Parasympathetic Nervous System Function, Temperament, and Adjustment in Preschoolers

by

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ABSTRACT

This study examines the relations among three aspects of temperament (shyness, impulsivity, and effortful control), resting respiratory sinus arrhythmia (RSA) recorded during a calming film and RSA suppression during three behavioral measures of effortful control, and adjustment (anxiety and externalizing behavior) in a sample of 101 preschool-age children. Principal components analysis was used to create composites for effortful control, shyness, impulsivity, anxiety, and externalizing behavior, and hierarchical regression analysis was used to test the study hypotheses. As expected, baseline RSA was negatively related to effortful control in shy children, but was unrelated to effortful control in children who were not shy. It was hypothesized that high baseline RSA would reduce the relation between shyness and anxiety, and between impulsivity and externalizing behavior; this hypothesis was supported for externalizing behavior, but not for anxiety. The interaction between impulsivity and RSA as a predictor of externalizing was statistically independent of effortful control, indicating that these are unique effects. Finally, it was hypothesized that RSA suppression would be positively related to effortful control for children low, but not high, in shyness. There was a marginal interaction between shyness and RSA suppression, with RSA suppression marginally negatively related to EC for children low in shyness, but unrelated to effortful control for children high in shyness; the direction of this association was opposite predictions. These findings indicate that RSA is more strongly related to effortful control for children high in shyness, and that it consequently may not be appropriate to use RSA as an index

of EC for all children. This study also draws attention to the need to consider the context in which baseline RSA is measured because a true baseline may not be obtained for shy children if RSA is measured in an unfamiliar laboratory context. The finding that high RSA moderated (but did not eliminate) the relation between impulsivity and externalizing behavior is consistent with the conceptualization of RSA as a measure of self-regulation, but further research is needed to clarify the mechanism underlying this effect.

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Introduction and Literature Review

Autonomic nervous system activity has long been known to index emotional reactivity (Cannon, 1927; James, 1884). In fear, for example, autonomic nervous system changes result in an increased heart rate, vasoconstriction, pupillary dilation, shallow and rapid breathing, decrease in salivation, and increased skin conductance (Darwin, 1872). Autonomic nervous system activation, in addition to being related to transient emotional states, has also been found to correlate with temperamental differences in emotional reactivity and self-regulation.

The autonomic nervous system consists of two branches, the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The heart, along with many other body organs, is innervated by both of these branches, which have opposing effects. The SNS underlies fight/flight behavior and increases heart rate, whereas the PNS promotes digestion and restorative behavior and decreases heart rate. The effects of the PNS on the heart are primarily mediated through the vagus nerve, also known as the Xth cranial nerve. The influence of the PNS on the heart fluctuates with breathing, however, with the effects of the PNS waxing with expiration and waning with inspiration. The resulting oscillation of heart rate at the frequency of respiration is called respiratory sinus arrhythmia (RSA), and is commonly used as a measure of cardiac vagal tone (Beauchaine, 2001).

Interest in examining psychophysiological variables such as RSA has been increasing, as autonomic nervous system function can be measured noninvasively and inexpensively, and may provide additional information about internal states that are difficult to reliably assess using observation or self-report measures (Kagan, 1998). Measures of autonomic nervous system function are also valuable because they can provide evidence for the underlying physiological mechanisms that support individual differences in temperament and adjustment (e.g., Beauchaine, Hong, & Marsh, 2008).

Two major theoretical perspectives have been applied by researchers to help understand the relation between RSA and psychological constructs. Of these, the polyvagal theory (Porges, 2001, 2007) has been most influential. According to this theory, the PNS acts as a brake on metabolic output. In stressful situations, this brake is removed, facilitating the fight/flight response and mobilizing metabolic resources. This physiological mechanism allows for a vigorous, rapid behavioral response when required by situational demands, but otherwise conserves metabolic resources (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996). According to the polyvagal theory, PNS activity should be high and sympathetic nervous system activity should be low when environmental demands are low (Porges, 2007; however, see Berntson, Cacioppo, & Quigley, 1993). This pattern of resting autonomic function is thought to be an evolutionary adaptation to avoid wasting metabolic energy and to minimize stress on biological systems (Porges, 1995a).

The theory of neurovisceral integration (Thayer & Lane, 2000) also makes the assertion that PNS activity allows for flexible responding to threat; however, this theory also states that anxious individuals are unable to reduce their resting physiological arousal, and therefore demonstrate relatively inflexible behavior that is insensitive to the magnitude of threat. This theory focuses much more on individual differences in PNS activity and their relation to attention and emotional processing, whereas the polyvagal theory is more concerned with the phylogenetic origins of PNS function.

Both of these theories emphasize the role of PNS function as facilitating adaptation to the environment. High RSA is generally believed to index the ability to engage with the environment, as well as flexibility in responding, whereas low RSA is thought to index poor emotion regulation. For example, Calkins (1997) found that for two- and three-year-old children, baseline RSA was negatively related the expression of negative emotion in a frustrating task (toy removal), and positively related to positive emotion expressed in a positive emotional induction (puppet task). In a sample of adolescents, high resting RSA was associated with anger regulation in an unfair game (Vogele, Sorg, Studtmann, & Weber, 2010). In preschooler children classified as non-expressive, regulated, or highly expressive, baseline RSA was highest in the regulated group and lowest in the other two groups (Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996). Moreover, Fabes and Eisenberg (1997) found that resting RSA was negatively related to negative emotional arousal in college students only if they were exposed to high or moderate levels of stress; this relation was not observed at low levels of stress, suggesting that RSA buffered against the negative effects of stress.

Despite the claims that RSA measures emotionality and emotion regulation, baseline RSA has been found to correlate with a large number of psychological variables, including externalizing behavior problems (Pine et al., 1998), anxiety (Lyonfields, Borkovec, & Thayer, 1995; Thayer, Friedman, & Borkovec, 1996), worry (Brosschot, Van Dijk, & Thayer, 2007), stress (Pieper, Brosschot, Van Der Leeden, & Thayer, 2007), effortful control (Mezzacappa, Kindlon, Saul, & Earls, 1998), sustained attention (Suess, Porges, & Plude, 1994), executive function (Hansen, Johnsen, & Thayer, 2003; Staton, El-Sheikh, & Buckhalt, 2009), positive and negative emotional reactivity (Fox, 1989), behavioral inhibition (Kagan, Reznick, & Snidman, 1987), positive emotionality (Oveis et al., 2009), self-esteem (Martens, Greenberg, & Allen, 2008), and impulsivity (M. T. Allen, Matthews, & Kenyon, 2000). PNS activity is also influenced by physical variables such as posture (Mezzacappa et al., 1997), respiratory rate and tidal volume (Grossman, Karemaker, & Wieling, 1991), and motor activity (Bush, Alkon, Obradović, Stamperdahl, & Boyce, 2011).

The multiplicity of these relations emphasizes that there is a lack of specificity in the relations between psychophysiological variables and physical and psychological states (Berntson, Cacioppo, & Grossman, 2007). Some investigators have acknowledged that RSA does not reflect any single psychological process; however, there have been few attempts to understand how RSA relates to multiple psychological states or traits. The goal of the present investigation is to clarify the meaning of RSA in the context of multiple psychological traits.

Effortful Control

Effortful control (EC) has been defined as "the ability to inhibit a dominant response to perform a subdominant response" (Rothbart & Bates, 2006, p. 137). It involves the regulation of attention as well as behavior, and an important component of EC is the ability to plan and monitor errors (Posner & Rothbart, 1998).

Self-regulation of behavior is clearly observable in the second year of life (Kopp, 1982), and EC develops rapidly across early childhood (Kochanska, Murray, & Harlan, 2000). Behavioral measures of effortful control have been found to cohere only modestly at 22 months, but become more strongly related as children age (Kochanska et al., 2000). As with many measures of temperament or personality (Roberts & DelVecchio, 2000) the longitudinal rank-order stability of EC also increases over time (Kochanska & Knaack, 2003), although EC does continue to develop throughout childhood and adolescence (Eisenberg, Zhou, et al., 2005; Lengua, Honorado, & Bush, 2007; Rothbart, Posner, Rueda, Sheese, & Tang, 2009).

EC is composed of a number of related abilities. For example, one study of low-income preschoolers found that a diverse set of behavioral measures loaded on a single factor with teacher reports of attention focusing and inhibitory control (Sulik et al., 2009). Although EC in preschool-age children can be separated into more specific, albeit correlated, components such as the ability to delay or to suppress/initiate behavior (Murray & Kochanska, 2002), studies have not yet documented that specific aspects of EC have differential predictive utility for child outcomes of interest such as internalizing problems or externalizing problems. Furthermore, the anterior cingulate cortex shows increased activation for both error monitoring, which is involved in response inhibition, and executive attentional control (Posner & Rothbart, 1998), suggesting that there is a neural basis for grouping these different abilities together as subcomponents of a broader EC construct.

