challenges is Obrist's (1981) active and passive coping approach. Obrist posited that, depending on the demands posed by the challenge, individuals may engage in either active or passive coping. Accordingly, individuals tend to engage in active coping, which involves exertion of cognitive effort, when they anticipate that their overt or covert responses would be effective to either resolve or escape out of the situation. On the other hand, individuals engage in passive coping when they anticipate no means of avoiding the situation or its consequences. Active coping tends to evoke sympathetic activation, whereas passive coping tends to evoke sympathetic inhibition. Based on this rationale, Obrist suggested that challenges may be classified as active and passive challenges, such that active challenges may lead to sympathetic activation, whereas passive challenges may lead to sympathetic inhibition.

Obrist's (1981) active coping approach has been integrated with the Motivational Intensity Theory (Brehm & Self, 1989) to make specific predictions about the amplitude of the sympathetic activation during active coping (Wright & Kirby, 2001). Drawing on Obrist's ideas, this integrative perspective suggests that the effort or the extent to which one mobilizes energy during active coping is supported by sympathetic influences on the heart, and that the magnitude this sympathetic response is proportional to effort, such that greater effort spent would correspond to greater sympathetic activation (Obrist 1976, 1981). Thus, based on the idea that greater sympathetic response would reflect greater effort expenditure, an important question is what factors determine the amount of effort individuals spend on challenges. The Motivational Intensity Theory suggests that two factors determine the extent to which individuals spend effort on a task: (a) the experienced difficulty of the instrumental behavior, and (b) whether or not the goal is attainable (Brehm & Self, 1989). Based on this theory, the amount of effort that is mobilized on a behavior should parallel the perceived difficulty of the task: greater effort should be spent on tasks that are perceived to be more difficult. However, if success on the task is perceived as too difficult, either beyond the ability of the individual or that the task itself is impossible to resolve, then individuals should spend less effort because investing effort would not help attain the goal. Thus, individuals would mobilize effort as long as succeeding in the task is perceived to be possible. Based on Wright's integration of Obrist's views with the Motivational Intensity theory, one would expect greater sympathetic activation on challenges perceived as more difficult, as long as success on the task is possible. However, if success on the task would be perceived as unattainable, then individuals would experience no change in sympathetic activity given that they would not mobilize energy to promote active coping.

ANS Functioning and Adaptive Outcomes

Although understanding the normative ANS responses to distinct challenges is important, children's normative or group-level responses to challenges cannot elucidate on which patterns of autonomic functioning may support adaptive functioning. Therefore, in order to identify the specific patterns of ANS functioning that may contribute to adaptive outcomes, it is important to understand how ordinary variations or individual differences in ANS functioning may relate to adjustment outcomes. Moreover, given that the sympathetic and parasympathetic branches of the ANS work in an orthogonal but synergistic fashion in preparing and mobilizing individuals to respond effectively to challenges (Berntson, Cacioppo, & Quigley, 1991), it is critical to understand how these two systems function concurrently within the person to promote or hinder positive behavioral outcomes. Although there is greater consensus that both branches of the ANS play critical roles for individuals' behaviors, most available theories focus on the role of a single branch rather than considering the roles of both branches for behavioral outcomes. However, a pursuit towards understanding whether and how distinct profiles of ANS functioning may relate to children's behaviors and psychological adjustment requires an integrative review of the shared and distinct propositions of available theories.

The Polyvagal Theory (Porges, 2011) offers important propositions regarding the relations between ANS functioning and behavioral outcomes, particularly with respect to what different vagal cardiac indices may reflect and how the sympathetic system may play a role in adaptive functioning. Based on this theory, the sympathetic ANS is specialized to respond to external challenges, whereas the parasympathetic ANS maintains homeostasis by fostering the metabolic demands. Given that both fostering homeostatic functions and responding to external challenges are important for adaptive functioning, the ability to switch efficiently and timely between the states of homeostasis and stress has been theorized to be a critical mechanism for adaptive functioning. This has been proposed to be achieved largely by the vagus nerve that serves as a brake that can inhibit or disinhibit influence on the sympathetic system and the heart. Based on this theory, baseline vagal tone or RSA reflects the state of homeostasis and indexes the capacity to respond to challenges, such that higher baseline RSA would reflect greater capacity to respond. Based on this rationale, baseline RSA has been proposed to play a key role in attentional, emotional, and cognitive control. Moreover, this theory posits that vagal withdrawal in response to challenge reflects mobilization of metabolic resources to promote active coping responses (Porges, 2007). As such, based on this theory, the direction and amplitude of RSA change would reflect individuals' stress response to the challenge.

The Polyvagal Theory does not offer definite predictions regarding what amount of RSA withdrawal is conducive to positive outcomes. Instead, it suggests that physiological responses should match the demands of the situation. Based on this perspective, the disruption of homeostasis and activation of sympathetic responses may be adaptive in the short term but may be metabolically costly in the long term. As such, the duration and amplitude of the physiological response has been proposed to be an important determinant of adaptive functioning; such that longer and more intense physiological responses would be costly and relate to maladaptive outcomes. Overall, in addition to providing a rationale regarding the associations between the indices of the vagal system and behavioral outcomes, this theory offers an important perspective for understanding how the activation of the sympathetic system may be costly for the individual.

Another theoretical perspective that offers specific predictions regarding the relations between ANS functioning and adaptive outcomes is the Neurovisceral Integration Model (Smith et al., 2017; Thayer & Lane, 2000; Thayer et al., 2009). This model outlines how different neural structures and neurophysiological processes exert direct and indirect influences on the heart in the production of self-regulatory behaviors critical for adaptive functioning (Smith et al., 2017; Thayer et al., 2009). Specifically, the central autonomic network (CAN) – an integrated neural circuit including the anterior cingulate, frontoparietal regions, amygdala, medulla, and the nucleus ambiguous (NA) – supports self-regulatory processes by impacting the sympathetic (i.e., adrenergic) and parasympathetic (i.e., cholinergic) neurons' influence on the heart (Smith et al., 2017; Thayer et al., 2009). Given the integration between these neural regions and the heart, this model suggests that heart rate variability indexes the level of integration between the autonomic and the central nervous systems and is associated with self-regulatory behaviors supported by the central autonomic network (Smith et al., 2017).

Put simply, this model posits that the central autonomic network is constantly engaged in an iterative process of determining which hierarchically organized neural structures will have a stronger influence on heart via the vagus nerve (Smith et al., 2017). Based on this model, in safe contexts, the prefrontal cortex would be recruited to support deliberate, goal-directed behaviors, whereas in contexts appraised as threatening, the subcortical brain regions may be recruited to allow for the facilitation of more automatic and non-volitional emotional reactions necessary for survival (Smith et al., 2017; Thayer et al., 2009). Moreover, according to this model, compared to the subcortical regions, the prefrontal cortex facilitates responses that are more sensitive to larger contextual information necessary for successful self-regulation. Based on the idea that heart rate variability reflects the communication between higher-order structures such as the prefrontal cortex and the heart, this model supports the view that higher RSA both during baseline and during challenges reflects greater precision to prefrontally mediated control sensitive to the individual's goals and the contextual cues (Smith et al., 2017). Thus, based on this perspective, greater baseline RSA and lower RSA withdrawal during challenges would be associated with better self-regulation and adjustment outcomes because they would reflect greater engagement of the higher-level brain regions such as the prefrontal cortex.

Although both the Neurovisceral Integration Model (Thayer et al., 2009) and the Polyvagal Theory (Porges, 2011) suggest that greater baseline RSA reflects greater capacity for adaptive self-regulatory responses to challenges, some researchers have suggested that moderate levels of baseline RSA may be more optimal for certain outcomes (e.g., Kogan, Gruber, Shallcross, Ford, & Mauss, 2013). For example, it has been proposed that individuals with higher baseline RSA may tend to show lower prosociality because they may evaluate the environment as safe and have higher threshold for responding to the environment, which may prevent them to notice and respond to others' needs (Hastings, Zahn-Waxler, & McShane, 2006; Miller, Kahle, & Hastings, 2017). On the other hand, moderate baseline RSA has been proposed to be an optimal physiological state that allows individuals to notice others' emotional cues and respond to them (Hastings, Zahn-Waxler, & McShane, 2006; Miller, Kahle, & Hastings, 2017). Based on the idea that high levels of baseline RSA may interfere with the ability to notice and respond to environmental cues, one may expect high baseline RSA to associate negatively with other behaviors that require responding based on environmental cues. As such, more theoretical (as well as empirical) work is needed to understand what levels of baseline RSA is conducive to distinct self-regulation and adjustment outcomes.

Similar to the debates on what levels of baseline vagal tone support positive outcomes, there is also theoretical discussion on whether low, moderate, or high vagal withdrawal is more optimal for certain behavioral and psychological outcomes. For example, Marcovitch et al. (2010) suggested that moderate vagal withdrawal may facilitate the use of cognitive skills such as executive functions during laboratory challenges because this pattern of vagal withdrawal would increase heart rate modestly and allow individuals to attend and process environmental stimuli in a flexible manner. On the other hand, based on the idea that high vagal withdrawal would lead to increased heart rate and mobilization responses, these authors suggested that such excessive physiological response may interfere with the ability to attend or respond to environmental stimuli in a flexible manner (also see Beauchaine, 2001). Moreover, consistent with the Polyvagal Theory's proposition that excessive vagal withdrawal may activate sympathetic system's defense responses, it has been suggested that this form of physiological regulation may index emotional lability and proclivity towards engaging in fight/flight responses (Beauchaine, 2001). It is important to note that theoretical conceptualizations regarding what level of vagal withdrawal is more optimal for child outcomes are at least partially guided on assumptions regarding how the sympathetic ANS may be reacting to challenges. However, given that the sympathetic and parasympathetic systems may function in an orthogonal fashion (Berntson, Cacioppo, & Quigley, 1991), assumptions regarding sympathetic responses based solely on information on parasympathetic activity may be misleading. As such, in order to understand the optimal patterns of ANS functioning conducive to adaptive outcomes, it is important to consider the functioning of the two branches of the ANS together.

Consistent with this view, scholars have called attention to the need to understand how the concurrent functioning of the two branches of the ANS may promote or hinder adaptive functioning (e.g., Alkon et al., 2003; Boyce et al., 2001; El-Sheikh & Erath, 2011). This line of work is influenced largely by the Autonomic Space Model (Berntson et al., 1991; Berntson & Cacioppo, 2004), which suggests that the orthogonal functioning of the sympathetic and parasympathetic systems can support 9 distinct modes of autonomic control. Based on this model, one common mode of autonomic control is reciprocal sympathetic activation, which is characterized by sympathetic activation and parasympathetic inhibition. This mode has been proposed to reflect active coping responses to external challenges, given that it would lead to increases in heart rate and mobilization responses (Berntson et al., 1991; El-Sheikh et al., 2011). Other autonomic modes include coactivation and coinhibition of both systems; as well as patterns involving change in one system but no change in the other. Although there is limited theoretical work describing how these distinct modes may support adaptive function, El-Sheikh et al. (2011) proposed that coactivation may reflect an insufficient coping response given that the absence of vagal withdrawal may hinder effective coping, whereas the coinhibition pattern reflects an ambivalent coping response given that the sympathetic withdrawal may reflect failure to mobilize sufficient energy to deal with challenges. Moreover, given that mild challenges may require parasympathetic inhibition without the activation of the sympathetic system, it is possible that moderate levels of parasympathetic inhibition without a change in the sympathetic activity may also reflect an adaptive physiological response because this autonomic mode may not be metabolically costly. Although these perspectives provide a starting point for understanding what modes of autonomic control may be adaptive, there is a need for more theoretical work that draw specific links between distinct patterns of ANS functioning and adaptive outcomes.

Importantly, a recent evolutionary-developmental theory, The Adaptive Calibration Model (Del Giudice, Ellis, & Shirtcliff, 2011), may provide useful propositions regarding how distinct patterns of ANS functioning may be linked with adaptive outcomes. This model extends the Biological Sensitivity to Context theory to explain the sources of individual differences stress response patterns (i.e., ANS & the hypothalamic-pituitary-adrenal axis) and their functions in supporting behavioral responses to promote fitness. Based on this model, the large variations in the functioning of the stress response system emerge largely as a result of evolutionary adaptations that allow organisms to match their observable traits or behaviors to the demands of the environmental conditions in which they live in, a phenomenon referred to as conditional adaptation. Given that the variations in environmental conditions range from high levels of stress (e.g., low availability of food, safety and care) to low levels of stress (e.g., high availability of food, resources, and care), this model proposes that there is not one "best" stress response pattern that would promote survival in all environmental conditions, but rather distinct configurations of stress responses may better equip the organisms to deal effectively with certain types of environmental conditions. This model proposes four prototypical patterns of stress responsivity (i.e., sensitive, buffered, vigilant, and unemotional), each of which involve distinct profiles of physiological functioning. The stress responsivity patterns emerge as a function of exposure to different types and levels of stress in the environment and promote certain traits and behavioral responses that serve the organisms' life history strategies (Del Giudice, Ellis, & Shirtcliff, 2011).

A sensitive pattern is characterized by high levels of responsivity to the environment. The physiological profile is theorized to be marked by (a) high baseline parasympathetic activity and parasympathetic responsivity, and (b) moderate baseline sympathetic activity and sympathetic responsivity. Consistent with the Polyvagal Theory, greater baseline parasympathetic activity and parasympathetic withdrawal are theorized to support both cognitive and social-emotional competencies. In terms of cognitive competencies, this pattern of responsivity would support greater attentional flexibility, executive functions, and inhibition of responses (e.g., delay of gratification), and in terms of social-emotional competencies, it would support emotional stability, prosocial behaviors, and social collaboration.

A buffered pattern is characterized by a "low-to-moderate" range of stress responsivity that develops as a result of exposure to moderate levels of environmental stress. Given that high-levels of responsivity may be costly in the face of environmental stress, this moderate pattern of responsivity may constitute a more optimal response pattern that buffers individuals from risks associated with an environment that is not consistently nurturing and safe. Specifically, individuals in this profile are theorized to have (a) moderate baseline parasympathetic activity and parasympathetic responsivity, and (b) low to moderate baseline sympathetic activity and sympathetic responsivity. Compared to the unemotional and vigilant patterns of responsivity, buffered individuals are theorized to be less prone to aggression, anxiety, and risk-taking behaviors. Notably, this responsivity pattern is consistent with the "stress-inoculation" proposition suggesting that early exposure to stressful experience may act as a vaccine to prepare the individual to cope with stress.

A vigilant pattern is theorized to be a "sympathetically-dominated" responsivity pattern that develops as a result of chronic exposure to high levels environmental stress to support the ability to cope effectively with threats and dangers in the environment. Individuals in this profile would have (a) low to moderate baseline parasympathetic activity and low parasympathetic responsivity, and (b) high baseline sympathetic activity and sympathetic responsivity. Behaviorally, this responsivity pattern would be associated with heightened attentional responses to threat and high levels of anxiety, which would both facilitate adaptive responses to deal with dangers in the environment. This responsivity pattern has been theorized to give rise to distinct phenotypes in males and females. In males, this response pattern would be associated with more "fight" responses such as impulsivity, aggression, and increased risk-taking, whereas in females, it would be associated more with "flight" responses such as high levels of fearfulness and social anxiety and low levels of impulsivity and risk-taking.

An unemotional pattern is theorized to be a "low stress responsivity" pattern. Individuals in this profile would have (a) low baseline parasympathetic activity and parasympathetic responsivity, and (b) low baseline sympathetic activity and sympathetic responsivity. This pattern of low responsivity to stressors is theorized to be adaptive in severely stressful contexts. Although individuals with an unemotional responsivity pattern are expected to show low levels of physiological responses to certain types of challenges such as social evaluation or performance, they may show high levels of physiological activation in response to immediate dangers or threats. Behaviorally, this response pattern would be associated with callous-unemotional traits such as low empathy and guilt, and high levels of antisocial behaviors. Males are theorized to be over-represented in this group.

Although the Adaptive Calibration Model provides a useful, detailed framework for speculating about individual differences in patterns of ANS functioning, it is important to stress that this model has proposed these four prototypical physiological response patterns based on the integrative functioning of both the ANS and the HPAA. As such, given that this study only focuses on distinct profiles of ANS functioning and their relations to adaptive outcomes, the propositions of this theory may not be directly tested using only indices from ANS functioning. However, given the scarcity of theoretical work focusing on how distinct patterns of sympathetic and parasympathetic ANS functioning may relate to distinct outcomes, this model still provides one of the most comprehensive accounts on what possible profiles of ANS functioning may emerge, and whether these profiles would differ with respect to different outcomes.

Overall, the theoretical work reviewed in this section highlights several issues important for understanding the role of ANS functioning for adaptive outcomes. First, several perspectives suggest that both baseline levels of ANS activity as well as responsivity of the ANS to external challenges may provide meaningful information regarding individuals' behavioral and psychological outcomes. As such, it would be important to consider the roles of both baseline levels and responsivity patterns of ANS for adaptive functioning. Second, certain indices of ANS functioning and adaptive outcomes may not necessarily have a linear relationship, but rather may be associated in non-linear and/or quadratic way. As such, it would be important to consider methodological approaches that can allow to test for non-linear relations between indices of ANS functioning and child outcomes. Third, several theoretical perspectives emphasize the importance of understanding how individual differences in the functioning of both the sympathetic and parasympathetic branches of ANS may relate to adaptive outcomes. These three points together suggest that it would be important to examine individual differences in patterns of both sympathetic and parasympathetic ANS functioning that involves both baseline (i.e., baseline RSA & PEP) and responsivity (i.e., RSA & PEP change) measures, and whether these distinct patterns ANS functioning support important behavioral outcomes.

ANS Functioning and Specific Self-Regulation Outcomes

Given that a number of theoretical perspectives suggest that individuals' characteristic pattern of ANS functioning may support a range of adaptive outcomes, it is important to understand what specific psychological and behavioral outcomes may be supported by distinct patterns of ANS functioning. Particularly, both the Polyvagal Theory and the Neurovisceral Integration Model suggest that certain patterns ANS functioning would directly be linked to self-regulation outcomes. Moreover, the Polyvagal Theory emphasizes the role of the ANS functioning for social engagement outcomes such as prosocial behaviors (Porges, 2011), whereas the Neurovisveral Integration Model suggests that, as the output of a larger neuro-physiological circuit, indices of ANS functioning may be linked a wide variety of self-regulation outcomes supported by this circuit (Thayer et al., 2009). Importantly, the Adaptive Calibration Model drew on the propositions of both of these theories to describe how individual differences in patterns of ANS functioning may be linked with self-regulation outcomes (Del Giudice, Ellis & Shirtcliff, 2011).

Self-regulation is a multifaceted construct that includes a range of processes that allow individuals to regulate their arousal, attention, emotion, and cognition to manage goal-directed behaviors (Karoly, 1993; Bridgett et al., 2015; Calkins, Perry, & Dollar, 2016). Variations in ANS functioning may be associated with three specific aspects of self-regulation: emotion regulation, executive functions, and behavioral regulation.

Emotion regulation involves both a reactivity and a regulatory component (Calkins & Hill, 2007; Carthy, Horesh, Apter, & Gross, 2010). Emotional reactivity includes the threshold of stimuli needed for the generation of emotion as well as the intensity and duration of affective responding, whereas emotion regulation involves ‘‘behaviors, skills, and strategies, whether conscious or unconscious, automatic or effortful, that allow children to modulate, inhibit, or enhance emotional expressions and experiences’’ (Calkins & Hill, 2007, p. 229). Although reactivity and regulation are conceptualized as distinct processes, they are ultimately interrelated, such that reactivity to an upsetting event in terms of the intensity and duration of negative emotion would ultimately influence how much effort need to be put into regulation. Individual differences in these processes of emotion regulation have been important predictors of academic achievement, social skills, as well as psychological adjustment outcomes such as internalizing and externalizing behaviors.

Executive functions refer to a diverse range of general purpose or more volitional forms of attentional and cognitive processes, orchestrated largely by the prefrontal cortex, that support a wide range of self-regulatory processes including the regulation of emotions, thoughts, and behaviors (Best & Miller, 2010; Diamond, 2013; Zelazo & Cunningham, 2007). Executive functions are characterized as general-purpose because they support a wide range of abilities critical for adaptive functioning including the regulation of emotion (Zelazo & Cunningham, 2007), understanding other individuals' perspectives (Devine & Hughes, 2014), math competence (Bull, Espy, & Wiebe, 2008), and literacy (van der Sluis, de Jong, & van der Leij, 2007). One dominant perspective on executive functions suggests that there is a set of dissociable but interrelated executive functions that often work interactively to support goal-directed behaviors (Friedman et al., 2008; Huizinga, Dolan, & van der Molen, 2006; Miyake et al., 2000). The three basic units of executive functions that have received much attention are working memory, defined as the ability to actively manipulate or update information maintained in working memory (Lehto, 1996; Morris & Jones, 1990); inhibition, defined as the ability to deliberately suppress dominant and automatic responses in favor of subdominant responses, and lastly cognitive flexibility, defined as the ability to flexibly shift across tasks or operations. Based on empirical evidence suggesting that basic components of executive functions are less dissociable in early childhood (e.g., Hughes, Ensor, Wilson, & Graham, 2010; Willoughby, Wirth, & Blair, 2012), executive function/s is conceptualized as a unitary construct that embodies three of its core components.

Behavioral regulation refers to the use and coordination of attentional and cognitive processes to direct, coordinate, and plan one's own behaviors. The ability to listen and comply with instructions, maintain attentional focus and persist during challenging tasks, inhibit pre-potent responses in favor of appropriate, alternative responses, and perform self-directed behaviors are all indicators of successful behavioral regulation (Morrison, Ponitz, & McClelland, 2010). The ability to engage in successful behavioral regulation is critical in formal educational settings that demand children to comply with rules and instructions, follow classroom routines, and conform to social demands in a consistent manner. Successful behavioral regulation has been proposed to that facilitate children's engagement in learning activities and promote adaptive social relationships with peers and teachers. Given the ecological importance of the classroom context for examining behavioral regulation, behavioral regulation is conceptualized as a latent construct composed of: attention control, the ability to regulate attention and concentrate on tasks; work habits, the ability to engage in good work behaviors; and discipline/persistence, the ability to persist on tasks and direct behavior based on classroom rules.

Certain patterns of ANS functioning may be associated with better self-regulation outcomes. Specifically, higher baseline RSA, theorized to index greater integrity in the coordination between the brain and the heart, may support greater capacity for self-regulation. On the other hand, moderate RSA withdrawal may be associated with better self-regulation based on the idea that it may support greater orienting and attention responses and provide optimal levels of coping responses to deal with challenges. On the other hand, low levels of sympathetic activation may be associated with lower levels of emotional reactivity and better behavioral regulation given that this pattern would reflect low rather than high levels of mobilization that activates defense responses such as fight or flight.

CHAPTER III

LITERATURE REVIEW

The current section reviews empirical work providing support for the theoretical perspectives guiding the four goals addressed by this study: (a) sympathetic and parasympathetic ANS responses to emotional and cognitive challenges, (b) associations between sympathetic and parasympathetic ANS responsivity across distinct challenges, (c) stability and continuity in ANS functioning over early childhood, and (d) distinct profiles of ANS functioning and their relations with maternal emotional support, self-regulation and social adjustment outcomes.

ANS Responsivity During Emotional and Cognitive Challenges

The first question addressed by this study is how the sympathetic and parasympathetic autonomic systems respond to distinct emotional and cognitive challenges. One proposition shared across a number of theoretical perspectives on autonomic nervous system functioning is that individuals' sympathetic and parasympathetic cardiac responses are context-dependent (Porges, 2011; Smith et al., 2017). The type of coping response demanded by the challenge likely influences both the direction and intensity of activity in the sympathetic and parasympathetic systems. Given that sympathetic and parasympathetic systems are orthogonal, distinct challenges may lead to a) reciprocal activity (i.e., activation in one system coupled with inhibition in the other), b) non-reciprocal activity (i.e., activation or inhibition in both systems), or c) activation or inhibition in one system but no change in the other (Berntson, Cacioppo, & Quigley, 1991). Several studies with adults and children examined sympathetic and parasympathetic responses to different types of challenges experienced in everyday life. In research with adults, autonomic cardiac responses to emotional and cognitive challenges have been studied largely separately, whereas in developmental research, children's responses to a wide range of tasks are examined in the same sample of participants.

Research on Emotional Challenges

A large body of adult emotion research examined whether discrete emotions such as anger, fear, and joy are accompanied by distinct ANS responses (e.g., Sinha, Lovallo, & Parsons, 1992; see Cacioppo et al., 2000). Inherent in this line of investigation is the idea that an event evokes a particular emotion, which is either preceded, accompanied, or followed by an ANS response (Mauss & Robinson, 2009). Based on this conceptualization, researchers used a variety of laboratory tasks such as emotionally evocative imagery, videos, or stories to invoke discrete emotions and assessed participants' ANS responses during these tasks (Kreibig, 2010). In a review paper on adults' experiences of discrete emotions and ANS responses with 134 studies, it has been reported that individuals experience sympathetic activation for anger and fear, but sympathetic inhibition for sadness (Kreibig, 2010). On the other hand, individuals experience parasympathetic inhibition during anger, fear, and sadness, but experience parasympathetic augmentation during disgust. Although these findings do not provide conclusive evidence regarding whether distinct emotions are accompanied by unique

ANS responses, they lend strong support for the view that different contexts or events lead to different ANS responses, particularly contexts that elicit sadness (but not anger) likely lead to sympathetic inhibition (i.e., PEP inhibition) and contexts that elicit negative emotions such as anger and sadness (but not disgust) likely lead to parasympathetic inhibition (i.e., RSA withdrawal).