In addition to behavioral measures, questionnaires are frequently used to assess EC in children. The Children's Behavior Questionnaire (Rothbart, Ahadi, Hershey, & Fisher, 2001) is a commonly used measure of temperament that includes scales that measure attention focusing, attention shifting, and inhibitory control. Based on the results of factor analyses, the attention and inhibitory controls scales from the CBQ, have good internal consistency (Cronbach's α) and tend to load on together on a factor that is distinct from negative emotionality and extraversion/surgency (Rothbart et al., 2001). A version of the CBQ for younger children, the Early CBQ (ECBQ), has also been found to possess similar psychometric characteristics (Putnam, Gartstein, & Rothbart, 2006). Consistency for the CBQ and ECBQ scales is more modest across reporters, however, which may partially reflect situational differences that influence the behavioral expression of EC. For example, a child may act differently at home and at school, so parent and teacher reports would be expected to differ to the extent that parents and teachers observe objectively different behavior (Kagan & Fox, 2006). For this reason, it is often desirable to have multiple reporters to obtain a more complete view of children's EC.

Relations with baseline RSA. Positive relations between EC and resting RSA have been documented in the literature. Attentional control, an important component of EC, has been found to be associated with resting RSA. In one study, mothers reported on the length of their infant's attention span. These reports were positively correlated with measures of these infants' resting RSA (Huffman et al., 1998). In a study of fourth and fifth graders, performance on a continuous performance task (a measure of attentional control) was found to be positively associated with resting RSA, although these variables were only correlated for one out of three blocks of trials (Suess et al., 1994). Hansen, Johnsen, and Thayer (2003) replicated this finding in a sample of adults, also finding that resting RSA was positively related to performance on a continuous performance task. In a sample of children and adolescents ranging from eight to 17 years old, resting RSA was positively related to parent reports of EC (Chapman, Woltering, & Lewis, 2010).

Studies also show that resting RSA is related to performance on complex cognitive tasks involving executive function (EF), which demonstrates considerable conceptual overlap with EC (Zhou, Chen, & Main, in press). In one study of school-age children, resting RSA was positively related to EF and processing speed, but unrelated to more general measures of cognitive ability (Staton et al., 2009). Similarly, resting RSA was negatively related to processing time in a stroop task in adults (Mathewson et al., 2010). In a sample consisting mostly of male children, half of whom had emotional or behavioral disorders, Mezzacappa and colleagues (Mezzacappa et al., 1998) found that resting RSA was positively correlated with a composite measure of EF and EC. In one study of 3.5-year-old children, resting RSA was positively related to performance on two EF/EC tasks (Marcovitch et al., 2010).

In contrast to this evidence, some studies have failed to document significant relations between baseline RSA and EC/EF. For example, performance on two behavioral EC measures was unrelated to resting RSA in sample of low-income preschoolers enrolled in Head Start (Blair & Peters, 2003). Null relations between resting RSA and a cognitive signal detection task have also observed for college students (Duschek, Muckenthaler, Werner, & Reyes del Paso, 2009).

Overall, the literature suggests that resting RSA is related to EC in school-age children and adults; however, the pattern of findings is more limited for preschool-age children. A limitation of previous studies using younger children is that indices of EC may be unreliable. Most studies examining relations between RSA and behavioral measures of regulation use only one or two such measures (e.g., Blair & Peters, 2003; Boyce et al., 2001; Graziano, Keane, & Calkins, 2007). Behavioral measures of EC tend to intercorrelate only weakly to moderately (Murray & Kochanska, 2002; Sulik et al., 2009), which lowers reliability and attenuates measures of association.

Relations with RSA suppression. In addition to studying the relation between resting RSA and EC/EF, some investigators have also explored relations between changes in RSA and performance on laboratory tasks measuring these constructs. Decreases in RSA (relative to baseline values) are referred to RSA suppression, whereas increases from baseline are referred to as RSA augmentation.

RSA has been theorized to index responsivity to changing environmental demands (Porges, 1995b). One possibility is that low RSA during tasks reflects engagement with the task. In a study of attentional performance and reaction time in a sample of college students, RSA suppression was negatively related to the number of errors made by participants however, task RSA was more strongly related to performance than RSA suppression (Duschek et al., 2009);. In this study, the authors interpreted the ability to suppress RSA as reflecting the ability to engage with the task. Similarly, negative relations were obtained for task RSA (but not RSA suppression) and performance on a go/no-go task in a sample of children and adolescents age eight to 17 (Chapman et al., 2010). Other studies have failed to find relations between RSA suppression and performance on EC tasks in preschool-age and school-age children (Blair & Peters, 2003; Staton et al., 2009). One potential explanation for these mixed results is that that there are nonlinear relations between RSA suppression and task performance; supporting this view, one study has have found that children with moderate (rather than low or high) RSA suppression demonstrated the best task performance (Marcovitch et al., 2010).

Shyness and Behavioral Inhibition

Coplan and Rubin (2010, p. 9) define shyness as "(Temperamental) wariness in the face of social novelty or self-conscious behavior in situations of perceived social evaluation." Behavioral inhibition, in contrast, is a dimension of temperament characterized by high emotional reactivity to the unfamiliar (Snidman, Kagan, Riordan, & Shannon, 1995). According to Fox and colleagues (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001, p. 2), “Reticence [i.e., shyness] is conceptually related to behavioral inhibition based on the common underlying motivation to avoid novelty due to the negative affect elicited by novel stimuli.” Behavioral inhibition is characterized by emotional reactivity to unfamiliar situations in general, whereas shyness is specific to social situations, and may also involve fear of being evaluated in addition to emotional reactivity to the unfamiliar (Xu, Farver, Yu, & Zhang, 2009). As might be expected based on the overlap between these constructs, shyness and behavioral inhibition have been found to be positively correlated (Xu et al., 2009). Furthermore, shyness and behavioral inhibition have both been found to predict the development of anxiety problems (Biederman et al., 2001; Hirshfeld et al., 1992; Prior, Smart, Sanson, & Oberklaid, 2000).

Heart rate variability (HRV), of which a substantial proportion consists of PNS influences (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996), has been found to relate negatively to behavioral inhibition in some studies. For example, children classified as behaviorally inhibited at 21 months of age had less HRV across a battery of tasks at age 4 (Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984) and at age 5.5 (Reznick et al., 1986), but not at age 7 (Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988). A number of investigators have also observed a negative relation children’s behavioral inhibition and RSA (Fox, 1989; Putnam, 2000; Rubin, Hastings, Stewart, Henderson, & Chen, 1997), and negative relations between RSA and parental ratings of shyness have been found in some studies (Doussard-Roosevelt, Montgomery, & Porges, 2003; Kagan, Reznick, Snidman, et al., 1988). In addition, RSA has also been found to relate negatively to social fear in infants (Stifter & Jain, 1996), to social reticence in preschool-age children (Henderson, Marshall, Fox, & Rubin, 2004), and to noncompliance during electrode placement, although positive relations between RSA and noncompliance were found for a clean-up task (Stifter, Spinrad, & Braungart-Rieker, 1999). Some studies have failed, however, to find significant relations, between RSA and behavioral inhibition (Burgess, Marshall, Rubin, & Fox, 2003; Marshall & Stevenson-Hinde, 1998) or shyness (Dietrich et al., 2009; Schmidt, Fox, Schulkin, & Gold, 1999), and one study has found that fearful children had higher RSA than less fearful children (Brooker & Buss, 2010). Overall, the evidence suggests that the RSA is negatively related to behavioral inhibition and shyness, although this relation may be modest.

Impulsivity

Eisenberg and Spinrad (2004) distinguished EC from reactive control. Whereas EC is voluntary (although not necessarily conscious), reactive control refers to relatively automatic behavioral reactions that are involuntary, such as impulsivity (Derryberry & Rothbart, 1997). A factor analysis of a number of tasks assessing EC as well as the motivational “pull” of rewards suggested that effortful and impulsivity can be distinguished using behavioral measures (Eisenberg et al., 2004; Kindlon, Mezzacappa, & Earls, 1995). Further supporting the distinction between these two constructs, effortful and reactive control have been found to independently predict children's adjustment. For example, impulsivity and EC, although positively correlated, have been found to independently predict the development of externalizing problems in the United States and China (Eisenberg, Chang, Ma, & Huang, 2009; Eisenberg et al., 2004, 2007; Valiente et al., 2003).

I am not aware of any studies examining the relations between impulsivity and RSA. One study did find that heart rate variability (consisting of sympathetic and parasympathetic nervous system influences) was unrelated to university students' self-reports of impulsivity (M. T. Allen, Hogan, & Laird, 2009).

There is, however, limited evidence on the relations between RSA and Gray's (1982) behavioral inhibition system (BIS) and behavioral activation system (BAS). The BIS is thought to be involved in negative reinforcement and punishment, whereas the BAS is thought to be involved in reward sensitivity and approach behavior. In one study of low-income preschoolers, baseline RSA, although positively correlated with Carver and White's (1994) questionnaire measure of BIS sensitivity was unrelated to BAS sensitivity (Blair, 2003). In this study, RSA suppression to an EC task was positively related to scores on the BAS drive scale and negatively related to BIS scores, but was unrelated to scores on the BAS reward responsiveness and fun-seeking scales. In another study, baseline measures of RSA and RSA suppression during a monetary reward task were not found to correlate with BAS scores, although baseline pre-ejection period, a measure of SNS influence on the heart, was negatively related to BAS reward responsiveness (Brenner, Beauchaine, & Sylvers, 2005). Based on these studies, there is little evidence to suggest that RSA can be considered a measure of impulsivity (although measures of SNS function such as skin conductance or pre-ejection period may be relevant). In contrast, and it has been suggested that RSA, conceptualized as an index of emotion regulation, may be of particular importance in preventing externalizing problems for impulsive children (Beauchaine, Derbidge, Mead, Neuhaus, & Shannon, 2008).

Externalizing Behavior

Low heart rate is considered one of the best biological predictors of externalizing problems in children (Lorber, 2004; Ortiz & Raine, 2004). Because heart rate is jointly determined by SNS and PNS activity, this well-replicated finding does not indicate which branch of the autonomic nervous system accounts for this effect (or alternatively, whether these systems interact to predict externalizing problems). Although boys tend to demonstrate lower heart rate and more externalizing problems relative to girls, a meta-analysis did not find evidence that the relation between heart rate and externalizing problems is moderated by gender (Ortiz & Raine, 2004).

RSA has also been identified as a predictor of externalizing problems in some studies. In a Dutch population cohort of preadolescents, resting RSA was positively (but weakly) associated with externalizing problems (Dietrich et al., 2007). In a study of children age two to five (Calkins, Blandon, Williford, & Keane, 2007), resting RSA was unrelated to initial levels of externalizing behavior, but was positively associated with growth in externalizing problems. In a second study of two-year-olds oversampled for externalizing problems, resting RSA was instead negatively related to externalizing problems for boys, and the relation between resting RSA and externalizing problems was nonsignificant for girls (Calkins & Dedmon, 2000). In two samples of high-risk male adolescents, externalizing problems were also negatively associated with resting RSA (Mezzacappa et al., 1997; Pine et al., 1998). Other studies have failed to establish a relation between resting RSA and externalizing problems (e.g., Beauchaine, Gatzke-Kopp, & Mead, 2007).

These contradictory findings suggest that the relations between RSA and externalizing behaviors are moderated by other variables. For example, experiences such as marital conflict may interact with resting RSA to predict externalizing problems in children (El-Sheikh & Whitson, 2006; El-Sheikh, Harger, & Whitson, 2001; El-Sheikh et al., 2009). Some investigators have suggested that negative relations between RSA and externalizing problems are typically observed in samples that are subject to high levels of risk (Obradović, Bush, Stampterdahl, Adler, & Boyce, 2010). In contrast, positive relations between RSA and externalizing problems appear to be observed only in samples subject to relatively low levels of risk (Calkins, Graziano, & Keane, 2007; Dietrich et al., 2007)

Anxiety

The PNS serves to inhibit the effects of the SNS on organs innervated by both branches of the autonomic nervous system. For this reason, individuals with low resting RSA are thought to be subject to physiological overarousal. A number of studies provide evidence for a negative association between resting RSA and anxiety problems. For example, generalized anxiety disordered (GAD) patients have been found to have lower RSA than non-disordered controls, and show less decline in RSA from baseline to a worry episode (Lyonfields et al., 1995), supporting the idea that anxiety patients are inflexible and inappropriately identify threat. In a second study, GAD patients were lower in resting RSA across three measurement periods (baseline, worry episode, post-worry recovery period) relative to non-disordered controls, RSA (Thayer et al., 1996). In another similar study, resting RSA was marginally lower (p = .06) in GAD patients relative to non-disordered controls (Hammel et al., 2011). In a non-clinical sample of adults, anxiety scores on the State Trait Anxiety Inventory were negatively associated with RSA across three measurement occasions (Fuller, 1992).

Investigators have also found that adult participants exposed to acute stress subsequently have lower RSA relative to participants in a control condition (M. Hall et al., 2004). This effect appears to be at least partially accounted for by worry about the stressor. Within-person worry intensity in non-anxiety disordered adults is negatively related to within-person RSA (Pieper et al., 2007), and that this contribution remains significant after controlling for stress levels (Brosschot et al., 2007). Thus, anxiety disorders (trait) and worry (state) appear to have parallel relations with RSA (however, see Jonsson, 2007).

Studies of anxiety and autonomic nervous system function have typically focused on adults, whereas studies of children more often examine a more general index of internalizing problems, of which only one component is anxiety. Some studies using child samples have provided evidence for an association between broadband internalizing problems and low resting RSA (Boyce et al., 2001; Forbes, Fox, Cohn, Galles, & Kovacs, 2006), but this pattern does not appear to replicate consistently (Dietrich et al., 2007; Hastings et al., 2008; Hinnant & El-Sheikh, 2009). This inconsistent pattern of findings may be due to stronger relations between anxiety and resting RSA than between depression and resting RSA; a meta-analysis of 13 studies found that RSA explains only 2% of the variance in depression (Rottenberg, 2007). Furthermore, the link between RSA and depression could potentially be explained by comorbidity between anxiety and depression.

In one study comparing 22 pediatric anxiety patients (mixed diagnoses) to 12 non-anxious controls, the anxiety patients had low, stable RSA prior to a physical stressor (CO2 inhalation), whereas controls had high, declining RSA over the course of this period (Monk et al., 2001). Although limited by a small sample size and a lack of distinction among anxiety disorders, this study suggests that the negative relation between RSA and anxiety disorders is found not only adults, but also in children. In addition, children (age 3 to 9) of depressed parents showed a negative relation between RSA and internalizing problems (Forbes et al., 2006).

The Present Investigation

Hypothesis 1. As reviewed in the introduction, a number of investigators have attempted to examine the direct relations between baseline RSA temperamental characteristics such as shyness and EC. To my knowledge, however, moderators of these relations have not been examined. In this study, I will use the interaction between baseline RSA and shyness to predict EC. I hypothesized that RSA would be more strongly related to EC for children who were high in shyness because shy children with better attentional resources should be better able regulate their emotional arousal in an unfamiliar setting. For children low in shyness, no relation between baseline RSA and EC was expected. RSA was only expected to relate to EC when measured under conditions that require effective emotional self-regulation (cf. Krypotos, Jahfari, van Ast, Kindt, & Forstmann, 2011).

According to Porges (2001), RSA decreases when we engage the sympathetic fight/flight system, but remains high when engaging in social behavior. Children high in shyness are expected to show lower resting RSA, especially considering the context in which RSA was measured. In this study, the resting measure of RSA took place immediately after the physiological hookup. Although the children in this study had previous exposure to the experimenters, the study took place in a novel location (the laboratory testing room) and the experimenters were a somewhat unfamiliar adult. The relation shyness and RSA was expected to be moderated by effortful control, in particular the control of attention. Shy children who are high in attentional control were hypothesized to have the ability to redirect attention away from potentially threatening information to regulate their emotion-related physiological arousal. Children with lower levels of attentional control were expected to be unable to regulate their physiological arousal, resulting in a stronger relation between RSA and shyness for children low in EC relative to children high in EC.

Hypothesis 2. Research indicates that resting RSA is related to temperament as well as adjustment. Specifically, resting RSA has been found to correlate positively with EC and negatively with behavioral inhibition and anxiety, whereas relations with externalizing behavior have been less consistent. Although a number of studies have examined RSA as a moderator of environmental risk factors and psychological maladjustment, it has been rare for studies to examine RSA as a moderator of temperamental risk factors.

Children who demonstrate high levels of temperamental reactivity (i.e., high shyness or high impulsivity) and who also show physiological dysregulation (i.e., physiological overarousal or underarousal) in an unfamiliar laboratory setting are likely to be more at risk for adjustment problems than children who show only one of these vulnerabilities. Therefore, I expected an interaction between resting RSA and emotional aspects of temperament as a predictor of internalizing and externalizing problems. Specifically, the combination of low RSA and high shyness was expected to predict greater anxiety problems, whereas the combination of low RSA and high impulsivity was expected to predict greater externalizing problems. For shy children, low RSA be an index of fearfulness rather than low social motivation (Henderson et al., 2004). In the context of high impulsivity, RSA may act as an index of emotional self-regulation (Beauchaine, Derbidge, et al., 2008).