Research on Cognitive Challenges

Several adult studies tested whether cardiac autonomic responses depend on the nature or intensity of the cognitive challenge. For example, Berntson, Cacioppo, and Fieldstone (1996) examined adults' sympathetic and parasympathetic responses to two cognitive tasks: a cognitively challenging mental arithmetic task and an illusion tasks. During the mental arithmetic task, on average, adults experienced sympathetic activation (i.e., PEP shortening) and parasympathetic inhibition (i.e., RSA withdrawal). However, during the illusion task, on average, adults experienced no change in sympathetic activity and showed parasympathetic activation (i.e., RSA augmentation). Consistent with the proposition of the motivational intensity theory, one explanation for these findings is that challenges that pose greater "cognitive effort" may require greater energy mobilization, supported by a response pattern of sympathetic activation and parasympathetic withdrawal. However, challenges that do not demand cognitive effort may not require energy mobilization and "active coping" responses accompanied by sympathetic activation and parasympathetic inhibition.

Based on the idea that sympathetic activity (i.e., beta-adrenergic influence) mediates energy mobilization, it has been suggested that the intensity of sympathetic activation would be proportional to cognitive effort because greater effort likely requires greater energy. Given that more difficult tasks would require greater cognitive effort and mobilization, individuals are expected to show greater sympathetic activation in more difficult tasks. In a randomized experimental design, Richter, Friedrich, and Gendolla (2008) examined differences in adults' sympathetic responses across four conditions of task difficulty: low, medium, high, and impossible. Findings showed that the intensity of sympathetic activation paralleled the task difficulty, such that more difficult tasks elicited greater sympathetic activation, as long as success was possible. Consistent with the motivational intensity theory's proposition that energy expenditure would be low if success on a task is unattainable, adults did not show sympathetic activation in the impossible condition. These findings provide support for the idea that greater task difficulty leads to greater sympathetic responses likely because of the need for energy mobilization.

Developmental Research

Few developmental studies examined children's ANS responses to both emotional and cognitive challenges. Buss, Goldsmith, and Davidson, (2005) examined whether toddlers' sympathetic and parasympathetic functioning differed from baseline to three laboratory challenges: mental scale, stranger approach, and toy removal. Their results indicated that, overall, children experienced parasympathetic withdrawal across all three tasks, but there was no change in children's sympathetic activity. Using a similar design, Quigley and Stifter (2006) examined children's and adults' ANS responses across four laboratory tasks: an emotionally evocative video, reaction time task, interview, and cold forehead task. Children experienced significant RSA withdrawal across all four tasks and experienced sympathetic inhibition during the emotionally evocative video and the interview. There was no change in children's sympathetic responses to the other two tasks. These studies together suggest that during challenges that require active coping responses, on average, children experience parasympathetic withdrawal. On the other hand, findings suggest that the challenges that elicit changes in parasympathetic activity do not necessarily lead to changes in sympathetic activity. These findings may support the notion that individuals may rely solely on the faster-responding parasympathetic system during a range of mild challenges but recruit the sympathetic system only during certain types of challenges. As such, it is important to understand the type of challenges that demand sympathetic activation or inhibition.

Goal 1. To Examine Children's Sympathetic and Parasympathetic Cardiac Responses to Emotional and Cognitive Challenges in Early Childhood

1a). Will there be significant mean-level changes in children's sympathetic activity from baseline to task across emotional and cognitive challenges? If so, during which tasks, will children experience sympathetic activation (i.e., PEP shortening) or inhibition (i.e., PEP lengthening)?

Cognitive tasks. The Motivational Intensity Theory integrated with Obrist's approach suggests that individuals experience greater sympathetic activation during challenges there are perceived as difficult, as long as they are attainable (Wright & Kirby, 2001). Previous research showed that although cognitively challenging tasks led to sympathetic activation, cognitively easy or less challenging tasks did not (Berntson, Cacioppo, & Fieldstone, 1996). In line with this work, it is hypothesized that, on average, children will experience sympathetic activation (i.e., PEP shortening) during the cognitively challenging *spatial problem-solving tangrams task* that required children to solve puzzles increasing in difficulty. On the other hand, it is hypothesized that children's sympathetic responses will not change significantly during the *Go/No-Go cognitive task*, which constitutes a prolonged, repetitive, and cognitively less demanding task.

Emotion tasks. Based on the proposition that individuals tend not to mobilize their resources if success on a task is unattainable (Richter et al., 2008), no mean-level change in sympathetic activity is expected during emotion regulation tasks that required children to solve frustrating and unattainable problems (e.g., Locked Box, Impossible to Open Box, and Puzzle Box). However, given that some children may perceive such challenges as resolvable and thus exert greater effort to solve them, there will be a wide variation in children's sympathetic responses during these tasks. Moreover, consistent with the idea that individuals would experience sympathetic inhibition when they anticipate no means of escaping an aversive situation or its consequences (Obrist, 1981), as well as findings that have linked experiences of sadness with sympathetic inhibition (Kreibig, 2010), it is hypothesized that, on average, children will experience sympathetic inhibition (i.e., lengthened PEP) during the two emotion regulation tasks, Toy Removal and Not Sharing, designed to evoke negative emotions by making children experience injustice. Given that there would be variations in children's emotional responses with some experiencing anger as opposed to sadness, there will be variations in children's sympathetic responses with some experiencing sympathetic activation rather than inhibition.

1b). Will there be significant mean-level changes in children's parasympathetic activity (i.e., RSA withdrawal) from baseline to task during emotional and cognitive challenges?

Consistent with theoretical work and empirical findings suggesting that withdrawal of the parasympathetic influence on the heart supports coping responses (Porges, 2011), it is hypothesized that, on average, children will experience parasympathetic inhibition, as indexed by RSA withdrawal, across all laboratory challenges. Specifically, there will be a significant mean-level change from baseline to task RSA across all laboratory challenges. Based on the notion that tasks that are more challenging may require greater "active coping," children may experience greater RSA-withdrawal during both more demanding emotional (e.g., Locked Box) and cognitive tasks (e.g., tangrams) compared to tasks that are less cognitively or emotionally challenging (e.g., Go/No-Go, disappointing gift).

Associations Between Sympathetic and Parasympathetic Functioning During Laboratory Challenges

The second question addressed by this study is whether and during which challenges sympathetic and parasympathetic autonomic systems' activity would be associated or work reciprocally. Sympathetic and parasympathetic branches of the ANS likely work reciprocally if responsivity of these two systems are associated, such that greater activation in the sympathetic branch relates to greater inhibition of the parasympathetic branch. Correlations between sympathetic and parasympathetic responses to emotional and cognitive laboratory challenges were examined in several studies. In a study with adults, Berntson, Cacioppo, and Fieldstone (1996) showed that individuals' sympathetic and parasympathetic responsivity, as indicated by PEP and RSA change scores respectively, were correlated during a cognitively challenging mental arithmetic task, but not during a cognitively less demanding illusion task. Thus, one explanation for these findings may be that the sympathetic and parasympathetic systems may work reciprocally only during cognitive tasks that require greater cognitive effort, but not during those that demand less cognitive effort. Similar to the null finding on the illusion task, Guiliano et al. (2017) did not find an association between adults' sympathetic and parasympathetic responses to a selective attention task. Although the extent to which this specific task requires cognitive effort has not been reported, it is possible that the lack of association may be due to the cognitive effort required by the task.

Studies that examined the associations between sympathetic and parasympathetic ANS functioning in children also yielded mixed results. There were no associations between RSA and PEP change scores during emotional challenges in toddlers (Buss, Goldsmith, & Davidson, 2005), an incentive/motivation task in a sample of preschoolers diagnosed with ADHD (Beauchaine, Gatzke-Kopp, Neuhaus, Chipman, Reid, & Webster-Stratton, 2013), and during a physiological responsivity protocol composed of several challenge tasks in 3-to 8-year olds (Alkon et al., 2003). In contrast to these null findings, a recent study that examined children's ANS responsivity to a stressful challenge task (i.e., a worksheet task during which children received negative feedback) showed an association between RSA and PEP change scores, such that increases in sympathetic activation were associated with increases in parasympathetic withdrawal (Roos et al., 2017). Given these discrepant findings, it is possible that whether sympathetic and parasympathetic ANS responses correlate with each other may depend on the nature of the task. For example, in more physiologically arousing or frustrating tasks, increases in RSA withdrawal may be associated with increases in PEP shortening. However, in less challenging tasks, SNS and PNS responses may not correlate.

Goal 2. To Examine Whether and During Which Challenges Children's Sympathetic and Parasympathetic Cardiac Responses Correlate or Work Reciprocally

Previous research showed that individuals' sympathetic and parasympathetic responses are associated during certain tasks (e.g., mental arithmetic, stressful challenge), but not others (e.g., illusion task, attention task). Based on Obrists' distinction between "active coping" and "passive coping" tasks, sympathetic and parasympathetic responses may be associated only during tasks that require active rather than passive coping responses (see Obrist, 1976; Wright & Kirby, 2001). As such, it is possible that during more physiologically arousing or frustrating tasks that require active coping responses, the two branches of the ANS may work reciprocally, such that increases in RSA withdrawal may be associated with increases in PEP shortening; but in physiologically less arousing challenges, there may not be associations between the activity of the two branches. Given that the cognitively challenging tangrams task and emotionally frustrating tasks such as the Locked Box task likely require active coping responses, children's sympathetic and parasympathetic responses may be associated during these tasks. On the other hand, given that the cognitively less demanding Go/No-Go task and the interpersonally upsetting tasks may be considered as more passive tasks, children's sympathetic and parasympathetic responses may not work reciprocally during such tasks.

Development of ANS Functioning in Early Childhood

The third question addressed by this study is whether children's ANS activity across different tasks are stable and continuous over time. Examining the stability in children's ANS responses to different types of challenges is important for understanding both development, and the reliability of different laboratory measures. In regards to development, greater stability in individual differences across time may suggest that children tend to develop more trait-like or characteristic physiological responses for dealing with certain types of challenges. As such, it would be important to characterize the stability in individual differences across different tasks over the period of early childhood. In regards to reliability, a certain degree of stability in individual differences during a certain task may suggest that that task elicits similar physiological responses consistently over time. As such, evidence for greater stability in certain tasks than others may suggest that certain tasks may more reliably elicit physiological responses that reflect individuals' characteristic physiological response.

Moreover, examining continuity and change in children's physiological responses would help illuminate whether children show greater, lower, or the same magnitude of physiological responses over time. Calkins and Keane (2004) suggested that evidence for an increase in the magnitude of parasympathetic inhibition or vagal withdrawal may suggest that children engage in greater physiological regulation over time, whereas decreases in parasympathetic inhibition may indicate less reliance on physiological coping responses, especially if the laboratory tasks became easier for children over time. As such, understanding the continuity and change in physiological responses over time can help us understand the changes in how much children rely on physiological regulation over time.

Stability in Children's ANS Functioning

Parasympathetic functioning. Studies consistently demonstrated modest to moderate levels of stability in children's baseline levels of RSA in early childhood (e.g., Alkon, Boyce, Davis, & Eskenazi, 2011; Esposito et al., 2016; Patriquin, Lorenzi, Scarpa, Calkins, & Bell, 2015; Perry et al., 2013). In contrast to the consistent findings on the stability of baseline RSA, research that examined the stability in children's RSA change scores revealed mixed findings. For example, Calkins and Keane (2004) measured children's parasympathetic responsivity during four types of tasks (attention, empathy, frustration, and problem-solving) when children were 2 and 4.5 years of age and found modest levels of stability in RSA change across certain tasks. In particular, children's RSA change score during the problem-solving task at age 2 predicted RSA change during the problem-solving task as well as the empathy and frustration (but not the attention task) at age 4. Moreover, children's RSA change during the empathy and frustration tasks at age 2 also predicted the problem-solving task at age 4. These findings suggest that children's RSA change scores, at least during certain challenges, show modest stability from toddlerhood to preschool age. Likewise, Perry et al., (2012) reported modest levels of stability in children's parasympathetic responsivity to emotional challenges from 3 to 4 years, and from 4 to 5 years of age. These studies together lend support for a modest level of stability in children's parasympathetic responsivity in at least certain tasks during early childhood.

In contrast to these findings, a greater number of studies failed to find stability in children's RSA change scores. For example, Bornstein and Suess (2000) did not find stability in RSA change scores from infancy (2 months) to early childhood (5 years). Given that early childhood is a time of rapid transformation in children's stress responses, the null finding may be due to the long interval (i.e., 5 years) between the two assessments. As such, it would be important to examine the stability in children's parasympathetic responses across visits separated by shorter intervals. As such, in a strikingly different study design, Doussard-Roosevelt, Montgomery, and Porges (2003) examined the stability in 5- and 6-year old children's vagal withdrawal during a negative affect task across three sessions that were only 2-weeks apart, and found stability from the first session to the second, but not from the second to the third session. One explanation for a lack of stability in children's parasympathetic responses from the 2nd to 3rd visit, in a 2-week period, may be that because the same negative affect task used across all three sessions, children may have been familiarized to this task, showing lower levels of coping responses, and thus may not have showed a stable pattern of response across sessions.

In a recent study, Alkon et al. (2010) measured children's RSA responses at 6-, 12-, 42-, and 60-months of age, and reported moderate to high stability in mean scores derived from the challenge tasks but did not find stability in RSA change scores. Notably, in this study, the authors created an aggregate of RSA change scores in response to a battery of tasks. Given that ANS responses are context-specific, it is possible that an aggregate of children's physiological responses to distinct laboratory tasks may be less stable compared to stability in responses to the same task over time. Another explanation for the null findings is that the task durations may have been too short (i.e., 2-minute tasks) to capture children's characteristic ways of responding to challenges, and therefore may have been less stable over time. Similar to these findings, Hinnant, Philbrook, Erath, and El-Sheikh (2018) did not find stability in RSA change scores in middle childhood (from 8 to 10 years of age) but did find moderate-to-high levels of stability in adolescence (from 16 to 18 years of age), suggesting that RSA change may not become stable until later years in development. Overall, the discrepancy in findings may be due to several factors, including, (a) children's age, (b) the interval/s between assessments, (c) children's familiarity with the task/s, (d) duration of the task/s, and (e) whether physiological responses are assessed in the same type of tasks/contexts, or averaged based on responsivity towards different contexts. As such, an important task for researchers is to demonstrate the conditions in which individual differences in physiological responsivity show stability over time.

Sympathetic functioning. Similar to the findings on the stability of baseline RSA over time, there is some evidence suggesting that there is modest to moderate levels stability in children's baseline levels of PEP during early childhood (e.g., Alkon et al., 2011; Esposito et al., 2016). Compared to the number of studies examining the stability in RSA change scores, fewer studies were conducted to examine the stability in PEP change scores during early childhood. Similar to their findings on stability in RSA scores over time, Alkon et al. (2011) did not find stability in PEP change scores across infancy and early childhood, despite finding moderate to high levels of stability in mean PEP scores derived from the challenge tasks.

Continuity and Change in Children's ANS Functioning in Early Childhood

Parasympathetic functioning. Previous research reported increases in children's baseline parasympathetic cardiac functioning, as indexed by baseline RSA, during early childhood. For example, Perry et al. (2013) demonstrated increases in baseline RSA from 3 to 5 years of age, and Alkon et al. (2011) demonstrated increases from 4 to 6 years of age. On the other hand, the few studies that examined continuity and change in RSA change (i.e., vagal withdrawal) over time revealed mixed findings. For example, Calkins and Keane (2004) found that the magnitude of RSA withdrawal decreased from 2 to 4.5 years of age, such that children tended to engage in lower levels of vagal withdrawal as they got older. Given that vagal withdrawal reflects coping responses to challenge (Porges, 2011), it is possible that children needed to rely less on physiological coping responses if the laboratory tasks became easier for them over time. In another longitudinal study, Perry et al. (2013) examined change in RSA withdrawal in response to emotion regulation tasks from 3 to 5 years of age and found that there was no change in the means of vagal withdrawal over time. Moreover, the trajectory analyses suggested that for almost half of the children RSA withdrawal decreased and for the other half RSA withdrawal increased over time. Notably, this study used different emotion regulation tasks at different time points for the tasks to be novel and stressful for the children. Given that these tasks may not have been equivalent with respect to how frustrating or stressful they were, and that different children may find different types of tasks frustrating, the null findings may be a function of using different tasks over time. As such, it would be important to examine changes in RSA withdrawal in the same tasks over time. For example, if tasks become less challenging for children, there may be decreases the magnitude of RSA withdrawal; however, certain tasks may not get easier across early childhood, in which case there may be continuity in children's ANS responses.

Sympathetic functioning. The few studies that examined change in baseline sympathetic cardiac functioning, as indexed by baseline PEP, found increases during early childhood. For example, Alkon et al. (2010) reported increases in baseline PEP from 4 to 6 years of age, and Esposito et al. (2016) reported increases in baseline PEP in a mixed-age group sample across the early childhood period. Notably, there is a scarcity of research on continuity and change in PEP change over time; and therefore, it would be important to examine whether children elicit greater or lower levels of sympathetic activation for the same tasks across time.

Goal 3. To Examine the Stability and Continuity/Change in Children's Sympathetic and Parasympathetic Cardiac Responses in Early Childhood

3a). Are children's sympathetic and parasympathetic cardiac responses stable over the course of early childhood?

Baseline functioning. Consistent with the findings of previous work, it is hypothesized that there will be modest to moderate levels of stability in children's baseline sympathetic (i.e., baseline PEP) and parasympathetic (i.e., baseline RSA) activity across early childhood.

Sympathetic and parasympathetic responsivity (i.e., change scores). Based on findings suggesting that parasympathetic responsivity is somewhat stable over time, it is hypothesized that there would be modest levels of stability in RSA change over time. Laboratory challenges that elicit greater physiological responsivity and require "active coping" may show greater stability over time compared to tasks that elicit lower levels of physiological response and elicit "passive coping." Given the scarcity of research examining the stability in children's PEP change scores over time, whether or not there will be stability in PEP change scores will be an exploratory question.

3b). Are children's sympathetic and parasympathetic responses continuous or discontinuous across early childhood?

Baseline functioning. Based on previous findings indicating increases in baseline RSA and PEP from 4 to 6 years of age (Alkon et al., 2011), it is hypothesized that there will be increases in baseline RSA and PEP over the course of the study. In testing this hypothesis, this study will examine whether there is change from 4 to 5 years, and from 5 to 6 years, and test whether there is linear growth from 4 to 6 years.

Sympathetic and parasympathetic responsivity (i.e., RSA & PEP change scores). The limited work that examined continuity and change in parasympathetic and sympathetic responsivity across the early childhood yielded inconsistent findings. Therefore, this examination will be more exploratory. Continuity and change in ANS responsivity will be examined for two cognitive challenges (i.e., Tangrams & Go/No-Go) given that they were administered across all assessments.

Indices of Autonomic Nervous System Functioning and Adaptive Functioning

Vagal Tone

Vagal tone, often indexed by baseline RSA, has been proposed to index the integrity of the coordination between the prefrontal brain regions and the heart, and capacity for self-regulation (Thayer et al., 2009). A large body of evidence suggests that greater vagal tone is associated with better cognitive, emotional, and behavioral control. Greater baseline RSA has been linked with better recognition memory and attention in infancy (Linnemeyer & Porges, 1986), better response inhibition (Marcovitch et al., 2010) and performance in fluid intelligence measures including processing speed, working memory and cognitive efficiency in early childhood (Staton, El-Sheikh, & Buckhalt, 2009), better sustained attention in middle childhood (Suess, Porges, & Plude, 1994), and better response inhibition in adults (Gillie, Vasey, & Thayer, 2014; Hovland et al., 2012; Johnsen et al., 2003). There is also evidence suggesting that greater vagal tone is associated with better emotion regulation (Holzman & Bridgett, 2017). Moreover, findings from a recent metanalysis showed that although greater vagal tone was associated with multiple aspects of self-regulation including emotional and behavioral regulation, the effects were very small (r = .09; Holzman & Bridgett, 2017). Overall, although these studies support the proposition that greater vagal tone is associated with better self-regulation, given the very modest associations, it is important to consider non-linear associations between baseline RSA and self-regulation or understand the conditions under which these associations exist.

Although there is vast empirical work suggesting that greater baseline RSA may be associated with better self-regulation and social adjustment outcomes, there is newer evidence suggesting that there may be quadratic relations between baseline RSA and certain psychological and behavioral outcomes, such that moderate vagal tone predicts better outcomes, whereas lower and higher vagal tone predicts less adaptive outcomes. For example, across three samples of children, Miller, Kahle, and Hastings (2017) found quadratic relations between children's vagal tone and prosociality, such that moderate vagal tone was associated with greater child self-reported prosociality and better observed emphatetic concern toward others' distress cues, concurrently; and better self-, teacher-, and mother-reported prosical behaviors longitudinally. Likewise, in a sample of adults, Kogan and colleagues (2014) tested quadratic relations between vagal tone and a range of outcomes, and found that moderate vagal tone was associated with greater prosociality, compassion, and gratitude. These two studies suggest that the association between vagal tone and social adjustment outcomes may have a quadratic relation such that moderate vagal tone may be more optimal for social adjustment than either low and high vagal tone. Based on this evidence, it would be critical to understand whether high, moderate, and low baseline RSA would support self-regulation outcomes as well as other social adjustment outcomes such as externalizing behaviors.

Moreover, consistent with the notion that low baseline RSA may reflect low capacity for self-regulation, results from a meta-analysis have shown that in clinical or high-risk samples, children with considerable externalizing problems or who were diagnosed with an externalizing disorder such as conduct problems experienced low absolute levels of vagal tone (Graziano & Derefinko, 2013). Consistent with the idea of allostasis or to maintain stability through changes in the functioning of the biological systems, it is possible that individuals' baseline RSA may reflect their adaptation to environmental conditions.

Vagal Withdrawal

Vagal withdrawal, as indexed by RSA withdrawal, reflects inhibition of the parasympathetic influence on the heart. As such, vagal withdrawal and parasympathetic inhibition can be used interchangeably. According to the Polyvagal Theory, vagal withdrawal may mobilize metabolic resources to promote coping with challenges such as environment threats (Porges, 2011). Based on this perspective, greater vagal withdrawal may reflect higher levels of coping responses to deal with challenges, whereas moderate levels of vagal withdrawal facilitate orienting to stimuli and good attention (Porges, 1995, 2011). On the other hand, according to the Neurovisceral Integration Model, in contexts appraised as threatening, the prefrontal cortex withdraws its vagally mediated inhibitory influence on subcortical brain regions allowing for the facilitation of more automatic and non-volitional behaviors necessary for survival (Thayer & Lane, 2000; Thayer et al., 2009). Based on this model, greater vagal or RSA withdrawal may reflect greater activation of amygdala and lower involvement of frontal regions (Thayer et al., 2009). Given the central role of the frontal regions of the brain in “top-down” aspects of self-regulation, high vagal withdrawal therefore may reflect lower ability to perform well in executive functions or regulate their emotions.

Studies that examined associations between RSA withdrawal and child self-regulation and adjustment outcomes revealed mixed findings. In infancy, RSA withdrawal was associated with greater orientation to mother but not with greater distraction from aversive stimuli (Perry et al., 2016). Likewise, greater RSA withdrawal during a delay/emotion-regulation task was associated with greater other-oriented self-regulation behaviors such as engaging with adults (Calkins, 1997). However, in early childhood, studies failed to find linear associations between RSA withdrawal and self-regulation outcomes (Blandon et al., 2008; Marcovitch et al., 2010; Perry et al., 2013). It has been shown that moderate but not high levels of vagal withdrawal was associated with better response inhibition performance in young children (Marcovitch et al., 2010). Given the mixed findings, it would be important to examine the optimal levels of RSA withdrawal for effective self-regulation.

Several studies examined the associations between RSA responsivity and child adjustment outcomes. Results from a meta-analysis involving 44 studies suggested that greater RSA withdrawal was associated modestly with fewer externalizing and internalizing behavior problems, and better cognitive academic outcomes (Graziano &

Derefinko, 2013). However, it is critical to note that the association between RSA withdrawal and adjustment outcomes may depend on the nature of the laboratory task during which RSA was assessed. For example, in contrast to the findings of Graziano and Derefinko's meta-analysis, greater RSA withdrawal during tasks designed to elicit negative affect were associated with increased internalizing symptom severity during early childhood (Calkins et al., 2007) and adolescence (Boyce et al., 2001). Moreover, Fortunato, Gatzke-Kopp, and Ram (2013) found that greater RSA withdrawal in response to fearful and sad movies was associated with internalizing symptom severity, whereas attenuated RSA withdrawal during a happy film was associated with externalizing symptom severity. Greater RSA withdrawal during inhibitory control tasks was associated with greater externalizing behavior (Utendale, Nuselovici, Saint-Pierre, Hubert, Chochol, & Hastings, 2014). These mixed findings underscore the importance of examining the associations between RSA responsivity and behavioral outcomes may depend on the nature of the task. As such, it may be important to examine the relations between RSA responsivity and behavioral outcomes using multiple challenges.