Hypothesis 3. In this study, the relation between RSA suppression during three EC tasks and measures of performance across these same tasks were examined. On-task RSA was expected to relate negatively to performance on the EC tasks. Presumably, children who are most actively engaged with the tasks would show the lowest levels of RSA during the tasks after controlling for resting RSA. Performance on the tasks was also be predicted by resting RSA. The present investigation improved on previous studies by including three behavioral EC tasks (as well questionnaire measures of EC from multiple reporters). The inclusion of multiple measures of a single construct enhances reliability, thereby increasing power to detect a relation between RSA and EC if it exists in the population of preschool-aged children.

Method

The Arizona State University institutional review board gave ethical approval for this study, which consists of three components: (1) a laboratory visit in which RSA was recorded during a baseline film and while children completed three tasks measuring EC; (2) a second, shorter laboratory session in which children completed a continuous performance task (another behavioral measure of EC); and (3) parent, teacher, and observer questionnaires assessing children’s temperament and adjustment.

Participants

Participants were 106 children (42 girls) attending one of three research preschools at Arizona State University, Tempe, AZ, who gave assent for physiological recording. Two of these preschools offer a full-day schedule and although they are open to the public, enrollment principally consists of the children of university faculty and staff. The third preschool primarily serves families from the surrounding community, and only offers a half-day schedule (e.g., 9:00 AM – 12:00 PM on Monday, Wednesdays, and Fridays). All subsequent analyses report data for the 101 children (40 girls) who had complete physiological data for a baseline film and at least one of three self-regulation tasks. Physiological data were missing for five children due to problems with the recoding of respiration (e.g., improper placement of the respiration bellows).

Eighty-three (82%) of the parents in the subsample with physiological measures returned questionnaires that included demographic information. Education was reported on a 7-point scale (1 = did not graduate high school; 7 = Ph.D. or professional degree). The median level of parental education averaged across both parents was 4-year college graduate. Annual family income was also reported on a seven-point scale (1 = < $10,000; 7 = more than $100,000). Median family income was $75,000-$100,000. Six percent of children were from single-parent families. Children’s racial composition, as reported by parents, was as follows: 73% Caucasian; 2% African American; 9% Asian; 4% Native American; 12% Other/Multiracial. Eighteen percent of parents reported that their children were Mexican American/Hispanic.

Missing Data

Multiple imputation was used as a missing data treatment. Multiple imputation is a modern method for dealing with missing data that produces unbiased estimates for data that are missing completely at random or missing at random, meaning that the probability of missing data may be related to variables measured in the study, but not to variables that were not measured (Shafer & Graham, 2002). One-hundred data sets were imputed using SAS 9.2. Autocorrelation plots were used to verify the independence of imputed data sets (Enders, 2010). All results reported in this manuscript reflect the pooled estimates across imputations.

Laboratory Procedure

Each laboratory session was administered by one experimenter and one camera person, both of whom were trained undergraduate or graduate research assistants. If both the experimenter and the camera person were undergraduates, a graduate student or faculty member was present to supervise data collection. Laboratory sessions were video recorded for later coding.

Experimenters brought children from their preschool classroom into the lab, which was located close to the classrooms in each preschool. After obtaining child assent, experimenters attached three Red Dot electrodes in an inverted triangle configuration to the child's torso and placed a respiration bellows around the child's chest. Following physiological hookup, children watched a relaxing video and played three games with the experimenter while heart rate and respiration data were recorded. At the end of the session, children received a small toy to thank them for participating.

Dolphin film (physiological baseline). Children were seated in front of a laptop computer and instructed to watch a meditation video showing dolphins swimming while relaxing music played. The experimenter told children that he or she had to do computer work and would not be able to talk to the child while the movie was playing. If children stopped paying attention to the movie, fidgeted excessively, or attempted to talk to the experimenter or camera person, the experimenter redirected them to continue watching the film. The dolphin film lasted two minutes and 38 seconds.

Laboratory measures of effortful control. Three laboratory tasks were used to measure effortful self-regulation while physiological data were collected; these tasks were selected on the basis of their use in prior studies of preschool-age children and the requirement that they do not require much physical activity, which can affect RSA (Bush et al., 2011; Porges et al., 2007). Two of these tasks, bird and dragon and gift wrap, were adapted from Kochanska's (Kochanska & Knaack, 2003; Murray & Kochanska, 2002) battery of EC tasks, and are commonly combined to form an index of self-regulation. A third task, knock tap, has been used to measure executive function (Luria, 1966); variants of this task have been used in other studies of preschool age children (Blair, 2003; Diamond & Taylor, 1996). Tasks were modified to extend the length of physiological recording. For each task, the goal was to have approximately one minute of recording time. Each of the behavioral measures was coded by two trained undergraduate research assistants. A primary coder viewed all tapes, and a reliability coder independently viewed at least 25% of the tapes. To assess reliability, the intraclass correlation (ICC) between the main and reliability coders was computed for each measure. A fourth laboratory measure, a computerized continuous performance task (CPT), was also used to measure EC; however, this task was performed in a separate laboratory session and was not accompanied by physiological recording.

Bird and dragon. The experimenter had two puppets, which were introduced as the nice bird and mean dragon. Children were instructed to “Do what the nice bird says” but “Don’t do what the mean dragon says.” After completing practice trials to ensure that the child understood the game, the experimenter used the puppets to issue a series of commands (6 bird commands and 10 dragon commands). In this study, commands all involved a relatively small amount of body movement (e.g., touch your nose, wiggle your fingers) to minimize artifact in physiological recording and changes in respiration (Bush et al., 2011; Porges et al., 2007). Each trial was scored as correct (3), partially correct (2), or incorrect (1). An activation composite and an inhibition composite were calculated as the average score on the correct bird and dragon trials, respectively. The product of these two scores was used as a measure of effortful control. As a result of this scoring procedure, children would need to respond correctly to both types of trials to receive a high score; children who impulsively respond to both types of trials would receive a low score, as would inhibited children who did not respond to either type of trial. The average score for the bird trials was 2.71 (*SD* = .66), the average score for the dragon trials was 2.66 (*SD* = .81). Reliability for the bird trials and for the dragon trials was excellent, ICCs = 1.0 and .99, respectively.

Knock tap. In this task, children first completed eight imitation trials. During the imitation trials, when the experimenter knocked on the table (i.e., closed fist), the child was asked to knock on the table. When the experimenter tapped on the table (i.e., open palm), the child was asked to tap on the table. Following the imitation trials, the children played the game a “Tricky way.” During the tricky trials, children were asked to tap on the table when the experimenter knocked, and to knock on the table when the experimenter tapped. The experimenter performed 24 tricky trials, which were scores as correct (1) or incorrect (0). Trials in which a child responded at the same time or prior to the experimenter’s action were scored as incorrect unless the child corrected his or her answer. Some children became bored with the task and stopped playing; these trials were considered missing, rather than incorrect. The proportion of correct responses during the tricky trials was computed as a measure of effortful control. Reliability for this proportion score was excellent, ICC = .98.

Gift wrap. In this task, experimenters told children that they had a surprise for them, and children were asked to look straight ahead at the wall in front of them so that the experimenter could wrap the gift. The experimenter reminded the child not to peek and noisily wrapped a gift behind the child for one minute. At the end of this period, the experimenter gave the gift to the child. Children’s peeking behavior was coded as follows: 5 = Child does not peek; 4 = Child peeks, but does not turn body and does not turn head over shoulder; 3 = Child peeks, but does not turn body; 2 = Child turns body while peeking in last 10 seconds, or child turns body while peeking for three seconds or less; 1 = Child turns body while peeking for more than three seconds. Reliability the gift wrap peeking score was acceptable, ICC = .81.

Continuous performance task (CPT). In a separate laboratory session, children's effortful control was assessed using a computerized continuous performance task. Children were seated in front of a laptop computer with all keys covered except for the space bar. Children were instructed to press the space bar when they saw a fish, but to refrain from pressing the spacebar when other pictures were displayed (e.g., a beach ball, an umbrella). Fish were displayed on 32 (20%) of the 140 trials. The CPT is typically scored to yield two variables, the proportion of correct responses to the fish trials and the proportion of correct responses to the non-fish trials. This method has a problem, however, in that a child's rate of responding can influence scores independent of accuracy. For example, a child who presses the space bar on every trial would have a perfect score for the fish trials but a score of zero for the non-fish trails; an inhibited or noncompliant child who never responded would show the opposite pattern of scores. Due to this limitation, signal detection theory (Wickens, 2002) was used to score the results. Each trial in which the fish was presented was scored as a hit (1) or a miss (0), whereas each trial in which the fish was not presented was scored as a correct rejection (1) or a false alarm (0). The proportion of hits for the fish trails and the proportion of correct rejections for the non-fish trials were computed, and each of these probabilities was converted into *z*-scores, making an assumption that the distributions of hits and correct rejections have equal variances. By computing the difference between these two *z*-scores, these transformations allow the means of the two distributions to be compared on a standard deviation metric. This difference score, known as detectability, indexes how well children were able to behaviorally discriminate between fish and non-fish trials. Detectability was used in the analyses as an index of effortful control.

Physiological Data

Heart rate and respiration were measured during the dolphin film (physiological baseline) and three self-regulation tasks (bird and dragon, knock tap, and gift wrap). RSA was calculated using the peak-valley method (Grossman et al., 1991) using James Long Company software (James Long Company, 2008).

Outliers that were more than 3 *SD* above or below the mean were recoded so that there were no more than 3 *SD* from the mean (Tabachnik & Fidell, 2006); this procedure reduces the influences that outliers have on the analysis without discarding them completely. The number of outliers recoded for each task was as follows: $n = 1$ for the dolphin film (baseline), $n = 3$ for bird & dragon, $n = 2$ for knock tap, and $n = 3$ for gift wrap. These changes did not substantially alter the results of any subsequent analysis.

Mean baseline RSA was .082 (*SD* = .048). Mean RSA for each task was as follows: bird and dragon mean = 084 (*SD* = .063), knock tap mean = .055 (*SD* = .041), and gift wrap mean = .064 (*SD* = .045). An RSA change score was calculated by subtracting task RSA (averaged across all three tasks) from baseline RSA; for this score, positive values indicate RSA suppression (decreases from baseline), whereas negative values indicate RSA augmentation (increases from baseline). The mean of the RSA changes scores was .014 (*SD* = .024). Seventy-six percent of children exhibited RSA suppression and 24% exhibited RSA augmentation. RSA change scores were substantially correlated with baseline

RSA, $r = .38$, $p < .001$. Consequently, we computed a residualized RSA change score by regressing task RSA on baseline RSA, retaining the residual from this analysis, and multiplying this residual by -1 (Hastings et al., 2008). The resulting residualized change score is orthogonal to baseline RSA; positive values correspond to greater than expected RSA suppression and negative values correspond to less than expected RSA suppression. The residualized RSA suppression score was used in all analyses reported in this manuscript.

Questionnaires

Over the course of the semester, trained undergraduate research assistants observed children in their classroom while doing short observational scans coding for aggression and play behaviors (e.g., Spinrad et al., 2004). At the end of the semester, these observers also completed questionnaires about children's temperament and adjustment, as reported below. Between two and five classroom observers reported on each child. Observers reported their confidence in rating each child on a 7-point Likert scale. For children with a confidence rating of less than 4, observer data was discarded; this resulted in dropping approximately 5% of the observer questionnaire data. Because the number of observer ratings retained for each child ranged from one to eight ($M = 3.39$; $SD = 1.45$), scores on the individual items were averaged across observers, and these averages were used to create scale scores and calculate reliability numbers for these scales. Teachers and teachers' aides ($n = 100$), parents ($n = 83$; 13 fathers), and observers (at least one observer completed questionnaires for each of the 101 children) filled out the following questionnaires. A list of the scales used in this study can be found in the appendix.

Children's Behavior Questionnaire. The Children's Behavior Questionnaire (CBQ) is a widely used measure of temperament developed for children age three to seven (Rothbart, Ahadi, & Hershey, 1994; Rothbart et al., 2001). To assess EC, shyness, and impulsivity, we used the short form of the CBQ (Putnam & Rothbart, 2006) except for attention shifting because a short form for this scale not yet been developed or validated. The scales for inhibitory control (e.g., "Can wait before entering into new activities if s/he is asked to"), attention focusing (e.g., "When drawing or coloring in a book, shows strong concentration"), impulsivity (e.g., "Usually rushes into an activity without thinking about it"), and shyness (e.g., "Seems to be at ease with almost any person") each consisted of six items. For attention shifting (e.g., "Can easily shift from one activity to another"), we dropped two items from the full scale that were judged by expert raters to have overlap with psychopathology (Eisenberg, Sadovsky, et al., 2005), resulting in a 10-item scale. For teachers and observers, we used Teglasi's adaptation of the short form of the CBQ. Cronbach's α reliability coefficients were generally acceptable for inhibitory control, parent α = .70, teacher α = .80, observer α = .89; attention focusing, parent α = .63, teacher α = .85, observer α = .85; attention shifting, parent α = .76, teacher α = .81, observer α = .85; impulsivity, parent α = .76, teacher α = .71, observer α = .88; and shyness, parent α = .84, teacher α = .84, observer α = .89. With the exception of attention focusing and attention shifting for parent reports, r = .08, all three EC scales (attention shifting, attention focusing, and inhibitory control) were substantially correlated, *r*s = .35 – .83. Therefore, these scales were averaged to create a composite measure of EC for each reporter.

Anxiety and Externalizing Problems. A subset of 16 items from the Child Behavior Checklist (CBCL; Achenbach, 1991) was used as a measure of anxiety (Kendall, MacDonald, & Treadwell, 1998), and 23 items from the CBCL and the Revised Problem Behavior Checklist (Quay, 1983) were used to assess externalizing problems (Lochman & The Conduct Problems Prevention Research Group, 1995); an item that asks about starting fires was not included. A scale ranging from 1 (never) to 4 (often) was used for each item. Cronbach's α for the anxiety measure was .83 for parents, .86 for teachers, and .86 for observers, and Cronbach's α for the externalizing scale was .90 for parents, .97 for teachers, and .98 for observers.

Results

Correlations and Descriptive Statistics

In multiple imputation, point estimates can be calculated as the mean of the estimates across all imputations (Rubin, 1987). Unfortunately, the method for pooling results for significance tests is not straightforward. For correlation coefficients, Fisher's *z* transformation can be used. The SAS 9.2 Users Guide (SAS Institute, Inc., 2008) provides the following formulas:

$$z = \frac{1}{2}\log\left(\frac{1+r}{1-r}\right)$$

and

$$SE = \frac{1}{\sqrt{n-3}}$$

Given an *n* = 101 in the present investigation, *SE* = .10. To achieve significance at α = .05 with this *SE*, a correlation of .20 or greater is required. Because these formulas were used to estimate the significance of the correlations, the degrees of freedom for correlation coefficients are not reported.

Due to the large number of variables, correlations and descriptive statistics are presented in three tables. Correlations among the temperament variables (laboratory measures of EC, and questionnaire measures of EC, shyness, and impulsivity) are shown in Table 1. Correlations among other study variables including age, sex, baseline RSA and RSA suppression, and adjustment are shown in Table 2. The correlations between these two sets of variables are presented in Table 3. With the exception of observer-reported EC and the relation between bird and dragon and teacher-reported EC, all EC variables were significantly positively intercorrelated, with *r*s ranging from .31 to .45. Although the observer questionnaires were significantly related to teacher reports and the CPT detectability score, *r*s = .46 and .24, they were unrelated to other measures of EC. Correlations among the different reporters ranged from .22 to .34 for shyness, and from .30 to .40 for impulsivity. Although the externalizing scores for teachers and observers were significantly correlated, *r* = .58, neither variable was related to parent-reported externalizing. Correlations across reporters for anxiety ranged from .18 to .23. Sex (female = 1; male = 0) was positively correlated with questionnaire measures of EC, but not to the behavioral measures of EC. In contrast, age was positively correlated with the behavioral measures of EC, but not with the questionnaire measures. Baseline RSA was uncorrelated with all study variables, and the residualized RSA suppression score was only significantly correlated with parent-reported externalizing, $r = .24$.

Data Reduction

Principal components analysis (PCA) was used as a data reduction technique (Tabachnik & Fidell, 2006). PCA is an analytic technique that produces weighted component scores by extracting the common variance among a set of variables. This technique reduces a set of variables into a smaller number of composites that can be used in subsequent analyses. PCA differs from factor analysis in that all variance in assumed to be common variance (i.e., variables are assumed to be measured without error), and unlike factor scores, PCA scores are unique because there is no factor indeterminacy. For each construct (EC, task EC (composed of the three laboratory measures of EC with contemporaneous physiological recording), shyness, impulsivity, externalizing problems, and anxiety), a separate PCA was run using SAS 9.2. Even in randomly generated data, there will be some amount of correlation among the variables due to sampling error. Consequently, the largest eigenvalues for principal components analysis applied to randomly generated data will be greater than 1, and the smallest eigenvalues will be less than 1. To address this issue, Horn's (1965; Hayton, Allen, & Scarpello, 2004) parallel analysis criterion, which states that only eigenvalues that exceed the 95th percentile of eigenvectors from randomly generated data should be extracted as principal components. This method is regarded as more accurate than Kaiser's criterion of selecting all factors with an eigenvalue > 1, or the use of scree plots (Cattell, 1966) for identifying the correct number of components (Hayton et al., 2004; Lance, Butts, & Michels, 2006). For eigenvalues extracted from 1,000 randomly generated data sets for six variables (corresponding to the number of variables included in the EC composite; see below) and 101 cases, the 95th percentile for the first and second eigenvalues were 1.34 and 1.17. For three variables (corresponding to all other constructs except for externalizing, which only included two variables; see below), the 95th percentile for the first and second eigenvalue extracted from random data were 1.16 and 1.00 for the second eigenvalue. The second eigenvalue for the EC construct was .87, and the second eigenvalues for each of the other constructs were as follows: task EC = .69; shyness = .79; impulsivity = .70; and anxiety = .83. Each of the second eigenvalues obtained using the data in this study was less than the 95th percentile value generated from random data, indicating that a single component should be extracted for each construct.