Sympathetic Tone

Sympathetic tone, as indexed by baseline PEP, reflects sympathetic activity during resting state. Greater sympathetic tone is indexed by shorter or lower levels of baseline PEP. Previous research has linked lower baseline PEP with greater fearfulness and poorer emotion regulation (Buss, Davidson, Kalin, & Goldsmith, 2004). Compared to a control group, children diagnosed with ADHD and oppositional defiant disorder exhibited lower levels of baseline PEP (Crowell et al., 2006). Likewise, in a sample of children with ADHD, attenuated baseline PEP was linked with greater conduct problems and aggression (Beauchaine et al., 2013). Lower baseline PEP following adoption was associated with greater behavioral difficulties two years later (Esposito et al., 2016). These studies together suggest that greater sympathetic tone or lower baseline PEP may reflect difficulties with self-regulation or social adjustment, especially in high-risk or clinical populations.

Previous research has also linked exposure to stressful caregiving or contextual experiences with greater sympathetic tone. For example, in a sample of adopted children, previously institutionalized children were shown to have greater sympathetic tone than those who were previously foster cared (Gunnar, Frenn, Wewerka, & Van Ryzin, 2009). In a sample of children in foster care, children who had a history of neglect had greater sympathetic tone than those who did not (Oosterman, De Schipper, Fisher, Dozier, & Schuengel, 2010). These findings together suggest that exposure to high levels of contextual stress may lead to increases in sympathetic tone.

Sympathetic ANS Responsivity

An important body of research examined children's sympathetic responsivity during tasks that involved motivational components such as incentive or awards with externalizing behavior problems. Inherent in this line of research is the idea externalizing problems emerge as a result of vulnerability to impulsivity related problems (Beauchaine, 2012). Impulsivity is viewed as socially inappropriate behaviors that are emitted without thinking (Beauchaine, 2012). It has been suggested that individuals who have trait impulsivity frequently engage in reward-seeking behaviors to upregulate their underactive mesolimbic dopamine system. Based on the notion that PEP shortening during motivational tasks reflects dopaminergic reactivity to reward or punishment, individual differences in PEP responsivity has been proposed to reflect proclivity towards reward sensitivity, aggression, and/or externalizing behaviors (Beauchaine, 2012). As such, PEP shortening to incentives has been linked primarily with externalizing behaviors (Beauchaine, 2012). Despite this line of research that utilized tasks that involved motivational components, less research examined whether sympathetic responsivity during other challenges relate to self-regulation or social adjustment outcomes.

Profiles of Sympathetic and Parasympathetic ANS Functioning in Early Childhood

The adaptive calibration model was tested only in few empirical studies. Del Giudice, Hinnant, Ellis, and El-Sheikh (2012) conducted the first empirical study to test this model and examined profiles of sympathetic and parasympathetic functioning during baseline and a challenge task in a sample of 8- to 10-year-old children. In support of the adaptive calibration model, results from finite mixture modeling yielded four profiles: buffered (45%), sensitive (27%), unemotional (18%), and vigilant (10%). Compared to the buffered group, children in the unemotional and vigilant groups were more likely to be exposed to greater levels of negative family relationships and lower levels of family warmth and predictability. Although not proposed by the model, negative family relationships were also more common in the sensitive group as compared to the buffered group. Contrary to the propositions of the model, higher levels of ecological stress, a latent variable including indicators such as low socioeconomic status, economic strain and alcohol use, did not predict odds of membership in the groups.

In a second study, Quas et al., (2014) examined physiological profiles of sympathetic (PEP), parasympathetic (RSA), cardiac activity (HR), and adrenocortical activity (cortisol) across four independent samples with a total of 664 children ranging in age from 4- to 14-years. In addition to obtaining baseline levels of physiological activity, children's physiological responses to challenge were obtained during a standardized protocol that included a *social* task during children were asked about their likes and dislikes, a *cognitive* task during which children were asked to repeat numbers they heard, a *sensory* task which involved tasting a new substance, and an *emotional* task during which children watched emotionally evocative videos. Their results from latent profile analyses revealed six distinct profiles, four of which shared similarities with the profiles proposed by the adaptive calibration model. Similar to adaptive calibration model's buffered profile, the greatest proportion of children were in the moderate reactivity group (52-80%) characterized by low to moderate levels of responsivity across all systems. The parasympathetic specific reactivity profile (2-36%), characterized by parasympathetic responsivity to task but no change in sympathetic and cortisol responses, was argued to resemble the sensitive profile proposed by the adaptive calibration model. The anticipatory arousal profile (4-9%), characterized by high anticipatory responses (high baseline values prior to the challenges), but blunted responsivity to challenges, has been argued to show similarities with the adaptive calibration's vigilant profile (Kolacz et al., 2016). Notably, the underaroused profile (2-36%) resembled the unemotional profile proposed by the adaptive calibration model. The authors also found two additional groups that were not proposed by the adaptive calibration model: a multi-system reactivity group (7-14%) and an HPA-specific reactivity group (6-7%).

In a third study on children's physiological profiles, Kolacz, Holochwost, Gariépy, and Mills-Koonce (2016) examined children's profiles of basal levels of parasympathetic (RSA), sympathetic (salivary alpha-amylase), and adrenocortical activity (cortisol) and their associations with two temperamental styles, negative affectivity and surgency, as reported by parents. Their results yielded four profiles: sensitive (17%), buffered (45%), vigilant with low adrenocortical activity (24%), and vigilant with high adrenocortical activity (15%). Their findings demonstrating a large group of children with a buffered physiological pattern, and a small group of children with a vigilant high profile were consistent with the adaptive calibration model. However, the proportion of the children in the sensitive physiological pattern was smaller than what has been reported by Del Guide et al. Moreover, contrary to the adaptive calibration model, the authors did not find an unemotional group; but found a new pattern of physiological functioning referred to as vigilant low. The children in the buffered group were reported to have lower negative affectivity than those in the vigilant high group, and lower fearfulness and discomfort to sensitivity compared to the vigilant low group, suggesting that distinct patterns of physiological functioning can meaningfully relate to distinct temperamental styles. Notably, an important limitation of this study was that, although adaptive calibration model proposes distinct profiles based on both baseline values and responsivity to challenges, only baseline values were used in the examination of patterns of physiological functioning.

Goal 4. To Examine Whether There are Profiles of Children with Distinct Patterns of Sympathetic and Parasympathetic Functioning, and Whether These Profiles Differ with respect to Self-Regulation Outcomes

4a). Are there profiles of children with unique patterns of sympathetic and parasympathetic functioning during baseline and challenge tasks?

Based on the adaptive calibration model's proposition, it was hypothesized that there would be four patterns of stress responsivity: sensitive, buffered, vigilant, and unemotional. It was expected that a ***sensitive profile*** with high level of parasympathetic activity (i.e., high baseline RSA & RSA change) and moderate levels of sympathetic activity (i.e., moderate baseline PEP & PEP change) would emerge and constitute one of the largest groups given that this stress responsivity pattern is theorized to be overrepresented in low stress contexts. Moreover, a ***buffered profile*** with moderate levels of parasympathetic activity (i.e., moderate baseline RSA & RSA change) and sympathetic activity (i.e., moderate baseline PEP & PEP change) was expected to emerge. Given that the buffered profile is theorized to develop as a result of exposure to moderate-levels of environmental stress, we expected this group to constitute one of the largest groups. Finally, a ***vigilant profile*** with high levels of sympathetic activity and low level of parasympathetic activity, and an ***unemotional profile*** with low responsivity in both branches were expected to emerge. Given that these profiles are theorized to develop in high stress environments, these profiles were expected to be smaller in a community sample like in this study.

4b). Are there group differences across these profiles with respect to self-regulation outcomes?

Based on the adaptive calibration model, it is hypothesized that children in the buffered and sensitive profiles will have better self-regulation (i.e., executive functions, emotion regulation, behavioral regulation) and lower behavioral adjustment problems (i.e., externalizing problems) than those in the vigilant and unemotional profiles. Moreover, based on the adaptive calibration model, it is hypothesized that children in the sensitive profile will show better self-regulation and behavioral adjustment outcomes than those in the buffered profile.

CHAPTER IV

METHODS

Participants

The sample for this study were 278 children (55% girls) and their primary caregivers (96% mothers) who participated in a longitudinal study examining the physiological, emotional and cognitive predictors of early academic readiness. Children's mean age at the preschool, kindergarten, and first grade assessments were 56.37 (SD=4.68), 70.80 (SD = 3.86), and 82.76 (SD=4.02) months, respectively. At the preschool assessment, mothers' ages ranged from 19 to 58 (M=35) and approximately 61% of mothers had a 4-year college degree or had completed higher levels of education. Average income-to-needs ratio, calculated by dividing the total family income by the poverty threshold for that family size, was 2.11 (SD=1.41). The sample was diverse with respect to race and ethnicity with 59% of the children reported as European American, 30% as African American, and 11% as other races; 6.5% of the sample identified as Hispanic. Of the 278 participants in the original sample, 249 returned for the kindergarten assessment and 240 returned for the first-grade assessment. Participants who did not return for the last assessment did not differ from the remaining participants with respect to gender, minority status, maternal education, or observed caregiver behaviors.

Procedure

Overview

Children and their primary caregivers participated in laboratory assessments when children were at preschool, kindergarten and first grade. Participants were recruited from daycare centers, local establishments (e.g., children's museum) or via participant referral in a midsized Southeastern city in the United States. Laboratory assessments were scheduled with caregivers who either called the research center directly or provided contact information to be contacted by the researchers. Before each visit, mothers provided written consent and children were briefed about the games that they were going to play. Following the consent, children participated in a battery of tasks designed to assess their cognitive and emotional development, whereas mothers filled in questionnaires and participated in a mother-child interaction task. Physiological data was collected from children during the first half of the visits that typically lasted for 2 hours. In order to assess children's behaviors in the school setting, teachers were asked to complete online surveys using Qualtrics in the spring semester of the target children's kindergarten year. Only the teachers of children whose mothers completed a consent form to allow the researchers to contact the child's teacher were contacted. Mothers received monetary compensation for their participation, and children selected a small toy at the completion of the visit. All procedures were approved by the university institutional review board.

Laboratory Assessment

Across all time points, a similar laboratory procedure took place. After the informed consent, mothers left the room to fill in questionnaires in an adjacent room, and children participated in three academic assessments, particularly Woodcock Johnson's applied problems, literacy, and numbers reversed tasks. Next, approximately 20-25 minutes into the session, the experimenter placed the physiological equipment onto the child. After the placement, children participated in a series of tasks during which their cardiac electrophysiological data were collected. The first procedure involved two non-arousing, baseline tasks. During the fish task (2 minutes), children watched a video of colorful fish swimming. During the statue task (1 minute), children watched numbers decreasing gradually from 60 to 0 at the center of the screen. Following the baseline procedure, children participated in two learning engagement tasks: tangrams and story. During the Tangrams task (10 minutes), which required children to engage in spatial problem-solving, children were asked to fit wooden shapes into the pictures of shapes presented on paper. For some pictures, children needed to combine two shapes to make a larger shape and flip a shape to make it fit in the lines. Following a brief demonstration, children were presented with puzzles of increasing difficulty and instructed to ask for help if needed. Following the learning engagement tasks, children participated in two executive functions tasks, one of which was the Go/No-Go tasks (see below for detailed information). During the Go/No-Go task, which can be characterized as a long and repetitive task that requires attention, children were asked to press the button for all animals except for the dog. This task is typically used to assess inhibitory control. After this task, children participated in emotion regulation tasks designed to elicit negative affect. Given that novelty of the task is important for eliciting negative affect, different emotion regulation tasks were used at each time point. These brief tasks described below were terminated early if the child became very upset or in rare instances if the child left the situation. After the emotion regulation tasks, the physiological equipment were removed and children received snacks.

During the preschool assessment, there were two emotion tasks: Locked Box and Toy Removal. The Locked Box task originates from Lab-TAB's "transparent box" episode of distress (Gange, Hulle, Aksan, Essex, & Goldsmith, 2011). During this task, children were first demonstrated how to open a lock with a key. After ensuring that the child can use a key to unlock a lock, the child was asked to select a toy from a set of three attractive toys. The selected toy was then placed in a transparent box and Locked with a padlock. The experimenter provided the child with a large ring of wrong keys and instructed the child to use the keys to unlock the lock in order to play with the toy. The experimenter prompted the child to open the box in 15 second intervals throughout the 4-minute task. To terminate the task, the experimenter told the child that she has found the correct key and allowed the child to open the box to access the toy. The Toy Removal task followed the Locked Box task. After allowing the child to play with the toy removed out of the box momentarily, the experimenter took the toy away from the child and played with it for two minutes. The experimenter periodically commented on how fun it was to play with the toy. After two minutes, the experimenter returned the toy to the child.

During the kindergarten assessment, there were three emotion tasks: Not Sharing, The Impossible to Open Gift, and the Disappointing Gift. For the purposes of this study, only the first two emotion tasks were used. The Not Sharing task originates from Lab-TAB's "I'm not sharing" episode of distress (Goldsmith, Reilly, Longley, & Prescott, 2001). This interpersonal task targets the child's feelings of being treated unjustly and is intended to be upsetting/frustrating for the child. The task starts with the experimenter telling the child that the assistant has a surprise for them. The assistant comes into the room with candy and instructs the experimenter to divide the candy evenly between them both. After the assistant leaves, the experimenter shares the first 6 candies equally. However, after that, the experimenter gives themselves more candy than the child multiple times, and at one point eats a piece of the child's candy. At the very end of the unfair episode, the experimenter takes all of the child's candy. Following the unfair episode, the experimenter allowed the child to pick and eat 2 pieces of their favorite candy. After the recovery, the Impossible to Open Gift task, adapted from Carlson and Wang (2007) and Goldsmith, Reilly, Lemery, Longley, and Prescott (1999), was administered. In this task, the experimenter presented the child with a gift for all their hard work and encouraged the child to open the gift right away; however, the gift was sealed so it could not be opened. After giving the gift, the experimenter leaves the room, and returns after one minute and apologizes to the child for giving them the wrong gift box. The experimenter then gives the child a gift box that is very easy to open but has a disappointing gift inside: a piece of tree bark. The experimenter acts busy in the room while the child's responses are recorded for one minute. After one minute, the experimenter notices that the wrong toy was wrapped, and gives the child the toy they were supposed to receive: a small soft animal.

During the first-grade assessment, there were two emotion tasks: Puzzle Box and Broken Toy. In the Puzzle Box task, children were asked to assemble a wooden puzzle in a large box without looking at it (Eisenberg et al., 2000, 2001). One side of the box had plexiglass through which the experimenter could observe the child's hand movements and the other side had two sleeves through which the children were asked to slip their arms to access the puzzle. The sleeves were covered by a cloth that could be lifted if a child wanted to peek at the puzzle. Children were told to work on the puzzle without peeking and that it was an easy puzzle so they had only 4 minutes to finish it. Children were told that once they finished the puzzle, there was a surprise for them. The experimenter watched the child and made comments such as "finish the puzzle," and "that puzzle isn't very hard" in 15 second intervals. In the Broken Toy task, the experimenter told the child that she has a really cool toy for them to play with because the child worked hard on the puzzle box and left the room to bring two hand computer toys. Next, the experimenter brought toys, demonstrated how to turn on and pick a game on the toy, and then gave the child the toy that does not work. The experimenter played with her toy for two minutes periodically making comments like "I really like this game!" "This toy has so many fun games on it!" After 2-minutes, the experimenter said, "Oh no! Is your toy not working?" and gave her own toy to the child.

For the purposes of this study, children's ANS functioning was assessed during 2 emotional and 2 cognitive challenges across all assessments. At each assessment, children's ANS functioning was measured during 2 cognitive tasks: (a) the spatial problem-solving Tangrams task, (b) Go/No-Go task. The Tangrams task has been conceptualized as a cognitively more demanding task than the Go/No-Go task. Four of the 6 emotion tasks (Locked Box, Impossible to Open Gift Box, Puzzle Box, Broken Toy) were conceptualized as frustrating challenges during which children's goals were blocked, whereas the Toy Removal and Not Sharing tasks were conceptualized as interpersonally upsetting tasks that involve an injustice/unfairness component.

Measures

Physiological Measures

The cardiovascular data was collected using Mindware BioNex 8SLT Chassis (Gahanna, OH), which measured electrocardiogram (ECG) and impedance cardiogram (ICG) signals simultaneously. Seven spot electrodes were placed on participants to record cardiogram signals. ECG signals were obtained using the modified Lead II configuration with two ECG electrodes placed on the distal end of the right clavicle and lower left rib, with a ground electrode placed on the lower right rib. To quantify the HR data, the ECG signal was passed through an A/D converter with ECG sampled at 1,000 Hz and Zo sampled at 500 Hz. ICG signals were recorded using four electrodes. Two impedance electrodes were placed on the front of the participants' body, specifically on the left collarbone horizontal to the jugular notch and at the bottom of the sternum. Two current electrodes were placed on the back, specifically on the participant's neck and approximately one inch below the lower receiving electrode.

Respiratory sinus arrhythmia (RSA). RSA is heart rate variability measured in the interbeat interval (IBI) series associated with the phases of breathing. RSA was derived from the IBI series over the course of each 30 second epoch, using Mindware Technologies HRV 3.0 analysis software. This program calculates RSA by subjecting the IBI series for each epoch to Fast Fourier Transform (FFT) and applying a Hamming window for the .24-1.04 Hz frequency range (the frequency band appropriate for use in children this age; Bar-Haim, Marshall, & Fox, 2000) of the resulting spectral distribution, which offers a reliable estimate of the extent of parasympathetic influence on the heart (Bernston, Cacioppo, Quigley, & Fabro, 1994). Spectral distributions of the respiration signals were examined to ensure that integral power peaked within the .24 -1.04 frequency range as expected for all participants. The integral of the power in the .24 – 1.04 RSA band was extracted and the natural logarithm of this measure was the RSA statistic.

The RSA data files were cleaned and edited using software provided by MindWare Technologies to derive mean RSA for each 30-second epoch. Trained researchers have visually inspected each epoch to correct misidentified beats manually, identify and exclude spurious data due to equipment or sticker problems or child movement. Scores derived from these epochs were averaged to create mean RSA scores for each task. Task specific change in these measures were calculated by subtracting task RSA from baseline RSA (RSA Δ = Baseline RSA-Task RSA) such that positive scores indicate parasympathetic withdrawal, with larger scores indicating greater withdrawal. For short tasks (e.g., impossible to open gift), two artifact-free epochs were needed to retain participants' task RSA score. For the long tasks (e.g., tangrams), participants' task RSA scores were retained if at least 50% of the epochs were artifact-free.

Preejection period (PEP). PEP, derived from the ICG signals, refers to the time interval in milliseconds between the onset of ventricular depolarization (Q wave of the ECG) and onset of left ventricular ejection (B point of the dz/dt wave; Sherwood et al., 1990). The Q and B points were identified automatically using algorithms provided by the MindWare IMP 3.1 analysis software. The Q point was identified at the lowest point of the signal appearing within 25 seconds prior to the R-point (Bush, Caron, & Alkon, 2016). The B point was estimated using Lozano's method, which approximates the B-point based on the dz/dt peak (percent dz/dt was identified as 55%, plus 4; see Lozano et al., 2007).

The PEP data files are cleaned and edited using the IMP 3.1 software provided by MindWare Technologies to derive mean PEP for each 30-second epoch. Trained researchers have visually inspected each epoch to correct misidentified beats manually, identify and exclude spurious data due to equipment or sticker problems or child movement. Scores derived from these epochs were averaged to create mean PEP scores for each task. Task specific change in these measures were calculated by subtracting task PEP from baseline PEP (PEP Δ = Baseline PEP-Task PEP) so that positive scores indicate sympathetic activation, with larger scores indicating greater activation. For short tasks (e.g., impossible to open gift), two artifact-free epochs were needed to retain participants' task PEP score. For the long tasks (e.g., tangrams), participants' task PEP scores were retained if at least 50% of the epochs were artifact-free.

Child Self-Regulation Measures

(a) Child emotion regulation in preschool and kindergarten. Observed emotion regulation and teacher-report of child emotion reactivity scores were used.

Observed emotion regulation. Children's affect and regulation was coded for each emotion regulation task conducted in the laboratory. The three emotion regulation indicators used in this study are: global regulation, latency to distress, and verbal negativity. Global regulation reflects the ability to maintain or regain neutral or positive affect and was rated on a scale from 1 (unregulated) to 5 (well-regulated). Latency to distress refers to how long it takes for the child to show the first sign of distress and was calculated as the difference between the first display of distress and the start time of the task in seconds. Verbal negativity refers to the frequency of the child's negative verbal expressions of frustration and was rated on a scale from 0 (no negative vocalizations) to 3 (6 or more instances of negative vocalizations). In preschool, reliability was calculated on 53 double rated cases and intraclass correlation coefficients (ICC's) were .88 and .83 for global regulation, .87 and .90 for verbal negativity, and .70 and .91 for latency to distress, for Locked Box and Toy Removal respectively. In kindergarten, reliability was calculated on 40 double rated cases and ICCs were .89 and .91 for global regulation, .92 and .96 for verbal negativity, and .80 and .95 for latency to distress, for Not Sharing and Impossible Gift respectively. Given the good coder reliability for all indicators as well as moderate within-indicator correlations across two tasks (r = .39 - .60), composite scores were created for global regulation, verbal negativity, and latency to distress by averaging across the scores obtained from two laboratory tasks. Next, given that these 3 indicators of emotion regulation were strongly correlated both in preschool (r = .71-.81) and in kindergarten (r = .61-.73), a global emotion regulation composite was created by averaging the standardized scores of these three observed indicators for each assessment.

Teacher-report of child emotion reactivity in kindergarten. The Emotion Regulation Checklist (ERC) will be used as a teacher-report measure of child emotion regulation (Shields & Cicchetti; 1997, 1998). The version used in the STAR Project included 24 items. Each item describes how children control their emotional states using a 4-point Likert scale ranging from 1 (Never) to 4 (Always). The ERC includes two subscales: *reactivity* (15 items; e.g., "is easily frustrated") and *regulation* (8 items; e.g., "can modulate excitement in emotionally arousing contexts"). Items are averaged such that higher scores indicate greater reactivity and regulation respectively. Internal consistency reliability reported in the original publication of the ERC was .96 for the reactivity subscale, and .83 for the regulation subscale (Shields & Cicchetti, 1997).

(b) Observed executive functions in preschool and kindergarten. Three core components of children's executive functions were assessed. These are: updating/working memory, inhibitory control, and cognitive flexibility.

Working memory. Children's working memory capacity/updating was measured using the Numbers Reversed test of The Woodcock Johnson III (Woodcock, McGrew, & Mather, 2001). During this task, participants were instructed to listen to the experimenter recite a string of numbers and then repeat the numbers backward. In each block, there were five different series of numbers with equal number of digits. In the first block, children were asked to repeat two numbers backwards, and in each subsequent block there was one more number to recite. The task was terminated if participants missed all five trials in a given block. An overall accuracy score was calculated by adding children's correct responses (each trial 1 point) such that higher scores reflect more efficient working memory and updating.

Inhibitory control. Children's inhibitory control was measured via a computerized animal go/ no-go association task (Lahat, Todd, Mahy, Lau, & Zelazo, 2009), which was presented using E-Prime Version 2.0 (PST, Pittsburgh, PA). During this task, children were instructed to press the button as soon as they saw an animal (go stimulus) except for the dog (no-go stimulus). Before each trial, a fixation point, accompanied by a "ding" sound, appeared at the center of the screen, and stayed for 1500 ms. This was followed by an animal stimulus (i.e., cow, horse, bear, pig, or dog) that appeared on the screeen for 1500 ms., or until a response was registered. Following a brief introduction, children were presented with 10 practice trials composed of 6 go and 4 no-go stimuli. The practice block was repeated until children answered 9 out of 10 correct. The actual task included 144 trials (75% Go, 25% No-Go) divided into four blocks. After correct answers, a yellow smiley face appeared on the screen, whereas after incorrect or missed responses, a red frowning face was shown. Participants received a value of .185 (5 points/27 go trials) for every correct go stimulus, and a value of .56 (5 points/nine n- go trials) for every correct no-go stimulus (Zelazo et al., 2013). A discriminability index (d') was calculated as a measure of task performance such that d' = Z(Correct/Hit) – Z (Incorrect/False Alarm). Higher scores indicated better performance.

Cognitive flexibility. Children's cognitive flexibility was measured via the computerized version of The Dimensional Card Sort task designed to assess the extent to which children can use rules flexibly to direct their behavior (Espinet, Anderson, & Zelazo, 2012). During this task, children were presented with a fixation screen with stimuli at the bottom that varied across two dimensions: color and shape (e.g., red rabbit and blue boat). During the preswitch block (15 trials), children were asked to sort stimuli according to one dimension (i.e., shape) by pressing the corresponding sticker covered button. Children who performed at or below chance (7 or fewer correct trials out of 15) during pre-switch were considered to fail this task and were given a score of 0 for their post-switch score. This strategy allowed us to ensure that all children who received a post-switch score understood the basic rule of the game. During the postswitch block (30 trials), children were asked to sort the stimuli according to the other dimension (i.e., color). Performance on the postswitch task was scored as the number of correct responses out of 30 trials. The postswitch was followed by a more complex "borders" block of the task (12 trials); children were instructed to sort stimuli on one dimension (i.e., color) if the picture had a border around it but the other dimension (i.e., shape) if the picture did not have a border (Zelazo, 2006). Post-switch performance was scored as the number of correct responses out of 30 trials, whereas borders performance was scored as the number of correct responses out of 12. Scores of postswitch and borders tasks were averaged to create an overall cognitive flexibility score. Higher scores indicated greater cognitive flexibility.

(c) Teacher-report of child behavioral regulation in kindergarten.