One effortful control composite included indicators for the laboratory tasks (bird and dragon, knock tap, gift wrap, and the CPT), as well as parent, teacher, and observer ratings of EC. In addition, I created a second composite measure of observed effortful control during physiological recording (with indicators for bird and dragon, knock tap, and gift wrap) for use in the final set of analyses involving RSA suppression. For the other constructs (shyness, impulsivity, externalizing, and anxiety), parent, teacher and observer reports were included as indicators. For two variables in these analyses, observer-reported EC and parent-reported externalizing problems, communalities and factor loadings were low. In the PCA for the effortful control variables that included observer questionnaires, the communality for the observer questionnaire was .18, whereas the other communalities ranged from .29 to .50; the first eigenvalue in this analysis was 2.85. In the PCA for externalizing that included parent questionnaires, the communalities were as follows: .21 for parents, .76 for teachers, and .72 for observers; the first eigenvalue in this analysis was 1.68. On the basis of the low loadings for parents' reports of externalizing and for observers' reports of EC, these variables were excluded from the principal components analysis that was used to generate component scores for use in subsequent analyses. Communalities for each variable (see Table 4) are the proportion of total variance explained for each component. After the principal component scores were generated, I computed the correlations among the component scores and other study variables; these correlations are reported in Table 5. Girls were rated as lower in externalizing problems, $r = -.29$, and scored higher on the EC component, $r = .20$. Age was correlated with EC and task EC, rs = .44 and .48. As expected, EC was negatively related to externalizing problems, $r = -.26$, although task EC was not significantly related to externalizing problems, $r = -.07$. In addition, impulsivity was positively related to externalizing problems and negatively related to anxiety, rs = .57 and -.23, whereas shyness was positively related to anxiety, $r = .43$. Shyness and impulsivity were negatively correlated, $r = -.46$. Finally, anxiety and externalizing problems were positively correlated, $r = .25$. The correlations among variables within each reporter (see

Tables 1 – 3) were generally greater than the correlations among the principal component scores (see Table 5), which may indicate greater method effects for the individual reporters relative to the composites.

Analysis Plan

Hierarchical multiple regression analyses using the principal component scores were run testing each of the three hypotheses proposed in the introduction[1]. In the first step, age and sex were entered[2]. In the second step, the main effects of the substantive predictors were entered. In the third step, the interaction between the substantive predictors was entered. In the fourth and final step, two- and three-way interactions between the substantive predictors and sex were added to the model. For each step, r^2 is reported as a measure of effect size. I also tested whether the addition of each set of predictors improved model fit using the D_m statistic for multivariate inferences (Li, Raghunathan, & Rubin, 1991). This test approximates an F distribution with numerator degrees of freedom equal to the number of predictors in the set, and denominator degrees of freedom based on the fraction of missing information and the number of imputations (for formulas, refer to SAS Institute, Inc., 2008). Aiken and West's (1991) procedure was used to probe interactions, with the simple slope of the predictor on the outcome examined at values of moderator corresponding to -1 *SD* below the mean, the mean, and +1 *SD* above the mean.

One child had an extremely low score on the overall EC composite (z = -3.64) and the EC composite that included only behavioral measures (z = -3.78). These extreme scores made this child a highly influential case in the initial regression analyses. Because of concerns that this child may have had developmental delays, this child was excluded from the regression analyses reported below; this change did not substantively affect the results.

Baseline RSA X shyness → effortful control. My first hypothesis was that baseline RSA would only be related to self-regulation for children who are emotionally reactive. My rationale was that children high in shyness would be physiologically aroused by the unfamiliar laboratory context, but only if they were unable to regulate their emotional state. For children low in shyness, physiological arousal was not expected to be predictive of self-regulation. Girls had higher EC relative to boys, and age was positive associated with EC (see Table 6). The addition of the main effects of the effortful control and shyness principal component scores improved prediction, $D_m = 3.26$, $p < .05$, with baseline RSA positively related to EC in this analysis, $b = 3.96$, $t = 2.10$, $p < .05$. When the Baseline RSA X Shyness interaction was entered into the model, it also significantly improved prediction, $D_m = 4.59$, $p < .05$. The interaction term was significant, $t = 2.14$, $p < .05$, and increased the r^2 from .33 to .36. The simple effect of baseline RSA on EC was significant at 1 SD above the mean for shyness, $b = 7.42$, $t = 3.00$, $p < .01$ (see Fig. 1) and was marginally significant at average shyness, $b = 3.21$, $t = 1.70$, $p < .10$. There was no relation between baseline RSA and EC at -1 SD shyness, $b = -1.01$, $t = -.34$, *ns*. Adding interactions with sex did not improve the model fit, $D_m = .69$, *ns*.

Shyness X baseline RSA → anxiety. I hypothesized that the combination of high shyness and low baseline RSA would put children at elevated risk for anxiety relative to either risk-factor alone. Neither sex nor age predicted anxiety (see Table 7). When the main effects of shyness and baseline RSA were added in the second step, only shyness was a significant predictor of anxiety, $b = .46$, $t = 5.02$, $p < .001$; the r^2 for this step was .24. The addition of the shyness X baseline RSA interaction in the third step did not improve prediction, $D_m = .89$, *ns*, and the interaction term was not significant. Adding interactions with sex in the fourth step also did not improve prediction, $D_m = .43$, *ns*.

Impulsivity X baseline RSA → externalizing. I also hypothesized that the combination of high impulsivity and low baseline RSA would put children at elevated risk for impulsivity relative to either risk-factor alone. When sex and age were examined as predictors of externalizing behavior (see Table 8), being female was negatively related to externalizing behavior, $b = -.55$, $t = -2.78$, $p < .01$; the r^2 value for this model was .09. Adding the main effects of impulsivity and baseline RSA in the second step improved prediction, $D_m = 19.71$, $p < .001$. The r^2 value for the second step was .36, an increase of .27 over the first set. In this model, baseline RSA was unrelated to externalizing, $b = -.81$, $t = -.44$, *ns*, and impulsivity was positively related to externalizing, $b = .54$, $t = 6.27$, $p < .001$. These effects were qualified by a significant impulsivity X baseline RSA interaction in the third step, $b = -4.11$, $t = -2.12$, $p < .05$, Probing this interaction (see Fig. 2) revealed that impulsivity was positively related to externalizing behavior across the range of baseline RSA, but that this relation was stronger at low values (-1 *SD*) of baseline RSA, $b = .73$, $t = 5.84$, $p < .001$, and weaker at high values (+1 *SD*) of baseline RSA, $b = .35$, $t = 2.89$, $p < .01$. Adding the interactions with sex in the fourth step improved model fit, $D_m = 2.71$, $p < .05$. This was primarily due to a significant sex X impulsivity interaction, $b = -.45$, $t = -2.58$, $p < .05$; the three-way interaction between sex, impulsivity, and baseline RSA was not significant. Probing the sex X impulsivity interaction revealed that impulsivity was related to externalizing problems for boys, $b = .70$, $t = 6.93$, $p < .001$, but not for girls, $b = .24$, $t = 1.65$, *ns* (see Fig. 3). In supplemental analyses in which EC and the EC X impulsivity composites were added to the regression model, the baseline RSA X impulsivity remained a significant predictor, indicating that the moderating effect of RSA was independent of EC.

Shyness X RSA suppression → effortful control. The residualized RSA suppression score and shyness were used to predict performance on the EC tasks that corresponded to the measurement of RSA suppression. When demographic variables were added in the first step (see Table 9), age was positively related to task EC, $b = .81$, $t = 5.93$, $p < .001$, but sex was unrelated to task EC, $b = .16$, $t = .89$, *ns*. The r^2 for this model was .27. The addition of the main effects of shyness and residualized RSA suppression in the second step did not improve prediction, $D_m = 1.77$, *ns*. In this model, shyness was marginally related to task EC, $b = -.17$, $t = -1.83$, $p < .10$, and RSA suppression was unrelated to task EC, $b = -4.33$, $t = -.96$, *ns.* The addition of the shyness X RSA suppression interaction in the third step increased the r^2 value by .05, to .38, and resulted in marginally better prediction, $D_m = 2.87$, $p < .10$. The interaction term itself was marginally significant, $b = 7.82$, $t = 1.70$, $p < .10$. Probing this interaction (see Fig. 4) revealed that RSA suppression was unrelated to EC for children high (+1 *SD*) or average in shyness, *b*s = 2.20 and -5.62, *t*s = 0.38 and -1.24, *ns*, but was marginally negatively related at low (-1 *SD*) levels of shyness, $b = -13.43$, $t = -1.89$, $p < .10$. This was contrary to expectations because RSA suppression was expected to be positively related to EC. Adding the interactions with sex in the fourth step did not improve prediction, $D_m = 1.78$, *ns*. Given that quadratic relations between RSA suppression and EC/EF have been suggested (Marcovitch et al., 2010), quadratic RSA suppression was also tested as a predictor of EC in this study. This relation was not significant.

Discussion

The first question addressed by this study was whether RSA would differentially predict EC for children high and low in shyness. Consistent with the hypotheses, baseline RSA could be considered a correlate of effortful control only for children high in shyness. Given the evidence that stress and worry contribute to reductions in RSA (Brosschot et al., 2007; Pieper et al., 2007), low RSA is likely indicative of low EC for shy children because these children are unable to regulate their emotional reactivity to the unfamiliar. RSA was unrelated to effortful control for children low in shyness, perhaps because these children do not need to regulate their emotional reactivity in the context of the unfamiliar laboratory setting.

These results indicate that consideration of the measurement context is particularly important when attempting to relate RSA to psychological variables. In particular, variables that support emotion-related regulation (e.g., effortful control) will be more strongly related to RSA for participants who are likely to be emotionally reactive in a given measurement context (e.g., shy or behaviorally inhibited children or anxiety disordered patients in a novel testing situation, especially those with generalized anxiety disorder or social phobia). Because stress has been demonstrated to affect RSA (Pieper et al., 2007), individuals who find the measurement context to be a source of worry will likely demonstrate attenuated RSA to the degree that they experience anxiety in that context (Brosschot et al., 2007).

Consequently, a possibility that merits further exploration is that the measure of resting RSA used in this study (and similar measures of RSA used in many other studies) did not constitute a true baseline. Specifically, children who participated in this study were brought into an unfamiliar laboratory setting with two adults, the experimenter and camera person, whom they did not know very well and were subjected to physiological hookup, which involved the placement of electrodes on their chest and abdomen. It is likely that children who are shy or behaviorally inhibited, being emotionally reactive to unfamiliar persons and situations, would exhibit lower RSA in the laboratory context relative to RSA measured in a more familiar context (e.g., at home) or in the presence of familiar adults (e.g., parents). Although the finding will need to be replicated, the interaction between shyness and baseline RSA as a predictor of EC found in this study may help organize the body of literature documenting a relation between baseline RSA and two aspects of temperament, EC and behavioral inhibition/shyness. Moreover, this study highlights the importance of simultaneously considering the role of RSA as a measure of emotional reactivity (in this case, shyness in an unfamiliar laboratory setting) and self-regulation; investigators should not assume that RSA is equally related to constructs such as EC/EF for all children, but should instead consider individual differences that moderate these relations.

The second question addressed by this study is whether baseline RSA would moderate the relations between temperamental risk factors and maladjustment; previous studies have examined RSA as a moderator of environmental risk (Eisenberg et al., in press; El-Sheikh et al., 2009; Obradović et al., 2010), but have not examined RSA as a moderator of temperamental risk factors. Specifically, I hypothesized that the relations between shyness and internalizing problems and between impulsivity and externalizing problems would be attenuated for children high in RSA.

The relation between anxiety and RSA that has been observed in previous studies contrasting clinical populations with controls (Lyonfields et al., 1995; Thayer et al., 1996) was not found in the present investigation. One possibility is that this null result may have been due to the nonclinical, relatively low levels of anxiety in this study. Although anxiety symptoms in preschool do predict the development of later anxiety, preschool-age children lack some of the cognitive capacity for worry about abstract or hypothetical events, which may have also contributed to the lack of findings for anxiety; the measure of anxiety was initially designed for children age four to 18, and may be less valid for children younger than this age range. Finally, the anxiety measure used in this study is relatively nonspecific and covers a wide range of anxiety symptoms. If RSA is more indicative of certain types of anxiety (e.g., the social anxiety that is characteristic of interacting with an adult experimenter), relations may have been obscured by the use of a more general measure of symptomatology.

With regard to the prediction of externalizing behavior, a significant baseline RSA X impulsivity interaction was found in this study. Although impulsivity was positively related to externalizing behavior across the range of RSA, this relation was strongest at low levels of RSA. This finding is consistent with the conceptualization of baseline RSA as an index of self-regulation, as well as with the associations between baseline RSA and EC/EF in some studies.

Adding the EC composite to the analysis as a control variable did not, however, reduce the influence of the baseline RSA X impulsivity interaction on externalizing behavior, indicating that these effects are independent. Future studies could use laboratory measures of impulsivity or questionnaires that differentiate among aspects of impulsivity to determine whether specific aspects of impulsivity are related to RSA and externalizing problems (Reynolds, Ortengren, Richards, & Dewit, 2006). For example, Carver and White's (1994) behavioral activation scale includes three subscales: reward sensitivity (e.g., "when I see something I want, I get excited and energized"), drive (e.g., "I go out of my way to get things I want"), and fun seeking (e.g., "I crave excitement and new sensations"), each of which may measure a different aspect of impulsivity. Similarly, principal components analysis of the Barratt Impulsiveness Scale has yielded three second-order factors: attentional impulsiveness, motor impulsiveness, and nonplanning impulsiveness (Patton, Stanford, & Barratt, 1995). Thus, there are a number of different aspects of impulsivity identified by questionnaire measures (which appear to differ somewhat depending on which questionnaire is used), and these fine-grained distinctions may be lost in a more general questionnaire measure of impulsivity. Furthermore, the relation between questionnaire and behavioral measures of impulsivity has not yet been adequately explored (Evenden, 1999). At present, it is not clear what mediating processes could explain the protective effects of high baseline RSA if EC/EF does not play a role, but examining more specific measures of impulsivity may shed light on this question.

A number of studies have identified low baseline RSA as a risk factor for externalizing problems, especially for boys in high-risk environmental contexts (Mezzacappa et al., 1997; Pine et al., 1998). In this study, environmental quality was likely high due to the high average SES. Thus, RSA appears to moderate temperamental risk for externalizing problems even in high-quality environments. One limitation of this study is the restricted range for environmental quality and externalizing problems. Future work should investigate RSA as a moderator of temperamental risk for externalizing problems in a wider range of environments, and should also test whether environmental quality affects this relation. In addition, it is not clear whether these findings would generalize to children with clinical levels of externalizing behavioral problems, or to children from diverse ethnic and racial backgrounds.

It is also unclear whether the findings from this study would generalize to other ages. The children in this study ranged from age 3.5 to 5; this age range was chosen as this is a period during which EC develops rapidly, which was supported by the substantial correlation between laboratory measures of EC and age in this study. Beauchaine (2001) has argued that the interpretation of RSA changes from infancy to later childhood. The evidence, although somewhat equivocal, does support this position. For example, some studies find that positive or negative emotional reactivity are positively related to RSA in infancy (e.g., Stifter & Fox, 1990; Stifter & Jain, 1996), although studies showing relations between RSA and emotional reactivity (perhaps with the exception of shyness or behavioral inhibition) are not common in older children. Thus, longitudinal research is needed to determine whether the relations observed in this study are also present in younger and older children.

In this study, the relation between impulsivity and externalizing behaviors was also moderated by sex. Probing this interaction revealed that this relation was significant for boys, but not for girls. Studies using similar measures have not reported moderation by sex (Eisenberg, Valiente, et al., 2009; Zhou, Lengua, & Wang, 2009). Furthermore, given the low-risk sample and that boys were rated as higher in externalizing behavior than girls by over .5 *SD*, this finding may reflect a lack of variability in externalizing problems for girls.

Nonetheless, impulsivity may be more weakly related to externalizing in girls due to biological sex differences or to gender differences in socialization. Future studies should explicitly test whether impulsivity (using laboratory measures as well as questionnaires) is more strongly related to externalizing behavior for boys relative to girls in samples with more variability in behavior problems. In addition, although three-way interactions between RSA, impulsivity, and sex were tested in this study, the power to detect such effects was likely low. Because sex differences in the relation between autonomic nervous system function and psychological maladjustment have been observed in some studies (Beauchaine, 2009), this question should be addressed in future studies, especially given our ability to detect such effects was likely limited by the restricted range of externalizing problems for girls.