Attention control. Children's attention control at kindergarten was assessed via the attention problems subscale (10 items) of The Child Behavior Checklist Teacher Report Form (Achenbach & Rescorla, 2001). The teacher was asked to indicate how well each item described the target child currently or within the last six months using a scale of 0 (*not true*), 1 (*somewhat or sometimes true*), and 2 (*very true or often true*). Example items include "inattentive or easily distracted" and "can't concentrate, can't pay attention for long." Teachers' ratings on these items were summed and reverse scored such that higher scores indicated better attention control. Items of this scale had good internal reliability (Cronbach's alpha .95).

Work habits. The work habits scale of The Mock Report Card was used to measure teachers' judgments of children's work habits in the classroom setting. Teachers reported on children's classroom work habits (six items) on a 5-point scale ranging from 1 (*very poor*) to 5 (*very good*). Example items include "works well independently," "works neatly and carefully," and "uses time wisely." Teachers' ratings on these items were averaged to create the work habits scale. Higher scores indicated better work habits. The work habits scale demonstrated good internal reliability (.95).

Discipline/persistence. Children's discipline and persistence was assessed using the Discipline/Persistence subscale of the Learning Behaviors Scale (McDermott, 1999; Rikoon, McDer- mott, & Fantuzzo, 2012). Teachers reported on children's discipline and persistence (eight items) on a Likert-type scale, ranging from 0 (*does not apply*) to 2 (*most often applies*). Example items include "sticks to a task with no more than minor distractions" and "tries hard but concentration soon fades and performance deteriorates."

Teachers' ratings on these items were summed and reverse scored. Higher scores indicated greater discipline and persistence during activities. The items of this scale had good internal reliability (alpha=.82). The Learning Behaviors Scale demonstrates internal reliability, convergent and divergent validity, and predictive validity regarding children's future school adjustment (McDermott, Rikoon, & Fantuzzo, 2016; Rikoon et al., 2012).

CHAPTER V

RESULTS

Preliminary Analyses

Preliminary data analyses included the following procedures: (a) identifying the reasons for missing data, (b) examining outliers, and (c) checking normality of the distributions by evaluating descriptive statistics and histograms. Reasons for missing data are detailed in supplemental materials (see Appendix B). Outliers were examined for mean RSA, mean PEP, RSA responsivity, and PEP responsivity scores for each task at each time point. In each variable, there were either no outliers or no more than 3 outliers. In the case of outliers, the validity of the data was checked by examining the raw dataset as well as watching the video during which the physiological data was collected. If outliers were due to artifact or technical problems, they were removed from the dataset. Otherwise, analyses were conducted with and without the outliers to make sure results were not driven by the outliers. Analyses without the outliers are presented in the results section. All physiological variables had normal distributions.

Table 1 includes descriptive information for mean RSA. Table 2 includes descriptive information for RSA responsivity. Table 3 includes descriptive information for mean PEP, and Table 4 includes descriptive information for PEP responsivity. Each of these tables include descriptive information for scores obtained during baseline and the laboratory challenges conducted in preschool, kindergarten, and grade 1. Composite scores for ANS activity during emotion tasks were calculated by averaging the ANS scores obtained from the emotional challenges conducted during that year's assessment. For example, mean RSA for Emotional Tasks Composite is the average of mean RSA during the Locked Box and Toy Removal tasks.

Primary Analyses

Goal 1. To Examine Children's Sympathetic and Parasympathetic ANS Responses to Emotional and Cognitive Challenges in Preschool, Kindergarten, and Grade 1

A series of random-intercept hierarchical linear models (HLM) were conducted to examine which laboratory challenges elicited a change in ANS activity from baseline to task. Next, follow-up pair-wise comparisons of the fixed effects (hypotheses testing) were conducted to examine whether the magnitude of ANS responsivity differed across challenges. Although a repeated-measures ANOVA followed by post-hoc paired t-tests could also be conducted, using random intercept HLM provided two main advantages. The first one was missing data was handled by full-information maximum likelihood (FIML). Thus, all individuals with data for least one laboratory task was included the in the analyses. The second advantage was that the magnitude of the ANS responsivity across challenges could be compared within the same model, taking into account the dependency across the measures.

At each time point (preschool, kindergarten, and grade 1), two random intercept models were tested: one for RSA and one for PEP. In each model, ANS activity (e.g., RSA or PEP) was the outcome variable, the intercept reflected ANS activity during baseline, and each laboratory task was entered as a predictor of ANS activity. At each time point, 2 cognitive challenges (Tangrams & Go/No-Go) and 2 emotional challenges (e.g., Locked Box & Toy Removal) were entered as predictors. As an example, in preschool, the following two models were tested:

$$RSA_{ij} = \gamma_{00} + \gamma_{10}(Tangrams_{ij}) + \gamma_{20}(GoNoGo_{ij}) + \gamma_{30}(Locked\ Box_{ij}) + \gamma_{40}(Toy\ Removal_{ij}) + u_{0j} + r_{ij}$$

$$PEP_{ij} = \gamma_{00} + \gamma_{10}(Tangrams_{ij}) + \gamma_{20}(GoNoGo_{ij}) + \gamma_{30}(Locked\ Box_{ij}) + \gamma_{40}(Toy\ Removal_{ij}) + u_{0j} + r_{ij}$$

The intercept (γ_{00}) reflected average baseline ANS activity and a significant p-value associated with this coefficient suggested that baseline ANS activity was significantly different from zero. The fixed effect of each laboratory challenge indicated the extent to which ANS activity during the laboratory challenge was different than the intercept or baseline ANS activity. For example, in the RSA models, the coefficient for Tangrams (γ_{10}) indicated the magnitude of RSA responsivity during Tangrams and a significant *p*-value linked with this coefficient suggested that there was a significant change in RSA from baseline to Tangrams. Negative values indicated that RSA decreased from baseline to task (parasympathetic withdrawal), whereas positive values indicated that RSA increased from baseline to task (parasympathetic augmentation). In the PEP models, negative values indicated that PEP decreased or shortened from baseline to task (sympathetic activation), whereas positive values indicated that PEP increased or lengthened from baseline to task (sympathetic inhibition).

Parasympathetic Responsivity

Results from models testing the effect of laboratory challenge on RSA in preschool, kindergarten, and first grade are presented in Table 5. Across all time points, all fixed effect coefficients were negative and significant, $p < .001$, suggesting that all laboratory challenges led to a reduction in children's RSA values or elicited RSA withdrawal response.

Figure 1a includes results from the hypotheses tests comparing the magnitude of the fixed effects reflecting RSA responsivity in preschool. The magnitude of RSA responsivity during the Tangrams task was significantly larger than RSA responsivity during the Go/No-Go and Toy Removal tasks, but smaller than during the Locked Box task. Further, RSA responsivity in the Locked Box task was significantly larger in magnitude than RSA responsivity in the Go/No-Go task, and in the Toy Removal task. The magnitude of RSA responsivity in the Go/No-Go and the Toy Removal tasks did not differ from one another. Overall, these results suggest that RSA withdrawal was largest in the Locked Box task, which was followed by the Tangrams task, and the Go/No-Go and the Toy Removal tasks.

Figure 2a includes results from the hypotheses tests comparing the magnitude of RSA responsivity across laboratory challenges in kindergarten. The magnitude of RSA responsivity in the Tangrams task was significantly larger than RSA responsivity in the Go/No-Go task and the Not Sharing task, but smaller than RSA responsivity in the Impossible Gift task. Go/No-Go RSA withdrawal was significantly smaller than RSA withdrawal in the Impossible Gift. Among the emotion regulation tasks, RSA withdrawal in the Not Sharing task was smaller than RSA withdrawal in the Impossible Gift. There was no difference in the RSA responsivity between the Go/No-Go and Not Sharing tasks. Overall, these results suggest that RSA withdrawal was largest in the Impossible to Open Gift task, followed by the Tangrams task, the Go/No-Go and Not Sharing task.

Figure 3a includes results from the hypotheses tests comparing the magnitude of RSA responsivity across laboratory challenges in grade 1. The magnitude of RSA responsivity in the Tangrams task was significantly larger than RSA responsivity in the Go/No-Go task and the Broken Toy, but not significantly different than the Puzzle Box. On the other hand, RSA responsivity in the Go/No-Go task was significantly smaller than RSA responsivity in the Puzzle Box and Broken Toy tasks. Finally, the Puzzle Box task elicited greater RSA withdrawal than the Broken Toy task. Overall, these results suggest that RSA withdrawal was greatest in the Tangrams and the Puzzle Box tasks, followed by the Broken Toy and the Go/No-Go tasks.

Sympathetic Responsivity

Table 6 includes results from models testing the effect of laboratory challenge on PEP in preschool, kindergarten, and first grade. The Tangrams task led to a reduction in PEP values (PEP shortening) from baseline to task in preschool ($p < .001$), in kindergarten ($p = .052$), and in grade 1 ($p < .001$), suggesting that the Tangrams challenge elicited sympathetic activation across all time points. The Go/No-Go task did not lead to a change in PEP from baseline in preschool or kindergarten but led to PEP shortening or sympathetic activation in grade 1. Among the emotional tasks, only 2 out of 6 tasks led to a change in PEP from baseline to task. The Toy Removal task in preschool and the Not

Sharing task in kindergarten led to an increase in PEP from baseline to task (PEP lengthening), suggesting these challenges elicited sympathetic inhibition. The other 4 emotion regulation tasks (Locked Box, Impossible to Open Gift, Puzzle Box, & Broken Toy) did not lead to a change in PEP, suggesting that there was no mean-level change children's sympathetic activity during these emotional challenges.

Figure 1b includes results from the hypotheses tests comparing the magnitude of the fixed effects reflecting PEP responsivity in preschool. The magnitude of PEP shortening in the Tangrams task was significantly larger than PEP shortening in the Go/No-Go task, Locked Box task and the Toy Removal tasks. PEP responsivity in the Go/No-Go and the Locked Box tasks were larger than that of the Toy Removal task. However, there was no difference in PEP responsivity across the Go/No-Go and the Locked Box tasks. Overall, these results suggest that PEP activation was largest in the Tangrams task, followed by the Locked Box and Go/No-Go tasks. The smallest PEP responsivity was observed in the Toy Removal task.

Figure 2b includes results from the hypotheses tests comparing the magnitude of the fixed effects reflecting PEP responsivity in kindergarten. PEP responsivity or shortening in the Tangrams task was significantly larger than PEP shortening in the Go/No-Go, and the Not Sharing tasks but not different from that of the Impossible Gift. On the other hand, PEP shortening in the Go/No-Go task was not different than PEP shortening in the Not Sharing or the Impossible to Open Gift task. Among the emotion regulation tasks, PEP shortening in the Not Sharing task was significantly smaller than that of Impossible Gift. Overall, based on the mean PEP responsivity scores, the greatest

PEP shortening was observed during the Tangrams task, followed by the Impossible Gift, Go/No-Go and the Not Sharing tasks.

Figure 3b includes results from the hypotheses tests comparing the magnitude of the fixed effects reflecting PEP responsivity in grade 1. The Tangrams task yielded a greater PEP shortening response than both the Puzzle Box and the Broken Toy tasks but there was no difference in PEP responsivity between the Tangrams and the Go/No-Go tasks. The Go/No-Go task led to a greater PEP shortening response compared to both the Puzzle Box and the Broken Toy. The two emotion regulation tasks, Puzzle Box and Broken Toy, did not differ in relation to PEP responsivity. Overall, the results suggested that the Go/No-Go and the Tangrams tasks elicited the greatest PEP shortening response, followed by the Puzzle Box and Broken Toy tasks.

Goal 2. To Examine Whether and During Which Challenges Children's Sympathetic and Parasympathetic Cardiac Responses Correlate or Work Reciprocally

In order to examine whether and during which children's sympathetic and parasympathetic cardiac responses were associated, a series of bivariate correlation analyses were conducted. At each time point, correlations among PEP responsivity and RSA responsivity values were examined for each task to determine whether sympathetic and parasympathetic change scores work reciprocally with one another. For example, for the Tangrams task, if PEP and RSA change scores were correlated positively, this would indicate that greater PEP shortening is associated with greater RSA withdrawal during this task. Examining the correlations across each time point would help determine whether these associations emerge consistently across different time points.

As shown in Table 7, in preschool, there was a modest positive correlation between RSA and PEP responsivity across all tasks (ranged from .15 to .26) except for the Go/No-Go (r = .05) and the Toy Removal tasks (r = .05), suggesting that greater PEP shortening (sympathetic activation) was associated with greater RSA withdrawal (parasympathetic inhibition). As shown in Table 8, in kindergarten, PEP and RSA responsivity were correlated across the Not Sharing (r =.21, p <.01) and Impossible gift (r =.22, p <.01) but not during the Tangrams and Go/No-Go tasks. As shown in Table 9, unlike the small correlations that emerged between RSA and PEP responsivity scores during preschool and kindergarten, there were no significant correlations among RSA and PEP responsivity in first grade.

Goal 3. To Examine the Stability and Continuity in Children's Sympathetic and Parasympathetic Cardiac Responses in Early Childhood

3a). Stability in ANS responses

Cross-task stability in ANS responsivity within the same assessment. Cross-task stability in children's ANS responses within the same assessment was examined by conducting pairwise Pearson's correlations among ANS responsivity scores obtained from different tasks. Cross-task stability coefficients in RSA responsivity ranged from .47 to .70 in preschool, .40 to .60 in kindergarten, and .53 to .69 in first grade. Likewise, cross-task stability in PEP responsivity ranged from .52 to .71 in preschool, .38 to .58 in kindergarten, and .58 to .74 in first grade. These findings suggest that there was moderate stability in children's ANS responsivity toward different tasks within the same assessment.

Stability in ANS responses across time. In order to understand whether there was longitudinal stability in children's ANS responses, pairwise Pearson's correlations among scores obtained from the same task in preschool, kindergarten, and first grade were examined. For example, stability in children's sympathetic responsivity toward the Tangrams task was evaluated by examining the correlations among Tangrams PEP responsivity obtained in preschool, kindergarten, and first grade (see Table 11). Given that different emotion regulation tasks were used each year, longitudinal stability was examined for composite scores of emotion regulation tasks (e.g., average of RSA for tasks in preschool and kindergarten) as well as for individual tasks (e.g., Locked Box in preschool and Not Sharing in kindergarten). One major goal of these analyses was to understand whether all or only specific laboratory tasks elicit ANS responses that are stable over time. The second important goal was to understand whether the longitudinal stability in children's sympathetic responses (PEP responsivity) were similar to the longitudinal stability in children's parasympathetic responses (RSA responsivity).

For most laboratory challenges, there was modest to moderate levels stability in RSA responsivity over time (see Table 10). Baseline RSA was moderately stable over time (r = .56 - .66, p < .01). In Tangrams, there was moderate stability from preschool and kindergarten (r = .32, p <.01), from kindergarten to first grade RSA (r = .46, p <.01); and from preschool and first grade (r = .31, p <.01). In Go-No-Go, there was no stability in RSA responsivity from preschool to kindergarten (r =.10, NS), but there was modest stability from kindergarten to first grade ($r = .25$, $p <.01$). The overall emotion regulation RSA responsivity also demonstrated low to moderate stability from preschool and kindergarten ($r = .25$, $p <.01$) and from kindergarten and first grade RSA responsivity ($r = .31$, $p <.01$). In regards to individual emotion regulation tasks, there were correlations among some tasks but not others. In particular, RSA responsivity in the Locked Box task in preschool was associated with the Impossible to Open Gift ($r = .24$, $p < .01$) but not with the Not Sharing task ($r = .08$, NS). The Toy Removal task was associated with all kindergarten emotional tasks ($r = .21$-$.24$, $p < .01$). All kindergarten emotion regulation tasks were associated modestly with the first-grade emotion regulation tasks ($r = .15$-$.30$, $p < .01$).

Although there was moderate stability in baseline PEP over time ($r = .49$ - $.57$, $p < .01$), there was no longitudinal stability in PEP responsivity in most laboratory challenges. In Tangrams, there was no stability in PEP responsivity from preschool to kindergarten ($r = .12$, NS), but there was modest stability from kindergarten to first grade ($r = .26$, $p < .01$). There was no stability in PEP responsivity in Go/No-Go or in emotion tasks.

3b). Developmental continuity/change and growth in ANS responses.

Developmental continuity and change in ANS responses toward laboratory challenges were examined by conducting repeated measures ANOVAs in SPSS. In these analyses, the independent variable was time of assessment, whereas the dependent variable was the ANS score of interest. Given that sphericity is a main assumption of reseated-measures ANOVA, if there was a violation of sphericity (as indicated by a significant Mauchly's test), the Greenhouse–Geisser correction was applied (Greenhouse & Geisser, 1959). If there was a significant main effect of time, pairwise t-tests were conducted to determine whether and when there was change/discontinuity in children's physiological responses. If results from the repeated-measures and paired wise t-tests provided evidence for a consistent pattern of change across time (e.g., increase in values from preschool to first grade), then linear growth modeling was used to test whether there was a linear pattern of change in that variable across time. For these analyses the Mplus software was used.

Continuity and Change in Baseline ANS Measures

Baseline RSA. The repeated ANOVA comparing baseline RSA scores across the three time points was significant, $F(2, 205) = 15.94$, partial $\eta^2 = .03$, $p < .01$. The post hoc t-tests indicated that baseline RSA in kindergarten ($M = 7.32$, $SD = .07$) was significantly larger than baseline RSA in preschool ($M = 7.15$, $SD = .08$), $p = .01$. Baseline RSA in first grade ($M = 7.37$, $SD = .07$) was greater than baseline RSA in preschool, $p < .01$; but did not differ from baseline RSA in kindergarten, $p = .43$. Overall, these results suggest that there was a mean-level increase in baseline RSA from preschool to kindergarten, but not from kindergarten to first grade.

Given that the repeated-measures analyses indicated an overall increase in children's baseline RSA, a linear growth model was conducted to examine (a) the overall mean-level change in baseline RSA across time, and (b) to test whether there is between-individual variability in the intercept and slope. The fit of the linear growth model was acceptable, $\chi 2(1) = 1.50$, $p = .22$, CFI =1.00, RMSEA =.04 (.00-.17), SRMR = .02. As presented in Table 12, the unstandardized coefficient for the mean of the intercept was 7.22 ($p < .001$), suggesting that children showed moderate to high levels of baseline RSA in preschool. There was a significant and positive main effect for the slope (B =.09, p = .004), suggesting that on average, children's baseline RSA increased over time. The variance of the intercept was significant (B = .92, $p < .001$), suggesting that there was between-individual variability in children's baseline RSA scores in preschool. The variance of the slope was also significant (B = .11, p =.021), suggesting that children varied in how their baseline RSA scores changed from preschool to first grade.

Baseline PEP. The repeated ANOVA comparing baseline PEP scores across the three time points was significant, F(2, 168) = 16.05, partial η^2= .09, $p < .001$. The post hoc t-tests indicated that baseline PEP in kindergarten (M = 92.52, SD = .51) was significantly larger than baseline RSA in preschool (M = 91.31, SD = .49), p = .01. Similarly, baseline PEP in first grade (M = 94.01, SD = .49) was larger than baseline PEP in kindergarten, p = .004. Overall, these results suggest that there was a mean-level increase in baseline PEP over time.

Given that the significant results from the repeated-measures analysis and paired-wise t-tests suggesting an overall increase in children's baseline RSA, a linear growth model was conducted to examine (a) the overall mean-level change in baseline PEP across time, and (b) to test whether there is between-individual variability in the intercept and slope of baseline PEP. The unconditional linear growth model for baseline PEP yielded a negative variance for the slope, which is an impossible solution. One common approach for resolving this type of error is to constrain the variance of the slope to zero, which allows for 2 additional degrees of freedom (see Hinnant et al., 2017 for a similar finding). The fit of this model was good, $\chi 2(3) = 1.31$, $p = .73$, CFI =1.00, RMSEA =.00 (.00-.07), SRMR = .11. As presented in Table 12, the unstandardized coefficient for the mean of the intercept was 91.12 ($p < .001$), suggesting that children's baseline PEP scores in preschool was significantly different from zero. The mean of the slope was positive and significant (B =1.29, $p = .004$), indicating that children's baseline PEP scores showed an average increase of 1.29 per year during the study. The variance of the intercept was significant (B = 24.09, $p < .001$), suggesting that there was significant variability in children's baseline PEP scores in preschool. As indicated by the impossible negative variance in the slope of baseline PEP, there was no variability in the trajectories of baseline PEP across time.

Continuity and Change in RSA Responsivity Scores

The continuity and change in children's RSA responsivity was examined for the two cognitive challenges, Tangrams and Go/No-Go, because they were conducted at each time point.

Tangrams. The repeated ANOVA comparing RSA responsivity during Tangrams across the three time points was not significant, $F(2, 202) = .44$, $p < .64$, suggesting that there was no change in children's RSA responsivity during Tangrams across time.

Go/No-Go. The repeated ANOVA comparing RSA responsivity during Go/No-Go across the three time points was significant, $F(2, 191) = 4.58$, $\eta^2 = .02$, $p = .01$. Results from the paired t-tests indicated that there was no difference in RSA responsivity scores obtained in preschool, and in kindergarten, p = .48. However, RSA responsivity in first grade (M = .26, SD = .54) was significantly smaller than RSA responsivity in kindergarten (M = .40, SD = .51), p = .003, and in preschool (M = .36, SD = .47), p = .03, suggesting that children experienced lower levels of RSA withdrawal in in first grade than in preschool and kindergarten.

Continuity and Change in PEP Responsivity Scores

The continuity and change in children's PEP responsivity was examined only for Tangrams and Go/No-Go because these tasks were used across all time points.

Tangrams. The repeated ANOVA comparing PEP responsivity during Tangrams across the three time points was not significant, F(2, 145) = 12.73, p =.08, suggesting that there was no change in children's Tangrams RSA responsivity scores across time.

Go/No-Go. The repeated ANOVA comparing PEP responsivity during Go/No-Go across the three time points was significant, F(2, 142) = 12.83, partial η^2 = .08, p < .001. RSA responsivity scores during Go/No-Go decreased from preschool (M = .27, SD = 2.36) to kindergarten (M = -.41, SD = 2.80), p = .02; but increased from kindergarten to first grade (M = 1.23, SD = 3.32), p < .01.

Goal 4. To Examine Whether There are Profiles of Children with Distinct Patterns of Sympathetic and Parasympathetic Functioning in Preschool, and Whether These Profiles Differ with respect to Children's Self-Regulation Outcomes

Latent profile analyses were conducted to test whether there are profiles of children with distinct patterns of sympathetic and parasympathetic functioning in preschool. Latent profile analysis is a type of finite mixture modeling that allows us to test whether there are hidden subgroups or profiles of individuals based on a set of continuous indicators. The M*plus* 8.0 software was used to conduct this type of analyses. Missing data were estimated using full information maximum likelihood, a modeling technique that uses available data to estimate coefficients that have the highest probability of representing the sample. Model fit was evaluated using the following model fit indices: entropy, Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Adjusted Bayesian Information Criterion (ABIC) and the adjusted Lo-Mendell-Rubin (LMR) likelihood ratio test. Smaller AIC, BIC, and ABIC values, and larger entropy values indicate better model fit, whereas a significant LMR test indicates that adding one more profile improves model fit. Given that these fit indices may not converge on a best fitting model, decisions regarding the best fit should also be guided by the interpretability of the results.

A total of 10 variables from the preschool assessment were submitted to latent profile analyses. Five of these variables reflected children's sympathetic ANS activity and included baseline PEP and PEP responsivity scores to 4 laboratory challenges (Tangrams, Go/No-Go, Locked Box and Toy Removal). The other five variables reflected children's parasympathetic ANS activity and included baseline RSA and RSA responsivity toward the same 4 laboratory challenges. This analytic strategy is consistent with theoretical work suggesting that both baseline and responsivity scores are likely important indicators to identify subgroups of ANS functioning in the population. Moreover, given the context-dependent nature of physiological responses, this strategy allowed for capturing individual differences in responsivity toward multiple everyday challenges. Another rationale for including ANS responsivity to different challenges in the analyses was to prevent loss of information due to aggregation.

Number of ANS Profiles

An evaluation of the fit indices suggested that a four-profile solution fit the data well and was interpretable. The fit statistics for models with different numbers of profiles can be found in Table 13. As shown in this table, as the number of profiles increased, the entropy values increased and the AIC, BIC, and Adjusted BIC values decreased. These fit statistics suggested that the four- and five-profiles solutions provided better fit to the data than the models with fewer profiles. Moreover, the LMR test comparing the three-profile solution to the four-profile solution was significant (p = .02), suggesting that the four-profile solution provided better fit to the data than the three-profile solution. On the other hand, LMR test comparing the four-profile solution to the five-solution was not significant (p = .29), a result that also favored the four-profile solution.

Characterization of the ANS Profiles

Model estimates from the four-profile latent profile analysis are presented in Table 14. In order to best characterize the ANS profiles and understand how they differ from one another, two strategies were utilized. The first strategy was evaluating the profiles' mean values for each indicator (e.g., baseline RSA) and checking whether the p-values associated with each indicator was significantly different from zero ($p < .05$). For the RSA responsivity scores, positive mean values that are significant would suggest that, on average, individuals in that profile experience RSA withdrawal, whereas negative values that are significant would indicate that, on average, individuals in that profile experience parasympathetic activation or RSA augmentation. For the PEP responsivity scores, positive mean values that are significant would indicate that, on average, individuals in that profile experience sympathetic activation or PEP shortening, whereas negative values that are significant would indicate the experience of sympathetic inhibition or PEP lengthening. As such, by evaluating the mean values of the indicators and their significance presented in Table 14, one can determine whether individuals in a profile experience activation, inhibition, or change in their sympathetic and parasympathetic ANS systems.

The second strategy that was used to characterize the groups was to compare the profiles with respect to their sympathetic and parasympathetic functioning by conducting separate ANOVAs for each ANS indicator (e.g., baseline RSA). If the overall ANOVA was significant for that indicator, Tukey's post hoc pairwise analyses were conducted to identify which profiles differed from one another. These results are reported in the characterization of each profile.

Sensitive profile (high ANS responsivity). The sensitive profile, which constituted 30% of the sample, was the 2nd largest profile after the buffered profile. This profile showed high levels of parasympathetic inhibition (RSA withdrawal) and moderate to high levels of sympathetic activation (PEP shortening) across all tasks. Compared to the other three profiles, individuals in this profile showed significantly greater RSA withdrawal across all tasks (p <.05) except for the Toy Removal task. In the Toy Removal task, although the sensitive profile showed greater RSA withdrawal than the buffered and the vigilant groups (p <.05), its RSA withdrawal was only a marginally different than the inhibited group (p = .07). Compared to the buffered and the sympathetically inhibited profiles, the sensitive profile showed greater sympathetic activation across all tasks (p < .05). However, compared to the vigilant profile, the sensitive profile showed lower sympathetic activation across all tasks (p < .05).

Buffered profile (moderate ANS responsivity). The buffered group, which constituted 41% of the sample, was the largest profile. Individuals in this profile showed moderate RSA withdrawal across all tasks and sympathetic activation only in the Tangrams task. The PEP responsivity scores in the other 3 tasks were not significant (p < .05), suggesting that there was no change in their sympathetic activity during Go/No-Go, and the two emotional tasks. Across all tasks, the buffered profile's RSA withdrawal was smaller than the sensitive group's (p < .05), but comparable to the sympathetically inhibited group's (p >.05). Compared to the vigilant group, the buffered profile showed greater RSA withdrawal in the Go/No-Go and the Toy Removal tasks (p <.05), and marginally greater RSA withdrawal in the Tangrams task (p =.05). In terms of sympathetic functioning, the buffered profile's PEP responsivity scores were larger than the sympathetically inhibited group's scores but smaller than the sensitive and the vigilant profiles' scores (p < .05)

Coinhibition profile. The coinhibition profile, which constituted 24% of the sample, was the 3rd largest profile. The sympathetic inhibition group experienced moderate levels of RSA withdrawal and some sympathetic inhibition across all tasks. This profile showed lower RSA withdrawal than the sensitive profile, comparable RSA withdrawal to the inhibited profile, and greater RSA withdrawal than the vigilant group.

The defining characteristic of this profile was that its PEP responsivity scores were all negative and significant ($p < .05$), indicating sympathetic inhibition. Paired t-tests indicated that the PEP responsivity scores of the co-inhibition profile were significantly smaller than the scores of the other three profiles ($p < .05$).

Vigilant profile. By constituting only 4% of the sample, the vigilant profile was the smallest profile in the sample. This profile was characterized by low baseline RSA, low RSA responsivity, and high PEP activation. This profile's baseline RSA score (M = 5.50), which was significantly smaller than the baseline scores of the other three groups ($p < .05$). On the other hand, the vigilant profile's baseline PEP score (M = 96.85) was significantly larger than the sympathetically inhibited group's (M = 89.29) baseline PEP but comparable to the other profiles' baseline PEP scores. The vigilant profile's RSA responsivity score in the Tangrams and the Locked Box tasks were not different than zero ($p = 96$, $p = 86$, respectively), suggesting that this profile did not experience a change in its parasympathetic activity during these two tasks. On the other hand, for the Go/No-Go and the Toy Removal tasks, the RSA responsivity scores were negative and significant ($p < .05$), suggesting that individuals in this profile experienced parasympathetic augmentation during these two tasks. Finally, the vigilant profile's PEP responsivity scores were significantly larger than the PEP responsivity scores of the other groups ($p < .05$), suggesting that individuals in this profile showed greater sympathetic activation than the other groups.

ANS Profiles and Self-Regulation Outcomes

The next set of analyses were conducted to examine whether profiles differed in relation to self-regulation outcomes. Profiles were compared in relation to four indicators of self-regulation: (a) executive functions in preschool, (b) observed emotion regulation in preschool, (c) teacher-report of emotional reactivity in kindergarten, and (d) teacher-report of behavioral regulation in kindergarten. Descriptive information for child self-regulation outcomes can be found in Table 15. For each self-regulation outcome, the Wald equality test of means was used to determine whether profiles differed with respect to that specific self-regulation outcome. This procedure provides an overall chi-square significance test that help determine whether groups differ from one another, and pairwise comparisons of mean scores that allow to test which groups' mean scores differ from one another. In these predictive models, the three-step method was used to adjust for measurement error (Asparouhov and Muthén 2014).

Executive functions in preschool. The overall omnibus test comparing profiles in relation to executive functions was marginally significant $F(3, 260) = 7.25$, $p = .06$. As presented in Figure 4, the executive functions score of the sensitive group (M = .18, SE =.09) was significantly larger than that of the buffered group (M = -.09, SE = .09), $\chi^2 = 4.27$, $p = .04$, and the vigilant group (M = -.34, SE = .22), $\chi^2 = 5.06$, $p = .02$. There were no other significant differences among the profiles' executive functions scores.

Observed emotion regulation in preschool. The overall omnibus test comparing profiles in relation to observed emotion regulation was not significant.

Teacher-report of emotional reactivity in kindergarten. The overall omnibus test comparing the profiles' mean scores for teacher-report of emotional reactivity in kindergarten was significant $F(3, 260) = 20.74$, $p < .001$. As presented in Figure 5, the post hoc pairwise comparisons indicated that the emotional reactivity score of the sensitive group (M = 1.69, SE = .10) was significantly larger than that of the buffered group (M = 1.30, SE = .03), $\chi^2 = 13.87$, $p < .001$. There were no other significant differences among the emotional reactivity mean scores of the profiles.

Teacher-report of behavioral regulation in kindergarten. The overall omnibus test comparing the profiles' mean scores for teacher-report of emotional reactivity in kindergarten was significant $F(3, 260) = 39.03$, $p < .001$. As presented in Figure 6, the post hoc pairwise comparisons indicated that the behavioral regulation score of the buffered group (M = .50, SE = .06) was significantly larger than that of the sensitive group (M = -.23, SE = .18), $\chi^2 = 14.03$, $p < .001$ and that of the coinhibition group (M = -.27, SE = .19), $\chi^2 = 13.74$, $p < .001$. Likewise, the behavioral regulation score of the buffered profile was marginally larger than that of the vigilant profile (M = -.42, SE = .51), $\chi^2= 3.22$, $p = .07$. There were no other significant differences among the behavioral regulation means of the profiles.

CHAPTER VI

DISCUSSION

Children respond to emotional challenges (e.g., experiencing an interpersonal conflict) and cognitive challenges (e.g., working on a difficult puzzle) at the biological, psychological, and behavioral levels. Although the majority of research conducted under the rubric of self-regulation has focused on children's *behavioral* responses to emotional and cognitive challenges, understanding children's *physiological* responses to these external challenges or stressors can reveal novel information regarding children's inner experiences and their role in children's self-regulation and adaptive functioning. The autonomic nervous system is a stress response system that readily and pervasively responds to external challenges via the coordination of its sympathetic and parasympathetic branches (Kreibig, 2010). Although both branches of the ANS are theorized to support to the production of behavioral responses and are implicated in adaptive functioning, most research on children's ANS functioning has focused on children's parasympathetic ANS functioning only. Fewer studies have been conducted to examine children's sympathetic ANS functioning or how the sympathetic and parasympathetic ANS systems work within the same child. Moreover, although ANS responses are context-dependent, less is known about children's ANS responses toward different challenges across the early childhood period. In particular, some researchers rely on single measures for assessing ANS functioning whereas others combine multiple measures, and yet there is less clarity on what these assessments may index. An initial step toward understanding what ANS responsivity toward different challenges may index would be examining the similarities and differences in the magnitude of children's responses toward commonly used laboratory challenges. As such, the major goal of this dissertation was to investigate children's sympathetic and parasympathetic ANS responses toward emotional and cognitive challenges from 4 to 6 years of age (preschool to grade 1) and to examine whether certain patterns of ANS functioning are related to children's self-regulation outcomes.

Children's ANS Responsivity toward Emotional and Cognitive Laboratory Challenges

The first goal of this study was to examine normative or group-level sympathetic and parasympathetic responsivity patterns toward distinct emotional and cognitive laboratory challenges from preschool to grade 1, and to compare the magnitude of ANS responsivity scores across distinct challenges.

Parasympathetic ANS Responsivity

As hypothesized, across all time points, all laboratory challenges elicited parasympathetic inhibition or RSA withdrawal, which has been proposed to reflect coping responses (Porges, 2011). Given that the challenges used in this study, regardless of their domain (emotional vs. cognitive), were commonly used laboratory tasks designed to assess children's regulatory behaviors, it is not surprising that all tasks elicited parasympathetic inhibition suggesting that children engaged in coping. Moreover, results showing that children experienced parasympathetic inhibition across all tasks but experienced sympathetic responsivity only during certain tasks is consistent with the Polyvagal Theory's phylogenetic propositions. Based on this perspective, the myelinated vagus system – the parasympathetic system examined in this study – is the phylogenetically newest circuit that is recruited first in response to external challenges. The sympathetic-adrenal system, which is phylogenetically older than the myelinated vagus system, has been proposed to be recruited only during certain challenges when the responses of the myelinated vagus system are insufficient to cope with the challenge. As such, with the cognitively demanding Tangrams task for example, children not only responded with high levels of parasympathetic inhibition but also showed sympathetic activation, suggesting that this challenging task likely demands the recruitment of both branches of the ANS.

Differences across challenges. Although all challenges elicited parasympathetic inhibition, there were differences in how much parasympathetic inhibition was elicited by distinct challenges. In particular, across all time points, the Tangrams task elicited greater parasympathetic inhibition than the Go/No-Go task, supporting the idea that cognitively more demanding tasks elicit greater RSA withdrawal than cognitively less demanding tasks. Moreover, across all time points, one emotion regulation task elicited greater RSA withdrawal than the other emotion regulation task, suggesting that emotion regulation tasks differ with respect to their demands on the ANS. In particular, the Locked Box task elicited greater RSA withdrawal than the Toy Removal Task, the Impossible Gift elicited greater RSA withdrawal than the Not Sharing task, and Puzzle Box elicited greater withdrawal than the Broken Toy task. The findings indicating that the Toy Removal and

Not Sharing tasks elicited lower RSA withdrawal compared to the other emotion regulation task conducted at that assessment support the idea that these two tasks may elicit a more passive coping response (low RSA withdrawal, PEP lengthening) than the other emotion regulation tasks, perhaps due to the injustice component present in both tasks and/or lower opportunities to solve the problem. Overall, these findings suggest that certain emotionally demanding tasks require greater "active coping" responses and therefore elicit greater RSA withdrawal. As such, future work examining children's ANS responses to emotional challenges should take into account the demands posed by the emotional challenge given that normative responses to these challenges tend to differ.

Emotional vs. cognitive challenges. In regards to comparing emotional and cognitive challenges with respect to the extent to which they elicited RSA responsivity, there was no simple answer as emotion tasks elicited greater ANS responsivity than cognitive tasks or vice versa. Rather, results supported the view that certain emotional and cognitive challenges that required active coping responses elicited high levels of RSA responsivity that were similar in magnitude. For example, in the first grade, the cognitively demanding Tangrams task and the emotionally demanding Puzzle Box task both elicited high levels of RSA withdrawal that were similar in magnitude. Likewise, certain challenges that required lower levels of active coping (or perhaps even passive coping responses) elicited similar low levels of ANS responsivity. For example, in preschool, the cognitively less demanding Go/No-Go task and the Toy Removal task elicited similar levels of low RSA responsivity and, in kindergarten, the low intensity Go/No-Go and Not Sharing tasks were similar in magnitude. Overall, with respect to the magnitude of RSA withdrawal elicited by the challenges did not depend on the domain of the challenge (emotional vs. cognitive) but rather appeared to depend on how much active coping was required by the task.

Sympathetic ANS Responsivity

Cognitive challenges. As hypothesized, the cognitively demanding spatial problem-solving Tangrams task, on average, elicited sympathetic activation across all time points. Moreover, the cognitively less challenging Go/No-Go task, on average, did not lead to a change in sympathetic activity in preschool or kindergarten but led to sympathetic activation or PEP shortening in grade 1. In preschool and kindergarten, the Tangrams task elicited greater sympathetic activation than the Go/No-Go task, but in grade 1, these two tasks elicited similar levels of sympathetic activation. These results are partially consistent with the notion that individuals experience greater sympathetic activation during cognitive challenges that are perceived as difficult (Wright & Kirby, 2001) and previous findings showing no change in sympathetic activity during less challenging cognitive tasks (Berntson, Cacioppo, & Fieldstone, 1996). As such, given that the Tangrams task was a cognitively demanding task that required children to solve puzzles increasing in difficulty, the findings of this study support the proposition that such cognitively demanding challenges elicit sympathetic activation during early childhood. On the other hand, findings suggested that cognitively less demanding tasks like the Go/No-Go task, which was a repetitive and prolonged task that required children to maintain their attention, likely do not lead to a change in sympathetic activity in younger children. However, one finding that merits attention is that the Go/No-Go task elicited sympathetic activation similar to a level that Tangrams had elicited in grade 1, during a period when children would likely not perceive tasks as more difficult. One explanation for this finding may be that there is a developmental increase in the beta-adrenergic influence on the myocardium, as indexed by shortened PEP, during cognitive challenges across early childhood. As such, more research is needed to clarify whether there are developmental changes in children's sympathetic responses to certain types of cognitive challenges. Another explanation may be that although the Go/No-Go task likely did not become more difficult for children at grade 1, children may have exerted more effort to answer all trials correctly and therefore may have experienced sympathetic activation. It is possible that, after children start formal schooling, they exert greater effort in cognitive tasks to meet adult expectations to perform well. As such, given that the magnitude of sympathetic ANS responses have been proposed to be impacted by the perceived difficulty of the task as well as the amount of effort exerted, it would be important to examine relations between children's perceptions of task difficulty, the amount of effort they have exerted, and their sympathetic responses to understand sources of individual differences as well as why children experienced sympathetic activation during a less demanding cognitive task in first grade.

Emotional challenges. Two out of 6 emotion tasks led to a change in children's sympathetic ANS activity from baseline to task. As expected, the Toy Removal task in preschool and the Not Sharing task in kindergarten led to sympathetic inhibition as reflected by PEP lengthening or an increase in PEP from baseline to task, whereas the other 4 emotion regulation tasks (Locked Box, Impossible to Open Gift, Puzzle Box, &

Broken Toy) did not lead to a change in sympathetic ANS activity from baseline to task. Moreover, in preschool, children's sympathetic responsivity during the Toy Removal and Locked Box were significantly different and in kindergarten, children's sympathetic responsivity during the Not Sharing and Impossible Task were statistically different. However, in grade 1, the Puzzle Box and the Broken Toy tasks in grade 1 did not differ with respect to how much sympathetic responsivity they elicited. These findings together suggest that children's experiences during the Toy Removal and the Not Sharing tasks may be qualitatively different than the other emotion regulation tasks. These two tasks have been designed to evoke negative emotions by making children experience injustice (i.e., in Toy Removal, the experimenter takes away a toy that the child chose to play with; in Not Sharing, the experimenter does not share candy equally and takes away the child's candy). However, the other four tasks have been designed for children to actively solve a problem to reach a goal (e.g., using keys to open a box, opening a wrapped gift). Sympathetic inhibition has been proposed to be experienced when individuals anticipate no means of escaping an aversive situation (Obrist, 1981) and has been linked with experiences of sadness (Kreibig, 2010). As such, it is possible that the Toy Removal and Not Sharing tasks may lead children, on average, to perceive the circumstances as aversive and difficult to escape and may elicit sadness more so than the other emotional challenges. Given that sympathetic ANS responses during emotional challenges may be related to how the situation is perceived as well as the actual emotional experiences experienced by children, it would be important for future research to examine whether children's perceptions of the emotional challenges and the emotions they experience play a role in children's sympathetic responses. It is also important to note that the effect sizes of the sympathetic responses to these two tasks were small, therefore, replications would be necessary in future work.

Emotional vs. cognitive challenges. In comparing emotional and cognitive challenges with respect to the extent to which they elicited sympathetic responsivity, findings suggested that only two emotional tasks but none of the cognitive tasks led to sympathetic inhibition. Given that sympathetic inhibition may be experienced during feelings of hopelessness or sadness, or during passive coping responses, these results suggest that only two of the tasks may have elicited these responses. Moreover, findings suggested that only cognitive tasks and, in particular, the cognitively demanding Tangrams task but none of the emotional challenges led to sympathetic activation. Based on the notion that effort or energy mobilization during active coping is supported by sympathetic activation, one explanation for these findings may be that the Tangrams task required greater overall effort than the emotional tasks. On the other hand, although children likely showed effort during the frustrating emotional challenges, they may have also spent more time in less active coping responses that required less effort (e.g., by observing the experimenter, looking around in the room). As such, tasks that require greater effort or active coping responses may be more likely to elicit sympathetic activation.

It is important to note that these findings do not suggest that emotions or emotional experiences do not lead to sympathetic activation. For example, it is possible that emotions such as anger and fear may lead to sympathetic activation (Kreibig, 2010) and, if so, the children in our sample may have experienced moments of sympathetic activation during the instances they experienced these emotions. However, given that we examined children's overall sympathetic responses during the tasks, our results cannot speak to whether children's sympathetic experiences in the moment were related to their emotional experiences. As such, future research would be needed to understand whether moment-to-moment changes in children's sympathetic activity may relate to moment-to-moment changes in certain types of emotional experiences.

Associations Between Sympathetic and Parasympathetic Functioning During Laboratory Challenges

The second goal of the study was to examine whether there would be associations between sympathetic and parasympathetic responses during certain laboratory challenges. It was hypothesized that, in more physiologically arousing or frustrating tasks, increases in sympathetic activation (PEP shortening) would be associated with parasympathetic inhibition (RSA withdrawal); however, in less challenging or arousing tasks, there would be no correlations between children's sympathetic and parasympathetic responsivity scores. In preschool, there was a positive association between sympathetic and parasympathetic responsivity during the Tangrams and Locked Box tasks (but not during the Go/No-Go and Toy Removal tasks), such that greater sympathetic activation was linked with greater parasympathetic inhibition. These findings may suggest that, during high intensity tasks or tasks that elicit greater physiological responses, the two branches of the ANS work reciprocally. In kindergarten, there was a positive association between sympathetic and parasympathetic responsivity only during the Not Sharing and

Impossible to Open Gift tasks, but not the Tangrams and the Go/No-Go tasks. The findings from kindergarten assessment could suggest that there is a reciprocal association between the two ANS branches during the emotional but not the cognitive tasks. Finally, in grade 1, there were no associations between sympathetic and parasympathetic responsivity scores across any of the challenges. Overall, findings of this study do not reveal a consistent pattern regarding when the two branches of the ANS work reciprocally.

These inconclusive findings are somewhat consistent with what has been reported in previous work with children. For example, no associations were found between sympathetic and parasympathetic responsivity scores during emotional challenges in toddlers (Buss, Goldsmith, & Davidson, 2005), an incentive/motivation task in a sample of preschoolers diagnosed with ADHD (Beauchaine et al., 2013), and during several challenge tasks in 3-to 8-year olds (Alkon et al., 2003). However, sympathetic and parasympathetic responsivity scores have been shown to be modestly associated during a stressful challenge task during which children received negative feedback (Roos et al., 2017). In studies with adults, although sympathetic and parasympathetic responsivity scores were correlated during a mental arithmetic task (Berntson, Cacioppo, & Fieldstone, 1996), no correlations were found during an illusion task (Berntson, Cacioppo, & Fieldstone, 1996) or a selective attention task (Guiliano et al. 2017). As such, future work may be needed to understand the circumstances that may lead to a correlation between the responsivity in these two systems.

There are several possible explanations for the inconsistency in findings. Based on the autonomic space model, the sympathetic and parasympathetic branches of the ANS work orthogonally and their functioning may lead to 9 distinct modes of autonomic control (e.g., coinhibition, coactivation). As such, it is possible that only few laboratory challenges elicit a reciprocal pattern of functioning with an increase in sympathetic activation and increase in parasympathetic withdrawal. Moreover, it is possible that children may experience reciprocal sympathetic activation during certain parts of a laboratory challenge. For example, they may experience this pattern of functioning at the very beginning of a given task with an effort to mobilize their energy in the task or during a part of the task that they find more challenging. It is also possible that some children may consistently experience a more reciprocal pattern of functioning in these two branches of the ANS, whereas others may not. Finally, given that there were no associations between the responsivity scores in grade 1, it is possible that as children may tend to experience greater levels of nonreciprocal modes of functioning as they get older. As such, more work is needed to understand when and for whom do the two branches operate in a reciprocal pattern, such that as one increases the other decreases.

Development of ANS Functioning in Early Childhood

Stability in Children's ANS Functioning in Early Childhood

The third goal of this study was to examine stability (or instability) and continuity (or change) in children's ANS functioning from preschool to grade 1. With respect to stability, stability across different tasks within the same assessment, as well as stability within-tasks across time were examined. Within each assessment, there was moderate levels of stability in children's ANS responsivity across different tasks. This finding was consistent for both sympathetic and parasympathetic responses, suggesting that children tended to maintain their individual level of response toward distinct tasks relative to others. Evidence of moderate stability in children's responses to distinct challenges may also suggest that children's ANS responses to different challenges are to some extent context- or challenge-dependent.

Baseline sympathetic and parasympathetic ANS activity showed moderate-to-high stability across early childhood. These findings are consistent with previous research showing modest-to-moderate levels of stability in baseline levels of RSA (e.g., Alkon, Boyce, Davis, & Eskenazi, 2011; Esposito et al., 2016; Patriquin, Lorenzi, Scarpa, Calkins, & Bell, 2015; Perry et al., 2013) and modest-to-moderate levels of stability in baseline PEP across early childhood (Alkon et al., 2011; Esposito et al., 2016). Overall, evidence of moderate levels of longitudinal stability in baseline sympathetic and parasympathetic functioning suggest that these two aspects of ANS functioning begin to show trait-like characteristics from around 4 to 6 years of age.

Moreover, there was modest levels of task-specific stability in children's parasympathetic responsivity scores across time. Specifically, in Tangrams, there was modest-to-moderate stability in parasympathetic responsivity from preschool to kindergarten, and kindergarten to first grade. In Go/No-Go, there was no stability in parasympathetic responsivity from preschool to kindergarten but a modest stability from kindergarten to first grade. In emotion tasks, there was modest stability in most tasks across time. Specifically, Locked Box parasympathetic responsivity in preschool was associated with parasympathetic responsivity toward the Impossible to Open Gift task but not the Not Sharing task in kindergarten. Toy Removal parasympathetic responsivity in preschool was associated with parasympathetic responsivity across all kindergarten emotion tasks, and parasympathetic responsivity during emotion tasks in kindergarten were associated modestly with parasympathetic responsivity during emotion tasks in first grade. These findings are consistent with previous findings showing modest levels of stability in certain indices of parasympathetic responsivity during early childhood (e.g., Calkins & Keane, 2004; Perry et al., 2012). The modest levels of stability in children's parasympathetic responsivity across time may suggest that children tend to develop somewhat trait-like patterns of responding to external challenges.

In contrast to modest levels of stability in parasympathetic responsivity; overall, there was no stability in sympathetic responsivity scores across time. This finding is consistent with the findings of Alkon et al. (2011) who also did not find stability in sympathetic responsivity scores across infancy and early childhood. As such, children's sympathetic ANS responsivity toward challenges may not show trait-like patterns from around 4 to 6 years of age. However, it would be important to examine whether there would be stability in children's sympathetic responsivity using other measures such as skin conductance that index the functioning of the sympathetic-adrenal system.

Continuity and Change Children's ANS Functioning Across Time

Children's baseline parasympathetic activity showed an overall increase over time. Results from the repeated-measures analyses suggested that there was particularly a greater increase from preschool to kindergarten. Evidence for an increase in baseline

RSA in early childhood is consistent with previous findings (Perry et al., 2013; Alkon et al., 2011). There was between-individual variability in children's baseline RSA at four years (intercept) and how baseline scores changed from preschool to first grade (slope). These findings are consistent with previous research conducted during early childhood (Perry et al., 2013) and middle childhood (Hinnant et al., 2017).

Children's baseline sympathetic activity also showed an overall increase over time. Specifically, there was a significant mean-level increase in children's baseline PEP from preschool to kindergarten, and kindergarten to first grade. There was between-individual variability in baseline PEP in preschool (intercept) but no between-individual variability in the trajectories of baseline PEP over time (slope). These findings suggest that children's baseline PEP tended to increase in a similar fashion for most children. A non-significant between-individual variability for slope has also been shown in middle childhood (Hinnant, Elmore-Staton, & El-Sheikh, 2011).

Given that only two cognitive tasks (Tangrams and Go/No-Go) were administered across all three time-points, ANS responsivity analyses were conducted with these two tasks only. For the Tangrams task, there was no evidence of mean-level change in RSA responsivity or PEP responsivity across time. One explanation for this finding is the Tangrams task likely did not become easier for children as they received puzzles increasing in difficulty and compatible with their developmental level, and therefore they may have consistently relied on similar levels of sympathetic activation and parasympathetic withdrawal to actively engage in the task across all time points.

In Go/No-Go, there was no mean-level change in RSA responsivity from preschool to kindergarten; however, RSA responsivity decreased from kindergarten to first grade. As such, children tended to show lower levels of RSA withdrawal during the Go/No-Go task in first grade compared to preschool and kindergarten. This finding is partially consistent with the findings of Calkins and Keane (2004) who showed that the magnitude of RSA withdrawal decreased from 2 to 4.5 years of age. As such, it may be that in less challenging cognitive tasks which may become easier as they grow, children rely on lower levels of RSA withdrawal as they get older. On the other hand, PEP responsivity towards Go/No-Go decreased from preschool to kindergarten but increased from kindergarten to first grade. It is important to note that although PEP responsivity decreased from preschool to kindergarten, at both time points there was no significant PEP responsivity toward the task. However, in grade 1, children engaged in sympathetic activation. The finding that children engage in lower RSA withdrawal but greater sympathetic activation in grade 1 is rather surprising. One explanation may be that the sympathetic ANS starts to play an important role in not only challenging cognitive tasks but also less demanding cognitive tasks.

Profiles of ANS Functioning in Preschool

The fourth goal of this study was to test whether there were profiles of children with distinct patterns of sympathetic and parasympathetic functioning at 4 years of age, and if so, whether these profiles differed with respect to children’s self-regulation outcomes in preschool and one year later. Results from the latent profile analyses indicated that there were four profiles with qualitatively distinct ANS functioning. These profiles were: (a) buffered profile (moderate ANS responsivity), (b) sensitive profile (high ANS responsivity), (c) coinhibition profile, and (d) vigilant profile.

Buffered Profile (Moderate ANS Responsivity)

The largest profile that emerged from the profile analysis, referred to as the buffered profile, constituted 41% of the sample. Children in this profile showed moderate parasympathetic inhibition (RSA withdrawal) across all tasks and a significant but low level of sympathetic activation (PEP shortening) only in the Tangrams task but not in the other three laboratory tasks. The autonomic responsivity of this profile therefore highly resembled the Adaptive Calibration Model's *buffered* stress responsivity pattern characterized by moderate parasympathetic responsivity and low-to-moderate sympathetic responsivity. This profile's pattern of autonomic functioning can also be described as "moderate ANS responsivity" given that the responsivity scores of children in this profile fell between the other profiles' scores. Specifically, the magnitude of buffered group's RSA withdrawal was lower than the sensitive group's, about the same level with the coinhibition group's, and greater than the vigilant group's scores in most challenges. Likewise, children in this profile showed greater PEP shortening (sympathetic activation) than the coinhibition group but smaller PEP shortening than the sensitive and the vigilant profiles.

Consistent with this finding, two studies have also shown large profiles of children showing moderate ANS reactivity. Specifically, Del Guidice et al. showed that 45% of their sample belonged to a profile characterized by moderate levels of sympathetic and parasympathetic responsivity. Likewise, two of the largest stress responsivity profiles demonstrated by Quas et al. (2014) shared similarities with this study's buffered profile. Quas et al. argued that their largest profile, represented by 52-82% of their sample, showed moderate levels of responsivity across different physiological systems, whereas their "parasympathetic-specific responsivity" profile represented by 2-36% of their sample, showed RSA withdrawal without demonstrating change in other systems. Overall, results from this study suggest that, when responding to everyday challenges, the largest proportion of preschoolers experience a moderate degree of parasympathetic responsivity (RSA withdrawal) and a low degree of sympathetic activation, especially during cognitively challenging tasks.

Sensitive Profile (High ANS Responsivity)

The second largest profile, referred to as the sensitive profile, included 30% of the children in the sample. Children in this profile demonstrated high levels of parasympathetic inhibition (RSA withdrawal) and moderate to high levels of sympathetic activation (PEP shortening) across all laboratory challenges. Note that this type of ANS functioning corresponds to the "reciprocal sympathetic activation" mode of autonomic control described by the autonomic space model. This profile was named after the Adaptive Calibration Model's *sensitive* stress responsivity pattern, which was theorized to also be characterized by high parasympathetic and moderate to high sympathetic responsivity (Del Giudice et al., 2012). This profile's ANS functioning can also be described as "high ANS responsivity" because children in this profile showed greater RSA withdrawal than the other 3 profile groups and demonstrated greater PEP shortening than the buffered and the coinhibition groups across almost all laboratory changes.

Consistent with these findings, Del Guidice et al. have found a profile of children, represented by 27% of their sample, whose response pattern was moderate-to-high levels of sympathetic activation and parasympathetic withdrawal during a star-tracing task. Overall, the emergence of this relatively large profile in our community sample suggests that, in the actual population, about one third of preschoolers may show moderate to strong levels of sympathetic and parasympathetic ANS responsivity toward everyday challenges.

Coinhibition Profile

The third largest profile, the coinhibition group, constituted about 24% of the sample. Children in this profile showed moderate parasympathetic inhibition (RSA withdrawal) and low-to-moderate levels of sympathetic inhibition (PEP lengthening) across all tasks. This profile is named after the autonomic space model's coinhibition mode of autonomic functioning, which was characterized as inhibition in both branches of the ANS. Importantly, children in this profile showed sympathetic inhibition across all laboratory challenges, a response pattern unique to this profile only, and showed moderate parasympathetic inhibition comparable to the buffered group's. There is some evidence suggesting that coinhibition is a common ANS response pattern in children. For example, Alkon et al. (2003) hard-classified children into distinct ANS responsivity groups by using cross tabulation of positive and negative RSA and PEP scores and found that coinhibition was the largest group in 3 to 8-year-olds (Alkon et al., 2003). Likewise, Salomon, Matthews, and Allen (2000) showed that coinhibition was a common response pattern in certain tasks such as a social competence interview task. Although researchers that used hard classification techniques found coinhibition as a common ANS response pattern in children, recent studies involving latent profile analyses did not identify coinhibition as one of the common ANS response patterns (e.g., Del Guidice et al., 2012; Quas et al., 2014). One potential reason for why a coinhibition group emerged in this study and in the studies that hard-classified children into groups may be that these studies all measured children's ANS functioning via RSA and PEP responsivity scores. As such, it is possible that when RSA and PEP responsivity are used as the main indices of ANS response patterns, coinhibition emerges as a common response pattern. On the other hand, the reason why other studies that included latent profile analysis did not find a coinhibition profile may be because different physiological measures were used. For example, Quas et al. submitted baseline and responsivity scores for RSA, PEP, HR, and cortisol to latent profile analysis, and received 3 to 6 profiles depending on the sample that they have used. On the other hand, Del Guidice et al. submitted baseline and responsivity scores for RSA and skin conductance, and found four profiles but only three of these profiles matched closely with our findings. As such, it would be important to replicate these findings in other community samples by testing whether latent profile analysis with RSA and PEP scores yields a coinhibition profile similar to the one that emerged in this study and in the studies that used hard-classification.

Vigilant Profile

The smallest profile that emerged from the profile analysis was the vigilant profile, which constituted only about 4% of the sample. Children in this profile showed low baseline parasympathetic activity (baseline RSA), no change or activation in parasympathetic activity from baseline to task (RSA augmentation or no RSA change), and high sympathetic activation (PEP shortening). This profile's ANS characteristics were similar to the Adaptive Calibration Model's *vigilant* stress responsivity pattern, which was characterized as low baseline parasympathetic activity, low-to-moderate parasympathetic responsivity, high baseline sympathetic activity, and low-to-moderate sympathetic responsivity (Del Giudice et al., 2012). Consistent with this description, the vigilant profile in this sample had a baseline RSA score was smaller than the other three groups' and a baseline PEP score that was at least larger than the sympathetically inhibited group's but comparable to the other profiles' scores. In line with the propositions of the Adaptive Calibration Model, children in this profile showed lower RSA responsivity compared to other groups in most laboratory challenges and showed greater PEP shortening than all other groups.

Overall, these findings supporting the existence of a vigilant profile are similar to the findings of Del Giudice et al. and Kolacz et al. (2016) who also found vigilant profiles in their community samples. Specifically, Del Giudice et al. showed that 10% of their sample had a vigilant pattern of stress responsivity, characterized by high baseline sympathetic activity, high sympathetic activation, and moderate levels of parasympathetic activity. Likewise, Kolacz et al. (2016) examined profiles based on children's baseline parasympathetic, sympathetic, and adrenocortical activity, and found two vigilant profiles that were both characterized by low baseline parasympathetic activity and high sympathetic activity but differed with respect to their basal levels of adrenocortical activity. These two profiles together constituted about 39% of their sample. Given that the proportion of the children belonging to the vigilant profile in our sample was much smaller than the proportions reported in these previous studies, it is important to speculate about the factors that may have contributed to the discrepancy in results. One reason may be related to the differences in the samples. Based on the proposition that vigilant stress responsivity patterns develop in families exposed to greater levels of stress, it is possible that Del Giudice et al. and Kolacz et al.'s community samples involved a larger proportion of families exposed to high levels of stress, which may have led to the emergence of a greater proportion of children with vigilant stress responsivity patterns. Another possible explanation for the discrepancy in results may be related to how stress responsivity was measured. For example, in measuring children's sympathetic ANS functioning, Del Giudice et al. used skin conductance, Kolacz et al. used salivary alpha-amylase (sAA), whereas this study used pre-ejection period. As such, the use of different measures for measuring sympathetic ANS activity may have led to this discrepancy. Given that Kolacz et al. used only baseline measures and found a greater proportion of children belonging to the vigilant groups, it is also possible that the reason why Del Guidice et al., and this study found smaller vigilant profiles is because both studies involved both baseline and responsivity scores. As such, future research should examine the circumstances in which a greater proportion of children belong to vigilant groups.

It is also important to note that the Adaptive Calibration Model's unemotional pattern of stress responsivity was not identified in this sample. Although Del Giudice et al. (2012) found that 18% of their sample belonged to a profile characterized by the unemotional pattern of stress responsivity, Quas et al. (2014) identified this profile in only two out of four of their samples, whereas Kolacz et al. (2016) did not identify this profile in their sample. Given that both Kolacz et al. and this study examined profiles in young children, one explanation for why these two studies failed to identify this profile may be because this profile may not emerge in early childhood but begin to emerge later in middle childhood or adolescence. Another explanation may be related to the characteristics of the samples. Based on the idea that the type, dose, and chronicity of environmental stressors may play a role in the development of stress responsivity patterns, samples that include children from diverse backgrounds in terms of exposure to stress may detect more profiles and some of these profiles may be harder to capture in community samples. Finally, the laboratory challenges in which physiological responsivity is assessed or not including responsivity scores as in Kolacz et al.'s study may determine the number and type of profiles that emerge from latent profile analysis.

ANS Profiles and Self-Regulation Outcomes

Based on theoretical work suggesting that physiological response patterns may be related to self-regulation outcomes, the four profiles that emerged from the latent profile analysis were compared with respect to self-regulation outcomes. As such, profiles were compared in relation children's self-regulation outcomes, particularly observed executive functions and emotion regulation in preschool, and teacher-report of emotional reactivity and behavioral regulation in kindergarten.

Consistent with the notion that children with greater ANS responsivity, characterized by high parasympathetic withdrawal and sympathetic activation, would be sensitive and open to their environments, it has been suggested that children with such physiological response patterns would develop better executive functioning, particularly in safe environments, likely because greater engagement with stimulating experiences would promote the development of children's executive functioning (Del Giudice et al. 2012). Thus, it was hypothesized that children with a sensitive ANS response pattern would show better executive functioning compared to the buffered group. Consistent with this speculation, results suggested that children in the sensitive profile had better executive functions than children in the buffered and the vigilant groups.

These findings are consistent with previous research that has linked greater RSA withdrawal with positive self-regulation outcomes such as better attention and regulation in community samples (Blair, 2003; Calkins, 1997; Suess et al., 1994), but inconsistent with previous findings showing that moderate but not high levels of vagal withdrawal relate to better response inhibition performance in young children (Marcovitch et al., 2010) or results from a recent metaanalysis that failed to find an association between RSA withdrawal and child executive functioning or effortful control (Holzman & Bridgett, 2017). However, it is important to note that there are many differences between the current study's design and analytic approach, and the other studies. First, the previous studies listed have only focused on RSA withdrawal but did not examine sympathetic and parasympathetic systems together. Second, a vast majority of these studies examined the linear relations between RSA withdrawal and executive functioning (see Marcovitch et al. for an exception), whereas this study examined profiles. Third, this study examined responsivity towards multiple laboratory measures, whereas the other studies have either used composite scores of RSA responsivity or RSA responsivity toward a single challenge. As such, these findings provide support for the idea a sensitive profile of children, who show relatively higher sympathetic activation and high parasympathetic to multiple laboratory tasks, show relatively better executive functioning than particularly the buffered and the vigilant groups.

The buffered (moderate ANS responsivity) profile showed lower levels of emotional reactivity than the sensitive (high ANS responsivity) profile, and showed better behavioral regulation than the sensitive, coinhibition, and vigilant groups. These findings suggest that children with moderate level of ANS responsivity, characterized by moderate vagal withdrawal and sympathetic activation in only a cognitively demanding challenge, may show relatively lower levels of emotional reactivity (as compared to children with high ANS responsivity) and better behavioral regulation than children with other ANS profiles. Given that the laboratory challenges used in this study are relatively low intensity stressors that children can often experience in their everyday life, these results suggest that a pattern of moderate levels of ANS responsivity toward low intensity everyday challenges may be coined by low emotional reactivity and optimal behavioral regulation. The groups' observed emotion regulation scores did not differ.

Strengths and Limitations

The current study had several strengths. First, although most research on children's autonomic nervous system functioning focused only on parasympathetic functioning, this study examined both parasympathetic and sympathetic ANS functioning in early childhood. As such, the design of the study was advantageous for investigating basic yet under-investigated questions regarding children's sympathetic ANS functioning such as normative sympathetic responses toward laboratory challenges, within-person stability in sympathetic responses toward different challenges, between-person stability in sympathetic responses across time, and/or continuity and change in sympathetic response across time. Moreover, examining parasympathetic and sympathetic ANS responses toward laboratory challenges within the same study allowed us to evaluate how these two systems respond to different laboratory challenges. For example, this design was advantageous for examining questions such as whether certain challenges (e.g., Tangrams) lead to both more heightened sympathetic and parasympathetic responses relative to other challenges (e.g, Go/No-Go) or whether they lead to only heightened responses in one branch only. A second important strength of this study was that, as part of the fourth goal, individual differences in the way the two branches of the ANS work together were examined via latent profile analyses. This line of investigation is especially important for understanding individual differences in ANS functioning as a whole and their implications for adaptive functioning. A third important strength of the study was that children's ANS responses were examined across multiple laboratory challenges, which helped examine the context-dependent nature of ANS functioning. Moreover, the longitudinal nature of the study made it possible to examine whether laboratory challenges elicited similar responses over time, and whether there was stability and continuity over time.

Despite these strengths, this study also had notable limitations. An important limitation was that although 2 of the laboratory challenges (i.e., Tangrams & Go/No-Go) were administered across all three assessments, different emotional challenges were administered at each assessment. The rationale behind this decision was that children could potentially remember important components of the emotional challenges and therefore not become frustrated the second or third time they encountered the challenge. For example, if the Locked Box task was used at each time point, children may have remembered that "none of the keys work" and that the experimenter forgot to give the right key to the child. Alternatively, only a subset of children, perhaps with better memory, could remember these tasks and not get as upset or frustrated as the other participants, which likely would have introduced an important confound (i.e., child cognitive ability/memory) to the design. Although using different emotional challenges likely prevented such potential problems from arising, this aspect of the study's design did not allow for examining questions related to the longitudinal stability and/or change in physiological responses toward these challenges. In terms of the type of emotional challenges examined, it is also important to note that none of the laboratory challenges were specifically designed to elicit fear responses and therefore normative ANS responses toward fear-eliciting tasks were not examined.

A second limitation was that, compared to studies conducted with older children and adults, it is likely that there was greater missing data in physiological variables, specifically in pre-ejection period (see S1 for missing data patterns). An important proportion of missing data in PEP was due to movement or sticker-connection artifact. This is partly because the locations of the stickers (i.e., belly, back) used in the calculation of this measure are more prone to artifact due to movement. As such, given that missing data may increase the error in our results, replication of this study's findings on children's sympathetic responsivity would be necessary.

A third limitation of this study was that, although certain theoretical propositions were used to understand the types of ANS responses different laboratory challenges would elicit, some of these propositions were not tested directly. For example, although the proposition that greater cognitive effort would lead to greater sympathetic activation was used to formulate hypotheses regarding which tasks would lead to greater sympathetic activation, this hypothesis was not tested directly given that tasks were not objectively compared with respect to how much cognitive effort they demanded. Likewise, although physiological responses to distinct emotional challenges were compared, questions related to why certain tasks elicited greater physiological responses were not investigated. Therefore, in future research, it would be important to examine questions such as whether experiencing certain emotions such as anger or sadness would be associated with specific patterns of ANS responses in developmental populations.

Finally, a fourth limitation was that profiles of autonomic nervous system functioning was only investigated using data from the preschool assessment. As such, it would be important to examine profiles of ANS functioning at other time points such as in kindergarten and first grade. This line of investigation would be critical for understanding whether similar profiles emerge across time, what proportion of the children remain in the same profile, and what factors may play a role in children's transition from one profile to another. In doing such analyses, it would be important to examine children's ANS responses during nearly equivalent challenges across different time points so that differences in the profiles (e.g., size of the profile, mean of the indicators) can be attributable to developmental or contextual changes rather than changes in the laboratory challenges.

Implications for Theory, Methods, and Application

The current study has several implications for theoretical work on children's ANS functioning. One major implication is related to understanding the role of different stressors or external challenges in children's ANS responses. First, findings from this study suggested that children's normative or group-level ANS responses to challenges depend largely on the laboratory challenge but not simply on whether the challenge is considered as a "cognitive" or "emotional" challenge. For example, results showed that overall children's normative responses to two cognitively demanding challenges differed systematically in magnitude and/or type of response (e.g., sympathetic activation vs. no change in sympathetic ANS activity). Likewise, there were mean-level differences in children's responses to certain emotionally demanding challenges. Finally, although sympathetic activation was a unique normative response to the Tangrams task and sympathetic inhibition appeared to be a unique normative response toward emotional tasks involving injustice; there were many emotional and cognitive challenges that elicited ANS responses similar in magnitude. Based on these findings, it is reasonable to argue that although there may be systematic differences in the ANS responses based on the intensity of the task, how much effort is demanded, and/or the type of coping response required (e.g., active coping vs. passive coping); there are no simplistic patterns of physiological differences across emotional and cognitive tasks. As such, it may not be reasonable to assume that "emotionally demanding" and "cognitively demanding" challenges index or mark distinct psychological processes or behaviors.

Second, results suggested that there was only moderate stability in individuals' ANS responses toward different challenges within the same assessment (i.e., intra-individual stability across challenges), suggesting that the intensity of the same child's physiological response relative to others may differ across tasks. For example, there may be individuals who experience relatively more heightened ANS responses toward frustrating challenges than fear-eliciting challenges, and vice versa, and such responses may be specifically related to externalizing problems rather than internalizing problems. As such, an important future direction for research may be understanding which children experience more heightened ANS responses toward certain challenges relative to other challenges and whether individuals' "context-specific" physiological responses or sensitivity toward certain challenges may have implications for adaptive functioning.

Finally, a third important implication for understanding ANS responses toward different challenges is related to the conceptualization of profiles of ANS functioning. This study is likely the first study that examined children's ANS profiles by including physiological responses toward different stressors as indicators. As such, this strategy allowed for the emergence of profiles of children whose physiological responses differed based on the laboratory challenge. For example, children in the buffered profile showed sympathetic activation during the cognitively challenging Tangrams task but not the other tasks. Likewise, children in the vigilant profile tended to experience no change in parasympathetic activity during 2 tasks but experience parasympathetic augmentation in other tasks. As such, these findings suggest that rather than conceptualizing individual differences in terms of those who experience "sympathetic activation" and those who do not, there likely are subgroups of children who show distinct patterns of physiological responses toward different tasks. These findings likely highlight the importance of considering children's responses toward multiple challenges rather than a single challenge.

Another set of implications of this study are related to the differential findings on parasympathetic and sympathetic ANS functioning. Findings suggested that although children, on average, experienced parasympathetic inhibition across all laboratory challenges at all assessments, they experienced sympathetic responsivity (inhibition or activation) only during certain challenges. These findings are consistent with Polyvagal Theory's proposition that individuals mostly rely on the phylogenetically newer myelinated vagal system's functioning (e.g., RSA withdrawal) in their everyday lives;

however, recruit the phylogenetically older sympathetic system only when the myelinated vagal system's response is insufficient (Porges, 2011). However, another explanation for these findings may be methodological. It may be that sympathetic responses as measured with PEP may show lower levels of deviation from baseline scores during the challenges; however, these findings may not accurately reflect how the sympathetic-adrenal system responds to these challenges. As such, it would be important to examine sympathetic responses to challenges via other measures such as skin conductance and also to compare whether sympathetic responses as measured via different measures (e.g., skin conductance vs. PEP) show similarities. Likewise, given that there was no stability in PEP responsivity over time, it would be important to examine the longitudinal stability of sympathetic responsivity as measured via skin conductance measures.

The findings of this study may also have important implications for theoretical work on the relations between ANS functioning and self-regulation, as well as prevention and intervention strategies guided by this line of research. First, the emergence of distinct profiles of ANS functioning highlight the importance of understanding how individuals vary with respect to the functioning of the sympathetic and parasympathetic branches of ANS. Moreover, findings showing that these ANS profiles differ with respect to major self-regulation outcomes suggest that the pattern in which these two ANS systems work within the same child may be related to certain self-regulatory behaviors. Although results of this study suggest that certain ANS profiles may be associated with better or worse self-regulation outcomes, there are important questions that remain to be answered. One question concerns the causal relation between ANS-specific stress physiology and self-regulation. Specifically, do certain patterns of ANS functioning support or hinder children's ability to engage in better self-regulation in the moment? Alternatively, does the way in which children regulate themselves result in certain patterns of ANS responses? Given that findings of this study suggested that children with distinct ANS profiles at age 4 differed with respect teacher-report of self-regulation outcomes at age 5, one can argue that patterns of ANS functioning may reflect trait-like characteristics that predict or contribute to future self-regulatory outcomes. However, it is also possible that the ways in which one regulates his/her emotions, attention, and thoughts may also play a role in how the ANS systems respond to challenges over time. For example, a child's cognitive appraisal of very challenging tasks as "very easy" may play a role in that child's experience of mild-to-moderate ANS responsivity; whereas another child's cognitive appraisal of very easy tasks as "very challenging" may lead that child to experience high levels of sympathetic activation and parasympathetic withdrawal. As such, psychological processes such as how a challenge is perceived or successful behavioral responses such as "looking away from the source of distress" may also affect children's ANS responses during challenges.

Based on this argument, in future work, it would be important to conduct studies aimed towards understanding the causal relations between patterns of ANS functioning and self-regulation. Specifically, one line of research can investigate the longitudinal relations between patterns of ANS functioning and specific self-regulation outcomes with the aim to understand whether certain patterns of ANS functioning lead to changes in self-regulation over time or whether certain self-regulatory behaviors predict changes in

ANS functioning over time. Another line of investigation can be devoted to understanding the dynamic relations among ANS responses and processes related to self-regulation in the moment. The rationale behind this question is that changes in the patterns of ANS functioning in the moment may contribute to the changes in processes related to self-regulation, or vice versa. As such, the dynamic relations among children's physiological and behavioral responses during a challenge can be studied as a longitudinal *process* using time-series data. This approach may be a more direct way of understanding the relations among the homeostatic functions of the ANS and processes related to self-regulation.

This study is perhaps one of the first studies that showed that the way in which the two branches of ANS work have implications for self-regulation outcomes. The findings of this study, as well as this line of investigation in general, may have important implications for prevention and intervention work. For example, this line of work can ultimately help develop strategies for identifying children whose patterns of ANS functioning may not be conducive to the development of adaptive self-regulation outcomes. For example, if future research demonstrates that children with a vigilant profile characterized by a dominant sympathetic ANS response to challenges experience emotional dysfunction and behavioral problems, it would be important to understand the contextual (e.g., lack of neighborhood safety) or familial factors (e.g., abuse) that lead to the emergence of this type of physiological functioning. As such, if future research identifies severe contextual stress as a main factor for the development of a vigilant ANS profile, then perhaps measuring children's stress physiology may become a clinical method for identifying children who are experiencing such contextual stress. Likewise, monitoring changes in children's stress physiology can also help examine the progress made by prevention and intervention strategies.

On a different note, it is also important to emphasize that although certain patterns of ANS functioning may be associated with difficulties with self-regulation or behavioral problems, they may still serve adaptive purposes. For example, in very dangerous contexts, children with a vigilant ANS profile may be able to detect and escape from life threatening circumstances. Therefore, working towards altering children's stress physiology instead of changing the circumstances that lead children to develop such stress patterns may do more harm than good as such practices would take away children's survival strategies. Therefore, in future work, it would be important to examine the adaptive purposes of distinct profiles of ANS functioning. However, given that what may be adaptive in the short term may not be adaptive in the long term, it is also important to understand the role of ANS functioning both for short-term and long-term outcomes. Although certain patterns of ANS functioning may help escape from threats in everyday life, they may also lead to serious health problems in the long term. Overall, it would be important to understand the role of ANS functioning both for short-term and long-term outcomes to guide prevention and intervention strategies aimed towards improving children's adaptive functioning.

Overall, this study was conducted to examine children's sympathetic and parasympathetic ANS functioning during emotionally and cognitively demanding challenges from preschool to first grade, and to test the relations between profiles of ANS functioning and self-regulation outcomes. Findings highlight the importance of understanding the "context-dependent" nature of ANS functioning. In particular, results suggested that there were systematic differences in children's group-level ANS responses toward distinct laboratory challenges. Likewise, there was only moderate within-person stability in children's responses toward distinct challenges, suggesting that the same individual may respond differently to distinct challenges. As such, it would be important to understand whether a pattern of heightened ANS responsivity toward only certain challenges (e.g. frustrating challenge) but not others (e.g., fear-related challenge) may be associated with certain self-regulation outcomes. Results also suggested that, from preschool to grade 1, there was a group-level increase in baseline RSA and PEP but no clear pattern of change in RSA and PEP responsivity. It would be important to understand the implications of the longitudinal increases in baseline levels of ANS functioning. Finally, results provided support for the idea that there are profiles of children with distinct patterns of ANS functioning and that children in these profiles may differ with respect to self-regulation outcomes. Examining profiles of ANS functioning across different populations including clinical populations and/or children exposed to greater contextual stress would help understand whether the profiles identified in this study are more or less common in other populations. Moreover, it would be important to understand the familial or contextual factors that may lead to the emergence of different profiles, and to further examine the intricate relations among distinct patterns of ANS functioning and processes related to self-regulation.

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APPENDIX A

TABLES AND FIGURES

Table 1. Descriptive Information for Mean RSA

	N	Min	Max	Mean	SD	Skew	*SE*	Kurtosis	*SE*
Preschool									
Baseline	259	3.65	9.56	7.21	1.11	-.32	.15	.00	.30
Tangrams	256	3.48	9.27	6.27	1.17	.04	.15	-.22	.30
Go/No-Go	249	3.66	9.54	6.83	1.06	-.18	.15	-.12	.31
Locked Box	250	3.26	9.63	6.17	1.14	.14	.15	.01	.31
Toy Removal	244	3.69	9.55	6.84	1.13	.07	.16	-.36	.31
Kindergarten									
Baseline	233	4.07	9.87	7.35	1.05	-.15	.16	.05	.32
Tangrams	231	2.44	9.39	6.44	1.17	-.08	.16	.11	.32
Go/No-Go	225	3.66	9.26	6.95	1.02	-.14	.16	-.19	.32
Not Sharing	227	4.37	9.91	6.89	1.11	.22	.16	-.25	.32
Impossible Gift	224	3.39	9.29	5.96	1.18	.23	.16	.04	.32
Grade 1									
Baseline	229	4.83	10.15	7.36	.98	.06	.16	-.18	.32
Tangrams	228	4.07	9.64	6.47	1.10	.28	.16	-.43	.32
Go/No-Go	223	4.40	9.97	7.10	.95	.09	.16	-.07	.32
Puzzle Box	226	4.00	9.82	6.52	1.05	.28	.16	.11	.32
Broken Toy	224	4.35	9.88	6.87	1.04	.15	.16	-.18	.32

Table 2. Descriptive Information for RSA Responsivity

	N	Min	Max	Mean	SD	Skew	*SE*	Kurtosis	*SE*
Preschool									
Tangrams	256	-.75	2.74	.93	.57	-.09	.15	.48	.30
Go/No-Go	247	-.99	2.00	.36	.48	.20	.16	.53	.31
Locked Box	250	-.99	3.34	1.05	.71	.04	.15	.07	.31
Toy Removal	244	-1.26	2.04	.39	.61	.04	.16	.44	.31
Kindergarten									
Tangrams	231	-.71	2.74	.91	.60	.09	.16	.16	.32
Go/No-Go	225	-.99	2.00	.39	.52	.09	.16	.36	.32
Not Sharing	227	-1.34	2.53	.46	.64	.08	.16	-.10	.32
Impossible Gift	221	-1.68	4.20	1.37	.94	.03	.16	.51	.33
Grade 1									
Tangrams	228	-.60	2.67	.89	.63	.26	.16	.03	.32
Go/No-Go	223	-1.25	2.50	.26	.53	.01	.16	1.38	.32
Puzzle Box	225	-.63	2.47	.84	.69	.03	.16	-.40	.32
Broken Toy	223	-1.16	2.49	.50	.67	.31	.16	.20	.32

Table 3. Descriptive Information for Mean PEP

	N	Min	Max	Mean	SD	Skew	*SE*	Kurtosis	*SE*
Preschool									
Baseline	233	71.63	107.50	91.14	6.43	-.15	.16	-.12	.32
Tangrams	222	75.00	105.79	90.67	6.09	-.07	.16	-.12	.33
Go/No-Go	224	74.31	107.25	90.87	6.25	-.09	.16	-.28	.32
Locked Box	221	75.25	107.63	90.87	6.59	-.03	.16	-.20	.33
Toy Removal	216	75.25	111.75	91.71	6.57	.11	.17	-.04	.33
Kindergarten									
Baseline	219	73.50	112.63	92.67	6.72	-.23	.16	.44	.33
Tangrams	210	66.35	108.37	92.09	6.68	-.50	.17	.87	.33
Go/No-Go	207	75.50	108.25	92.56	6.15	-.23	.17	.29	.34
Not Sharing	206	71.00	111.00	93.00	7.09	-.14	.17	.47	.34
Impossible Gift	195	67.50	118.00	92.50	7.47	-.17	.17	.99	.35
Grade 1									
Baseline	217	71.25	108.25	93.70	6.74	-.52	.17	.70	.33
Tangrams	211	73.00	106.33	92.75	6.52	-.37	.17	.19	.33
Go/No-Go	206	77.38	107.00	92.47	6.20	-.07	.17	-.43	.34
Puzzle Box	206	78.71	110.00	93.41	6.37	.08	.17	-.33	.34
Broken Toy	202	77.00	109.25	93.29	6.72	-.08	.17	-.33	.34

Table 4. Descriptive Information for PEP Responsivity

	N	Min	Max	Mean	SD	Skew	*SE*	Kurtosis	*SE*
Preschool									
Tangrams	217	-5.82	9.43	.65	2.28	.56	.17	1.95	.33
Go/No-Go	215	-7.50	8.13	.04	2.50	.05	.17	.73	.33
Locked Box	216	-7.50	9.50	.17	3.06	.15	.17	.25	.33
Toy Removal	208	-9.88	9.50	-.47	3.08	.06	.17	.80	.34
Kindergarten									
Tangrams	209	-7.85	7.36	.40	2.40	-.02	.17	.75	.34
Go/No-Go	203	-9.63	7.00	-.36	2.91	-.39	.17	.76	.34
Not Sharing	203	-11.53	8.00	-.61	3.60	-.12	.17	.62	.34
Impossible Gift	191	-12.13	12.50	.08	4.62	.12	.18	.10	.35
Grade 1									
Tangrams	210	-8.75	10.53	.89	2.91	-.03	.17	1.39	.33
Go/No-Go	205	-8.00	12.29	1.15	3.49	.17	.17	.20	.34
Puzzle Box	205	-11.13	13.25	.17	3.91	.24	.17	.72	.34
Broken Toy	199	-12.25	12.50	.13	4.28	.08	.17	.76	.34

Table 5. Fixed Effect Coefficients from the Random Intercept HLM Models Examining Task RSA in Relation to Baseline RSA

Fixed Effect	Coefficient	SE	*p*
Model 1: Preschool			
Intercept (baseline)	7.21	0.07	<0.001
Cognitive 1: Tangrams	-0.94	0.04	<0.001
Cognitive 2: Go/No-Go	-0.38	0.04	<0.001
Emotional 1: Locked Box	-1.05	0.04	<0.001
Emotional 2: Toy Removal	-0.39	0.04	<0.001
Model 2: Kindergarten			
Intercept (baseline)	7.35	0.07	<0.001
Cognitive 1: Tangrams	-0.91	0.05	<0.001
Cognitive 2: Go/No-Go	-0.39	0.05	<0.001
Emotional 1: Not Sharing	-0.46	0.05	<0.001
Emotional 2: Gift	-1.39	0.05	<0.001
Model 3: Grade 1			
Intercept (baseline)	7.36	0.07	<0.001
Cognitive 1: Tangrams	-0.89	0.04	<0.001
Cognitive 2: Go/No-Go	-0.27	0.04	<0.001
Emotional 1: Puzzle Box	-0.85	0.04	<0.001
Emotional 2: Broken Toy	-0.50	0.04	<0.001

Table 6. Fixed Effect Estimates from the Random Intercept HLM Models Examining Task PEP in Relation to Baseline PEP

	Coefficient	SE	*p*
Model 4: Preschool			
Intercept (baseline)	91.10	0.41	<0.001
Cognitive 1: Tangrams	-0.61	0.17	<0.001
Cognitive 2: Go/No-Go	-0.10	0.17	0.562
Emotional 1: Locked Box	-0.22	0.17	0.213
Emotional 2: Toy Removal	0.46	0.17	0.009
Model 5: Kindergarten			
Intercept (baseline)	92.57	0.46	<0.001
Cognitive 1: Tangrams	-0.45	0.23	0.052
Cognitive 2: Go/No-Go	0.25	0.23	0.279
Emotional 1: Not Sharing	0.59	0.23	0.010
Emotional 2: Impossible Gift	-0.17	0.23	0.481
Model 6: Grade 1			
Intercept (baseline)	93.65	0.45	<0.001
Cognitive 1: Tangrams	-0.95	0.24	<0.001
Cognitive 2: Go/No-Go	-1.06	0.24	<0.001
Emotional 1: Puzzle Box	-0.07	0.24	0.784
Emotional 2: Broken Toy	-0.22	0.24	0.359

Table 7. Correlations between RSA and PEP Responsivity
during Laboratory Challenges in Preschool

		1	2	3	4	5	6	7	8	9
1.	Tangrams RSA Change	-								
2.	Go/No-Go RSA Change	.61**	-							
3.	Emotion Tasks RSA Change	.69**	.58**	-						
4.	Locked Box RSA Change	.70**	.51**	.87**	-					
5.	Toy Removal RSA Change	.49**	.49**	.87**	.48**	-				
6.	Tangrams PEP Change	.15*	-.04	.13	.15*	.10	-			
7.	Go/No-Go PEP Change	-.01	.05	-.03	.05	-.08	.52**	-		
8.	Emotion Tasks RSA Change	.11	.06	.15*	.23**	.06	.64**	.74**	-	
9.	Locked Box PEP Change	.07	.09	.16*	.26**	.06	.63**	.71**	.92**	-
10.	Toy Removal PEP Change	.13	.02	.15*	.22**	.05	.52**	.63**	.91**	.65**

Table 8. Correlations between RSA and PEP Responsivity during Laboratory Challenges in Kindergarten

	1	2	3	4	5	6	7	8	9
1. Tangrams RSA Change	-								
2. Go/No-Go RSA Change	.60**	-							
3. Emotion Tasks RSA Change	.49**	.56**	-						
4. Not Sharing RSA Change	.42**	.40**	.84**	-					
5. Impossible Gift RSA Change	.57**	.51**	.62**	.541**	-				
6. Tangrams PEP Change	-.03	-.05	-.04	.04	-.12	-			
7. Go/No-Go PEP Change	-.03	.13	.15*	.15*	.00	.54**	-		
8. Emotion Tasks PEP Change	.04	.07	.23**	.23**	.03	.50**	.62**	-	
9. Not Sharing PEP Change	.07	.08	.23**	.18**	.10	.38**	.53**	.87**	-
10. Impossible Gift PEP Change	-.04	.05	.20**	.22**	-.05	.50**	.58**	.86**	.47**

Note. *p < .05, **p <.01.

Table 9. Correlations between RSA and PEP Responsivity during Laboratory Challenges in Grade 1

	1	2	3	4	5	6	7	8	9
1. Tangrams RSA Change	-								
2. Go/No-Go RSA Change	.54**	-							
3. Emotion Tasks RSA Change	.68**	.63**	-						
4. Puzzle Box RSA Change	.69**	.56**	.90**	-					
5. Broken Toy RSA Change	.53**	.58**	.90**	.61**	-				
6. Tangrams PEP Change	.03	.06	.07	.08	.05	-			
7. Go/No-Go PEP Change	.02	.04	.10	.11	.07	.64**	-		
8. Emotion Tasks PEP Change	-.06	.02	.05	.06	.04	.66**	.73**	-	
9. Puzzle Box PEP Change	-.01	.00	.07	.10	.03	.67**	.69**	.94**	-
10. Broken Toy PEP Change	-.09	-.01	.03	.03	.02	.58**	.68**	.94**	.74**

Note. *p < .05, **p <.01.

Table 10. Stability in RSA Responsivity Over Time

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Baseline P	—																
2. Baseline K	.66**	—															
3. Baseline G1	.56**	.66**	—														
4. Tangrams P	.15*	.09	.14*	—													
5. Tangrams K	-.12	.08	.12	.32**	—												
6. Tangrams G1	-.15*	-.09	.13	.31**	.46**	—											
7. Go/No-Go P	.34**	.08	.14*	.57**	.14*	.09	—										
8. Go/No-Go K	.05	.31**	.18**	.09	.60**	.21**	.11	—									
9. Go/No-Go G1	-.02	.05	.32**	.06	.16*	.56**	.13	.26**	—								
10. Emotion Tasks P	.28**	.14*	.21**	.69**	.21**	.20**	.52**	.06	-.02	—							
11. Emotion Tasks K	.14*	.33**	.21**	.21**	.49**	.25**	.18**	.56**	.11	.25**	—						
12. Emotion Tasks G1	-.05	.02	.27**	.26**	.30**	.68**	.11	.14*	.64**	.21**	.30**	—					
13. Locked Box P	.25**	.12	.16*	.70**	.18**	.15*	.48**	.04	-.03	.88**	.19**	.17*	—				
14. Toy Removal P	.24**	.08	.21**	.49**	.16*	.18*	.47**	.08	.04	.84**	.21**	.16*	.48**	—			
15. Not Sharing K	.09	.22**	.08	.12	.42**	.15*	.12	.54**	.05	.15*	.85**	.21**	.08	.20**	—		
16. Gift K	.16*	.33**	.28**	.23**	.42**	.25**	.19**	.40**	.13	.28**	.84**	.29**	.24**	.16*	.42**	—	
17. Puzzle Box G1	-.05	.01	.24**	.30**	.33**	.69**	.17*	.17*	.57**	.24**	.31**	.90**	.21**	.17*	.21**	.30**	—
18. Broken Toy G1	-.05	.03	.25**	.16*	.22**	.53**	.53**	.04	.60**	.12	.24**	.89**	.08	.11	.20**	.22**	.61**

Note. $*p < .05$, $**p < .01$.

Table 11. Stability in PEP Responsivity Over Time

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.	Baseline P	—																
2.	Baseline K	.56**	—															
3.	Baseline G1	.57**	.49**	—														
4.	Tangrams P	.21**	.00	.05	—													
5.	Tangrams K	.13	.23**	.22**	.12	—												
6.	Tangrams G1	-.06	-.03	.24**	-.04	.26**	—											
7.	GNG P	.23**	.06	.08	.52**	.15	.08	—										
8.	GNG K	.17*	.36**	.07	.05	.54**	.16*	.10	—									
9.	GNG G1	-.07	-.04	.30**	-.16*	.19*	.64**	-.04	.07	—								
10.	Emotion tasks P	.20**	-.01	.07	.64**	.16*	.10	.74**	.15	.00	—							
11.	Emotion tasks K	.04	.18*	-.04	-.05	.50**	.12	.01	.62**	.01	.10	—						
12.	Emotion tasks G1	-.08	-.13	.28**	-.03	.14	.66**	.03	-.01	.73**	.07	.12	—					
13.	Locked Box P	.18**	-.01	.12	.63**	.23**	.15	.71**	.15	.02	.92**	.14	.14	—				
14.	Toy Removal P	.16*	.01	.07	.52**	.05	.05	.63**	.12	.00	.92**	.06	.02	.65**	—			
15.	Not Sharing K	.05	.15*	-.06	-.08	.38**	.06	-.04	.53**	.01	.05	.87**	.13	.11	.00	—		
16.	Gift K	.05	.17*	.01	-.04	.50**	.16*	.02	.58**	.02	.11	.86**	.07	.14	.06	.47**	—	
17.	Puzzle Box G1	-.06	-.13	.27**	.00	.16*	.67**	.05	.03	.69**	.07	.10	.93**	.14	.01	.12	.09	—
18.	Broken Toy G1	-.08	-.12	.26**	-.03	.16*	.58**	.02	-.01	.68**	.08	.07	.94**	.14	.04	.08	.04	.74**

Note. $*p < .05$, $**p < .01$.

Table 12. Linear Growth Modeling Analyses for Baseline RSA and Baseline PEP

	Unstandardized		**Standardized**		
	Coefficient	SE	Coefficient	SE	*p*
Model 1: Baseline RSA					
Intercept					
Mean	7.22	.07	7.55	.54	.000
Variance	.92	.13	–	–	.000
Slope					
Mean	.09	.03	.27	.11	.004
Variance	.11	.05	–	–	.021
Covariance					
Intercept x Slope	-.16	.06	-.49	.09	.011
Model 2: Baseline PEP					
Intercept					
Mean	91.12	.39	18.57	1.12	.000
Variance	24.09	2.90	–	–	.000
Slope					
Mean	1.29	.21	.27	.11	.004
Variance	.00	.00	–	–	NS
Covariance					
Intercept x Slope	–	–	–	–	–

Table 13. Fit Statistics for the Latent Profile Models

Profiles	Entropy	AIC	BIC	Adj BIC	Lo-Mendell-Rubin Adjusted LRT Test
2 profiles	.71	8036.75	8147.13	8048.85	p = .002
3 profiles	.73	7902.31	8051.86	7918.70	p = .160
4 profiles	**.80**	**7788.54**	**7977.26**	**7809.23**	***p* = .023**
5 profiles	.82	7742.55	7970.44	7767.53	p = .290

Note. AIC =Akaike Information Criterion, BIC = Bayesian Information Criterion, Adj BIC = Adjusted BIC, LRT = Likelihood Ratio Test. Bold indicates that the profile was selected.

Table 14. Model Estimates from the Latent Profile Analysis

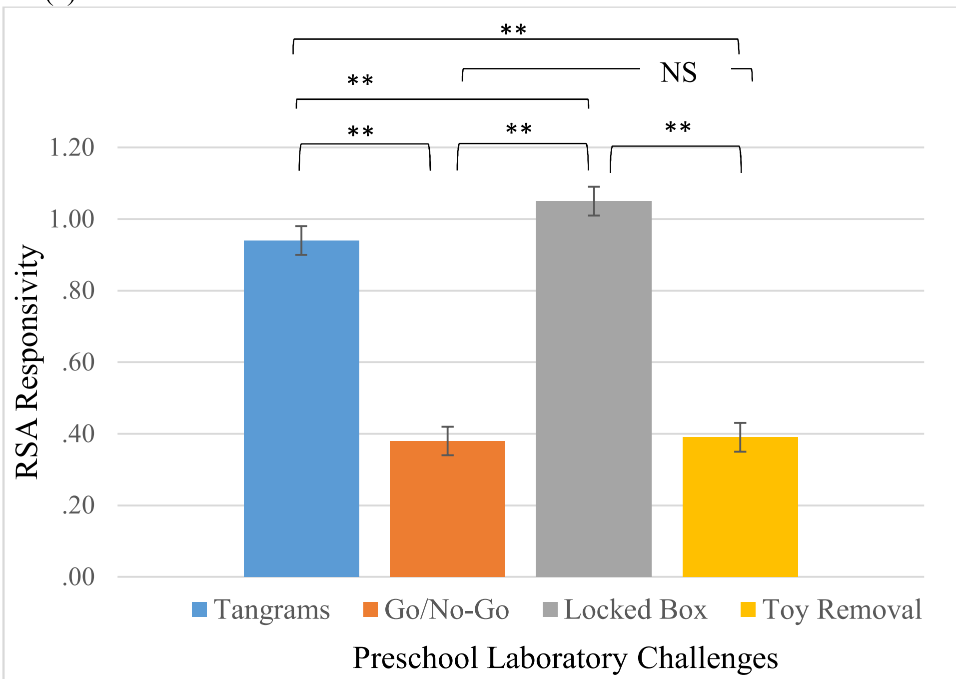
	Sensitive (High Responsivity) n = 77; 30%			Buffered (Moderate Responsivity) n = 109, 41%			Coinhibition n = 63, 24%			Vigilant (Sympathetic Activation) n = 11, 4%		
	Estimate	SE	*p*	Estimate	SE	*p*	Estimate	SE	*p*	Estimate	SE	*p*
Parasympathetic												
Baseline RSA	7.44	.12	.00	7.18	.13	.00	7.29	.15	.00	5.50	.30	.00
Tangrams RSA-c	1.40	.09	.00	.67	.09	.00	.97	.08	.00	.01	.21	.96
Go/No-Go RSA-c	.69	.09	.00	.19	.05	.00	.38	.06	.00	-.44	.12	.00
Locked Box RSA-c	1.68	.09	.00	.73	.13	.00	.98	.09	.00	-.04	.22	.86
Toy Removal RSA-c	.75	.09	.00	.18	.07	.01	.44	.09	.00	-.46	.24	.05
Sympathetic												
Baseline PEP	91.40	.81	.00	91.66	.69	.00	89.29	1.09	.00	96.85	2.36	.00
Tangrams PEP-c	1.91	.37	.00	.57	.19	.00	-1.31	.45	.00	5.81	1.19	.00
Go/No-Go PEP-c	1.61	.39	.00	.34	.22	.13	-2.73	.35	.00	4.58	1.12	.00
Locked Box PEP-c	2.48	.46	.00	.28	.32	.38	-3.17	.35	.00	6.26	.97	.00
Toy Removal PEP-c	1.70	.36	.00	-.28	.34	.42	-3.75	.47	.00	3.60	1.54	.02

N = 260. RSA-c indicates RSA change or RSA responsivity. PEP-c indicates PEP change or PEP responsivity.

Table 15. Descriptive Information for Child Self-Regulation Outcomes

	N	Min	Max	Mean	SD	Skew	SE	Kurtosis	SE
Executive Functions P	277	-1.45	1.69	-.01	.73	.02	.15	-1.02	.29
Observed Emotion Regulation P	274	-2.55	1.48	.00	.91	-.67	.15	-.33	.29
Emotional Reactivity K	220	1.00	3.60	1.49	.48	1.69	.16	3.35	.33
Behavioral Regulation K	220	-3.14	.99	.00	.93	-1.27	.16	.99	.33

(a)



(b)

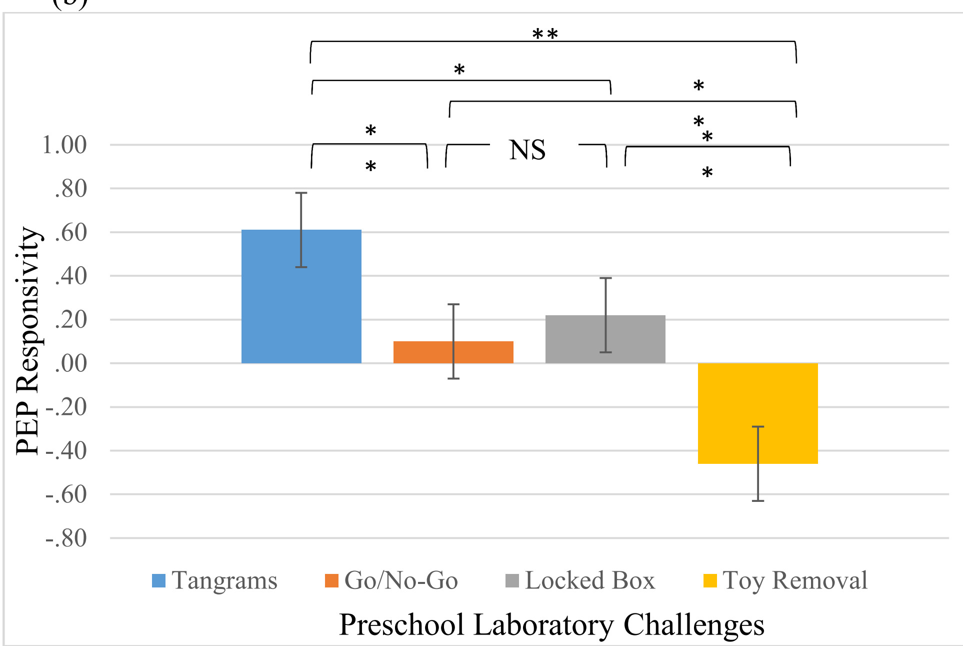


Figure 1. Results from the Analyses Comparing the Magnitude of the Fixed Effects Reflecting ANS Responsivity Toward Challenges in Preschool. Asterisks (*) indicate the significance level of the chi-square tests comparing fixed effects. *$p < .05$, **$p < .01$. Fixed effects were reversed such that positive RSA responsivity scores reflect RSA withdrawal, and positive PEP responsivity scores reflect PEP shortening/sympathetic activation. Error bars represent standard errors of the fixed effects.

(a)

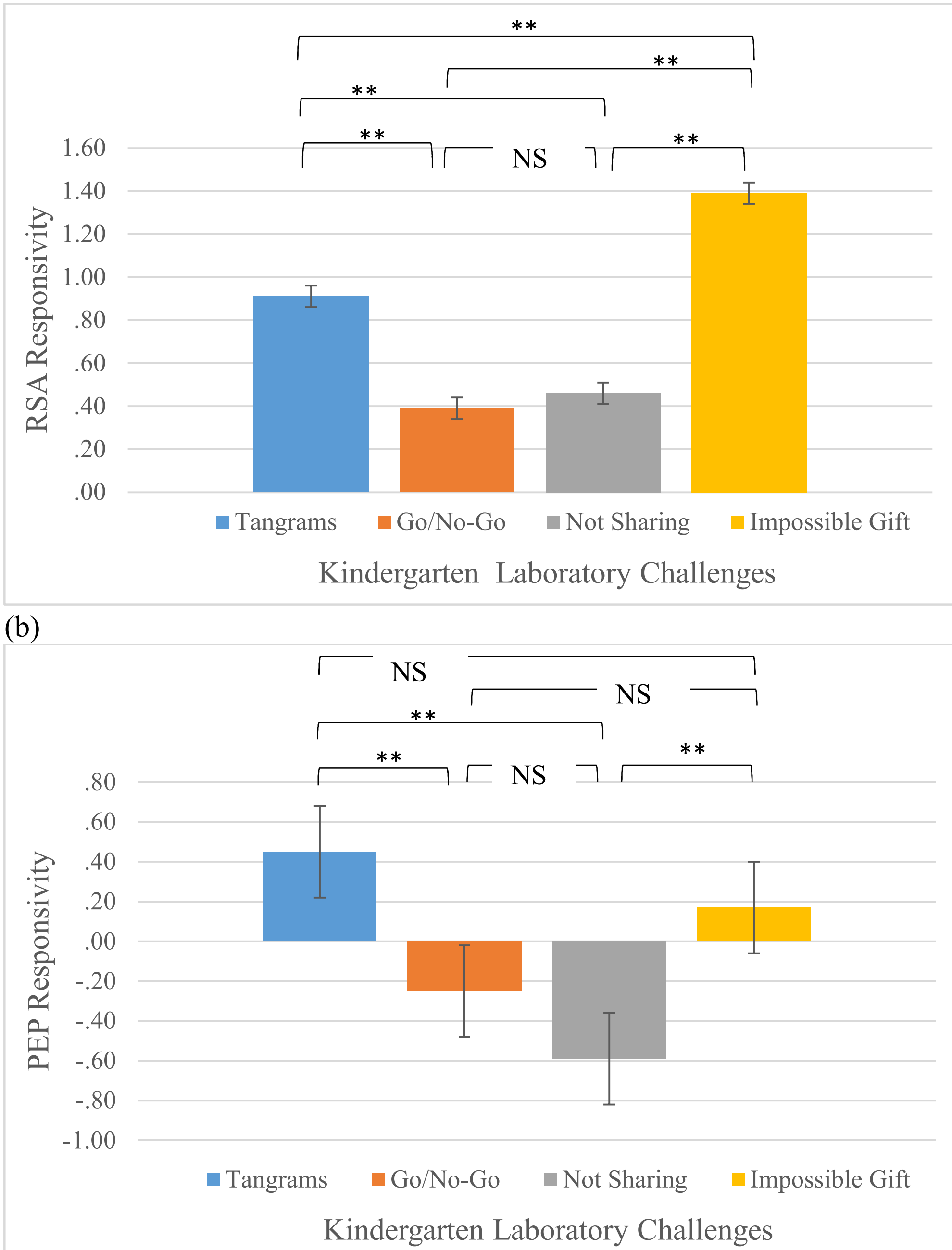
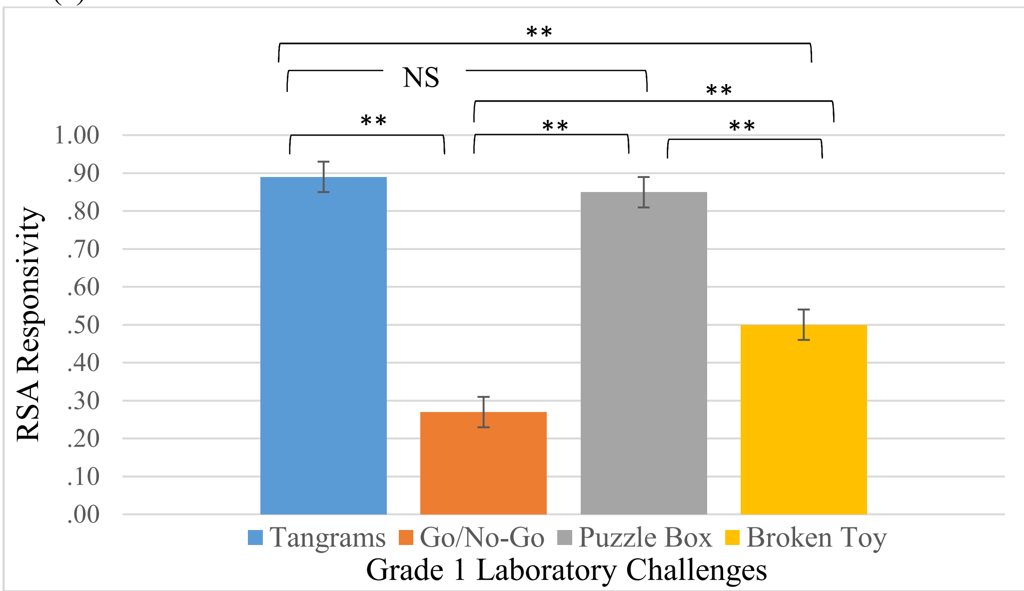


Figure 2. Results from the Analyses Comparing the Magnitude of the Fixed Effects Reflecting ANS Responsivity Toward Challenges in Kindergarten. Asterisks (*) indicate the significance level of the chi-square tests comparing fixed effects. *p < .05, **p <.01. Fixed effects were reversed such that positive RSA responsivity scores reflect RSA withdrawal, and positive PEP responsivity scores reflect PEP shortening/sympathetic activation. Error bars represent standard errors of the fixed effects.

(a)



(b)

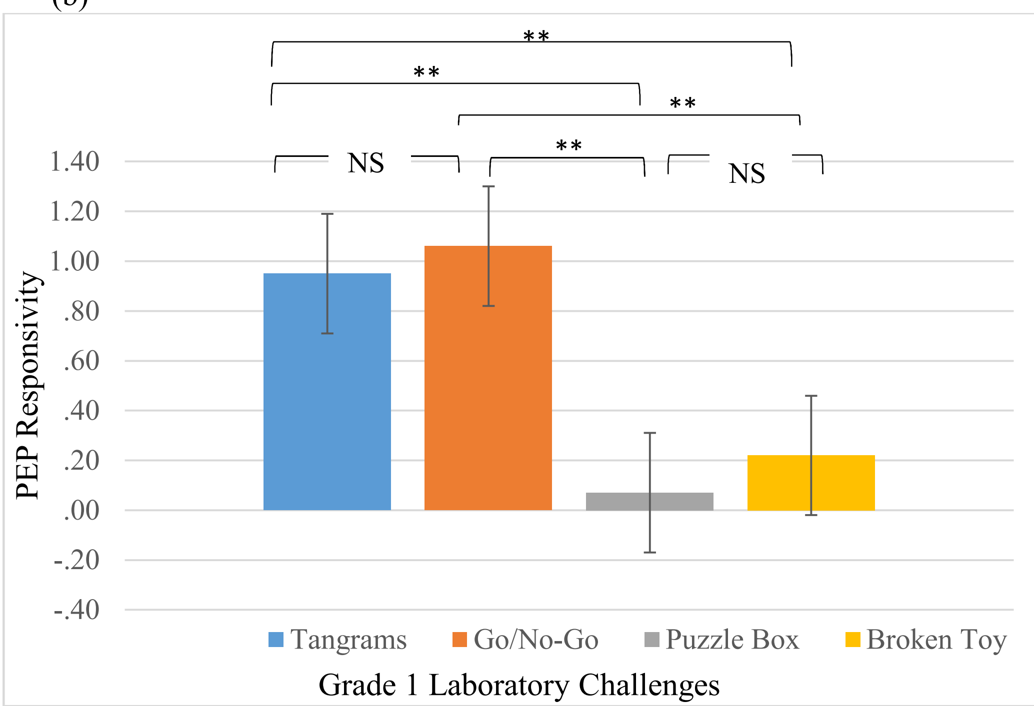


Figure 3. Results from the Analyses Comparing the Magnitude of the Fixed Effects Reflecting ANS Responsivity Toward Challenges in Grade 1. Asterisks (*) indicate the significance level of the chi-square tests comparing fixed effects. *p < .05, **p <.01. Fixed effects were reversed such that positive RSA responsivity scores reflect RSA withdrawal, and positive PEP responsivity scores reflect PEP shortening/sympathetic activation. Error bars represent standard errors of the fixed effects.

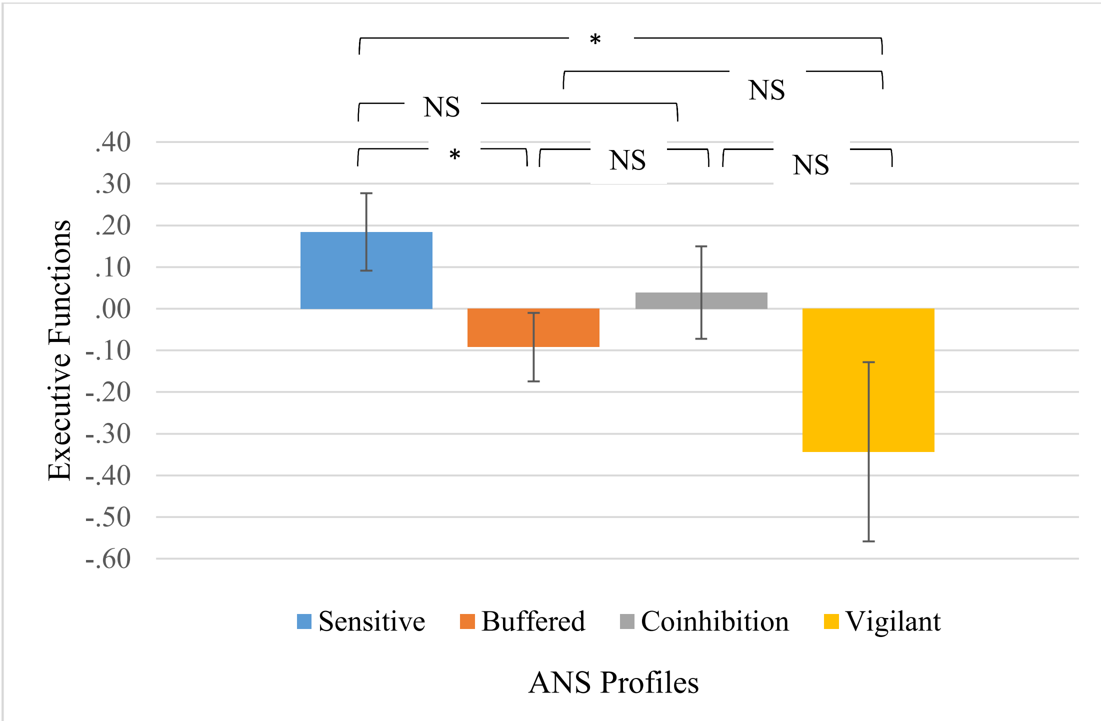


Figure 4. Executive Functions Scores Across the ANS Profiles. Error bars represent standard error of the mean. Asterisks (*) indicate the significance level of the paired-wise t-test differences in executive functions. †p <.10, *p < .05, **p <.01, ***p <.001.

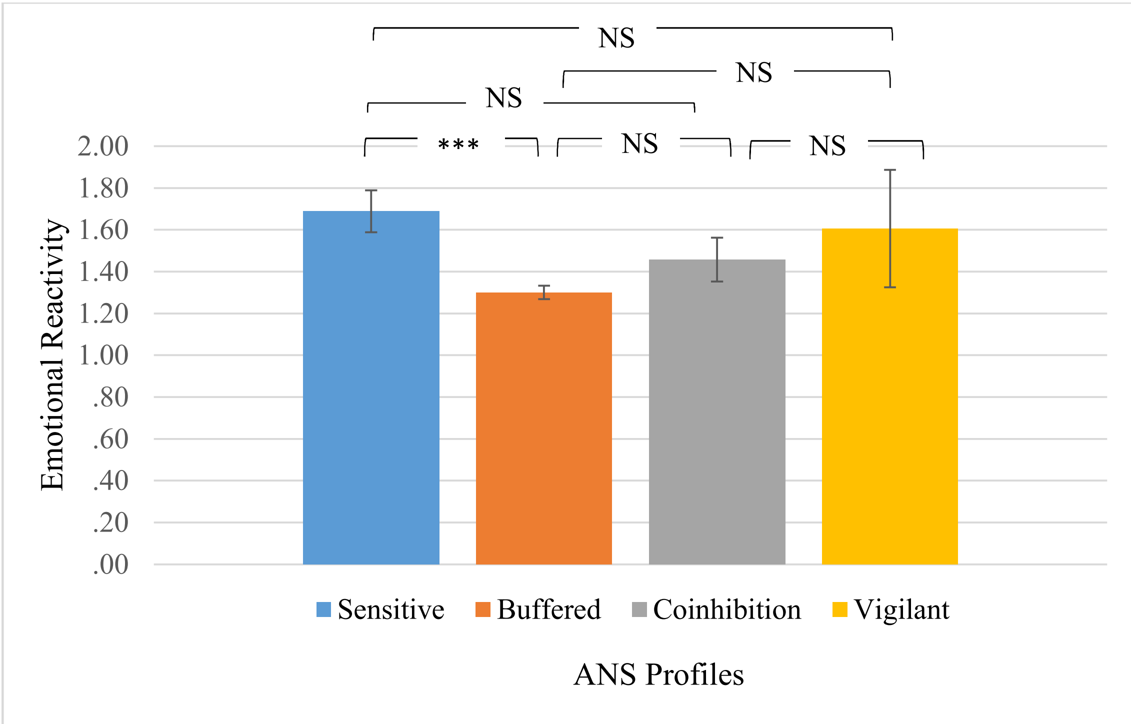


Figure 5. Teacher-report of Emotional Reactivity Scores Across the ANS Profiles. Error bars represent standard error of the mean. Asterisks (*) indicate the significance level of the paired-wise t-test differences in emotional reactivity. †p <.10, *p < .05, **p <.01, ***p < .001.

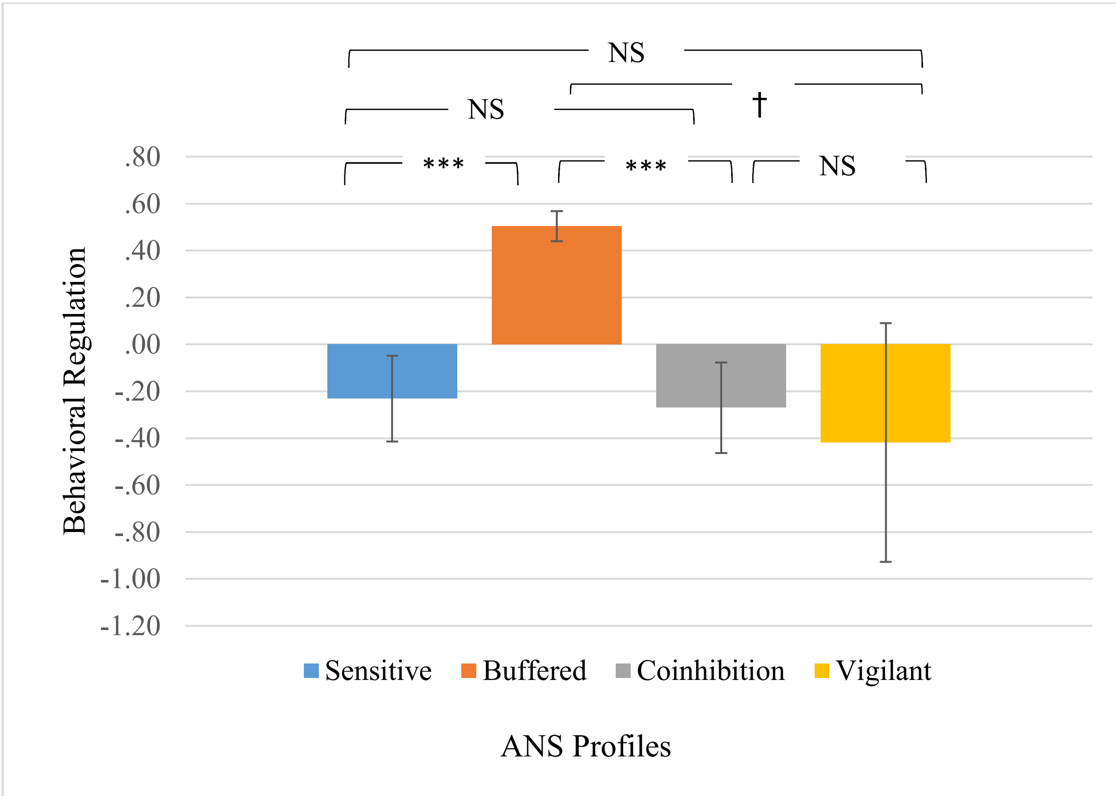


Figure 6. Teacher-report of Behavioral Regulation Scores Across the ANS Profiles. Error bars represent standard error of the mean. Asterisks (*) indicate the significance level of the paired-wise t-test differences in emotional reactivity. †*p* <.10, **p* < .05, ***p* <.01, ****p* < .001.

APPENDIX B

SUPPLEMENTAL MATERIALS ON MISSING DATA

Available RSA Data in Preschool

Among the 278 children who participated in the preschool visit, 259 had available RSA data. Reasons for missing data included child or caregiver refusal for the child to wear the heart rate equipment (n=12), equipment malfunctions (n=3), sticker placement/connection problems (n=3), and experimenter errors (n=2).

Baseline RSA. All participants with available RSA data (n=259) had at least 1-minute of artifact-free baseline RSA data.

Tangrams RSA. 256 had RSA data for the tangrams task. Reasons for missing data included removal or problems with stickers (n=3).

Go/No-Go RSA. For the Go/No-Go task, missing data was examined for each of the 4 blocks separately. If participants were missing more than half of the segments in a block (e.g., missing 3 out of 4), their data for that block was excluded. If children were missing more than 2 out of 4 blocks, their RSA data for this laboratory challenge was excluded. The rationale behind these criteria was that children who missed more than half the duration of the block/task likely do not have enough data to make their experience comparable to children who had most of their segments. Based on these criteria, 247 participants had available data for this laboratory challenge. Reasons for missing data included removal or problems with stickers (n=5), child did not play more than 2 blocks (n=5), no computer tasks due to equipment problem (n=1), and data lost to artifact (n=1).

Locked Box RSA. 250 children had RSA data for the locked box task. Reasons for missing data included removal or problems with stickers (n=7) and lost to artifact (n=2).

Toy Removal RSA. 244 children had RSA data for the toy removal task. Reasons for missing data included removal or problems with stickers (n=6), artifact (n=4), or child did not do the toy removal task (n=5).

Available RSA Data in Kindergarten

Among the 249 participants who came in for the kindergarten visit, 233 had RSA data. Reasons for missing data included the child or caregiver refusal to wear the heart rate equipment (n=13) and sticker placement or equipment problem (n=3).

Baseline RSA. 233 participants had at least 1-minute of baseline RSA data. All children had complete RSA data from the statue task. 5 participants had RSA data only from the statue but not the fish task. Reasons for missing fish RSA data included experimenter error (n=2), equipment malfunction (n=2), and movement artifact (n=1).

Tangrams RSA. Among the 233 participants who had RSA data, 231 had RSA data from the tangrams task. Reasons for missing data included sticker-related problems (n=2).

GNG RSA. 225 had RSA data for block 1 of the Go/No Go task. Reasons for missing data included removal of stickers (n=6), child did not play 2 levels (n=1), and equipment problem (n=1).

Not Sharing. 227 had RSA data for the frustration episode of the Not Sharing task. Reasons for missing data included removal or problems with stickers (n=6).

Impossible to Open Gift. 221 participants had RSA data for the frustration episode of the Not Sharing task. Reasons for missing data included removal of stickers (n=6), equipment problem (n=1), data lost to artifact (n=2), and having only 1 good segment (n=3).

Available RSA Data in Grade 1

Among the 240 participants who came in for grade 1 visit, 230 had RSA data. Reasons for missing data included the child or caregiver refusal to wear the heart rate equipment (n=9) and an equipment-related problem (n=1).

Baseline RSA. Among the 230 participants who had available RSA data, 229 had at least 1-minute of artifact-free baseline RSA data. The reason for missing baseline RSA data was sticker placement/connection problem.

Tangrams RSA. Among the 230 participants who had available RSA data, 228 had RSA data from the tangrams task. Reasons for missing data included sticker-related problems (n=2).

Go/No-Go RSA. 223 participants had RSA responsivity data the Go/No-Go task. Reasons for missing data included removal of stickers (n=4), child did not have baseline RSA (n=1), child did not do the task (n=1), and data lost to sticker problems or artifact (n=1).

Puzzle Box. 225 had RSA responsivity data for the frustration episode of the Puzzle Box task. Reasons for missing data included removal of stickers (n=4) and child did not have baseline RSA (n=1).

Broken Toy. 223 had RSA data for the frustration episode of the Broken Toy task. Reasons for missing data included removal of stickers (n=4), child did not have baseline RSA (n=1), and lost data to artifact (n=2).

Available PEP Data in Preschool

Among the 278 children who participated in the preschool visit, 241 had available PEP data. Reasons for missing data included the child or caregiver refusal to wear the heart rate equipment (n=12), sticker placement/connection problems (n=20), equipment malfunctions (n=3), and experimenter errors (n=2).

Baseline. Among the 241 participants, 233 had at least 1-minute of artifact-free baseline data. Baseline PEP data was missing mostly due to child sitting position or leaning, and/or sticker connection problems.

Tangrams. Among the 241 participants who had PEP data, 217 had PEP change data for the tangrams training. Reasons for missing data included sticker-related problems (n=10), lost to artifact (n=4), not having good baseline (n=8), and lot to artifact (n=2).

Go/No-Go. 215 participants had PEP responsivity data for the Go/No-Go task. Reasons for missing data included equipment malfunction (n=2), sticker-related problems (n=12), lost to movement artifact (n=6), and child played less than 2 levels (n= 6).

Locked Box. 216 participants had PEP change data for the locked box task. Reasons for missing data included sticker-related problems (n=16), no good baseline (n=8), and lost to artifact (n=1).

Toy Removal. Among the 241 participants who had PEP data, 208 had PEP responsivity data for the toy removal task. Reasons for missing data included child did not do task (n=5), sticker-related problems (n=15), movement artifact (n=4), no good baseline (n=8), and lost to artifact (n=1).

Available PEP Data in Kindergarten

Among the 249 participants who came in for the kindergarten visit, 222 had available PEP data. Reasons for missing data included the child or caregiver refusal to wear the heart rate equipment (N=13) and sticker placement or equipment problem (N=14).

Baseline. Among the 222 participants, 219 had at least 1-minute of baseline PEP data. Reasons for missing baseline PEP data included child leaning (n=1), child not still/fidgety (n=1), and sticker problem (n=1).

Tangrams. Among the 222 participants who had PEP data, 209 had PEP responsivity data from the tangrams task. Reasons for missing data included artifact (n=4), sticker-related problems (n=7), not having good baseline (n=2).

Go/No-Go. 203 participants had PEP responsivity data for the Go/No-Go task. Reasons for missing data included sticker-related problems (n=13), equipment problem (n=1), data lost to artifact (n=2), no good baseline (n=2), and child completed less than half of the task (n=1).

Not Sharing. Among the 222 participants who had PEP data, 203 had PEP data for the frustration episode of the Not Sharing task. Reasons for missing data included sticker-related problems (n=12), equipment problem (n=1), artifact or bad physiological data (n=3), no good baseline (n=2), and an outlier (n=1).

Impossible Gift. Among the 222 participants who had PEP data, 193 had PEP data for the frustration episode of the Not Sharing task. Reasons for missing data included sticker-related problems (n=11), equipment problem (n=2), lost to artifact (n=6), no good baseline (n=2), and having only 1 usable segment (n=8).

Available PEP Data in Grade 1

Among the 240 participants who came in for the first-grade visit, 218 had PEP data. Reasons for missing data included the child or caregiver refusal to wear the heart rate equipment (n=9), equipment-related problem (n=1), and sticker placement or connection problems (n=12).

Baseline. Among the 218 participants who had available PEP data, 217 had at least 1-minute of artifact-free baseline PEP data. The reason for missing baseline PEP data was sticker connection problem. The participant who does not have good baseline data have Mean PEP scores but not PEP change scores.

Tangrams. Among the 218 participants who had available PEP data, 210 had good PEP data from the tangrams training task. Reasons for missing data included sticker-related problems (n=5), child did not have baseline (n=1), and outliers (n=2).

Go/No-Go. 205 participants had PEP data for the Go/No Go task. Reasons for missing data included removal of stickers (n=6), child did not have baseline PEP (n=1), artifact and sticker connection problems (n=5), and child did not complete the task (n=1).

Puzzle Box. 205 participants had PEP data for the frustration episode of the Puzzle Box task. Reasons for missing data included removal of stickers (n=4), sticker placement/connection problems (n=5), child did not have baseline PEP (n=1), and lost to artifact (n=3).

Broken Toy. 199 participants had PEP data for the frustration episode of the Broken Toy task. Reasons for missing data included removal of stickers (n=4), sticker connection/placement problems (n=8), child did not have baseline PEP (n=1), and lost data to artifact (n=3) and excluded outlier (n=3).