The third and final research question addressed by this study was whether RSA suppression would relate to performance on EC tasks. The finding that RSA suppression was marginally negatively related to EC (with a greater relation observed for children low in shyness relative to children high in shyness) was surprising because RSA suppression was expected to be positively related to EC.

Some investigators have hypothesized that measures of RSA recorded during a laboratory task reflects engagement with the task demands and that low task RSA should predict better on-task performance (Chapman et al., 2010; Duschek et al., 2009). Contrary to findings commonly reported in the literature, RSA suppression was negatively related to task performance in this study, but is not clear why this result was obtained. Quadratic relations between RSA suppression and task performance have also been observed (Marcovitch et al., 2010), although there is little information about which individual differences or task characteristics might moderate the direction of the relation between RSA suppression and task performance.

The laboratory measures of EC in this study were moderately to strongly correlated and appeared to be valid based on their relations with the questionnaire measures of EC. Nonetheless, there was restricted variability on performance on the EC tasks, with many children exhibiting a ceiling effect. The ceiling effect was more evident for the bird and dragon and gift wrap tasks than for knock tap and CPT tasks. The high levels of performance appear to be due to the high SES nature of the sample because these children performed much better relative to low income preschoolers of comparable age (Sulik et al., 2009). The relatively low level of task difficulty for most children may have contributed to the negative relation between RSA suppression and task performance; one possibility is that the directionality of the relation between RSA suppression and task performance varies as a function of the difficulty of the task.

One potential limitation in the present study is that multiple baselines were not used in calculating RSA suppression (e.g., Obradovic et al., 2011). This may provide a somewhat misleading picture of RSA suppression for later tasks; in addition, the baseline did not control for movement, which could also be an important consideration (but see also Porges et al., 2007). Another difference among tasks was gift wrap involved a reward, whereas the other two tasks did not involve a reward. Metcalfe and Mischel (1999) argued that executive function in motivationally salient or emotional situations (“hot EF”) differs from executive function in purely cognitive situations (“cold EF”) , but it is not yet clear whether this distinction has implications for RSA.

One final limitation of this study is that it only considered PNS function. There is evidence that SNS function is also implicated in behavioral inhibition (Kagan, Reznick, & Snidman, 1988), and some theorists have suggested that autonomic balance may be more important to consider than SNS or PNS function alone (Berntson et al., 1993; Berntson, Cacioppo, Quigley, & Fabro, 1994). Future studies should explore these possibilities in more detail.

Despite these limitations, this study answers important questions about the interpretation of RSA. The primary goal of this study was to determine whether RSA would be more strongly related to EC for children high in shyness relative to children low in shyness. According to Cacioppo and Tassinary (Cacioppo & Tassinary, 1990), specifying the conditions under which a psychological variable (in this case, EC) is related to a psychophysiological variable such as RSA is needed for accurate inference. RSA is commonly used as an index of emotion regulation; this study indicates that RSA is related to EC only for some children (i.e., those high in shyness), and therefore should not be used as an index of self-regulation for all children.

This study also draws attention to the need to give more attention to the conditions under which resting measures of RSA are recorded. A direction for future research will be to determine whether the use of a true baseline recording of RSA (not influenced by the unfamiliar laboratory setting and experimenter) affects relations between RSA and other variables that have been reported in the literature.

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Footnotes

[1] Additional analyses were run in which composites were formed by standardizing and averaging variables to form composites of each construct. In these analyses, interaction results were substantively identical to the analysis of component scores reported below.

[2] Additional analyses were run with dummy codes indicating which preschool each student attended. Including these variables did not substantively change the results of any of the regression analyses, so these dummy codes were dropped from the analyses reported in this manuscript.

Table 1

Descriptive Statistics and Correlations among Temperament Variables

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Bird & Dragon	–	**0.33**	**0.45**	**0.31**	**0.25**	0.12	-0.04	-0.00	**-0.26**	-0.16	0.04	*0.20*	**0.21**
2	Knock Tap		–	**0.40**	**0.34**	**0.33**	**0.35**	*0.19*	0.14	-0.12	-0.12	-0.04	-0.05	-0.01
3	Gift Wrap			–	**0.41**	**0.40**	**0.26**	0.13	-0.02	*-0.17*	**-0.24**	0.08	0.10	0.14
4	CPT Detectability				–	**0.32**	**0.43**	**0.24**	-0.11	-0.13	*-0.19*	0.02	-0.14	0.03
5	Parent-Report EC					–	**0.44**	0.14	-0.02	-0.07	-0.01	-0.05	-0.13	-0.07
6	Teacher-Report EC						–	**0.46**	-0.06	-0.11	0.11	**-0.28**	**-0.55**	**-0.34**
7	Observer-Report EC							–	-0.05	0.05	0.06	**-0.27**	**-0.39**	**-0.58**
8	Parent-Report Shyness								–	**0.34**	**0.22**	**-0.36**	-0.12	-0.16
9	Teacher-Report Shyness									–	**0.33**	-0.14	**-0.24**	*-0.19*
10	Observer-Report Shyness										–	-0.13	**-0.31**	**-0.69**
11	Parent-Report Impulsivity											–	**0.40**	**0.30**
12	Teacher-Report Impulsivity												–	**0.40**
13	Observer-Report Impulsivity													–
	Mean	7.65	0.65	4.49	2.89	4.85	5.09	4.85	3.62	3.03	3.30	4.10	3.75	3.92
	SD	2.40	0.28	0.97	0.99	0.62	0.94	0.57	1.27	1.23	0.79	1.10	1.07	0.81

Note. *p* < .05 is bold; *p* < .10 is italic.

Table 2

Descriptive Statistics and Correlations Among Demographic, Physiological, and Adjustment Variables

		1	2	3	4	5	6	7	8	9	10
1	Female	–	-0.14	-0.11	0.15	*-0.19*	**-0.22**	**-0.28**	*-0.20*	-0.04	-0.03
2	Age		–	0.16	-0.08	-0.04	*0.19*	0.03	0.16	0.11	-0.05
3	Baseline RSA			–	0.00	0.04	-0.01	-0.02	0.16	-0.04	0.13
4	Residualized RSA Suppression				–	**0.24**	0.05	-0.03	0.00	-0.05	0.08
5	Parent-Report Externalizing					–	**0.21**	0.14	**0.41**	0.03	0.03
6	Teacher-Report Externalizing						–	**0.58**	0.00	**0.45**	-0.05
7	Observer-Report Externalizing							–	0.04	0.16	**0.34**
8	Parent-Report Anxiety								–	*0.18*	**0.23**
9	Teacher-Report Anxiety									–	**0.22**
10	Observer-Report Anxiety										–
	Mean	0.40	4.49	0.08	0.00	1.98	1.50	1.42	1.76	1.35	1.36
	SD	0.49	0.64	0.05	0.02	0.43	0.63	0.42	0.41	0.37	0.25

Note. *p* < .05 is bold; *p* < .10 is italic.

Table 3

Correlations between Temperament Variables and Demographic, Physiological, and Adjustment Variables

	Female	Age	Baseline RSA	Residualized RSA Suppression	Parent-Reported Externalizing	Teacher-Report Externalizing	Observer-Report Externalizing	Parent-Report Anxiety	Teacher-Report Anxiety	Observer-Report Anxiety
Bird & Dragon	0.09	**0.33**	0.05	-0.04	-0.03	0.15	0.02	-0.03	0.04	-0.03
Knock Tap	-0.06	**0.47**	0.06	*-0.18*	**-0.22**	-0.09	-0.15	0.09	0.10	0.01
Gift Wrap	0.05	**0.31**	0.15	-0.13	-0.12	-0.04	-0.16	-0.06	-0.10	*-0.17*
CPT Detectability	0.14	**0.37**	0.12	0.12	-0.04	-0.10	**-0.21**	0.05	-0.00	-0.04
Parent-Report EC	**0.30**	0.14	0.09	-0.05	**-0.43**	-0.10	-0.13	-0.09	0.06	0.02
Teacher-Report EC	**0.30**	0.13	0.06	-0.08	**-0.30**	**-0.57**	**-0.44**	-0.01	-0.14	0.09
Observer-Report EC	**0.30**	-0.06	0.01	0.04	-0.16	**-0.54**	**-0.81**	-0.01	-0.11	*-0.18*
Parent-Report Shyness	0.09	0.03	-0.10	-0.16	0.09	0.12	0.03	**0.43**	**0.29**	0.07
Teacher-Report Shyness	-0.12	-0.08	-0.12	*-0.20*	-0.14	0.06	*-0.17*	0.02	**0.34**	0.08
Observer-Report Shyness	-0.00	**-0.31**	0.05	-0.04	-0.02	*-0.18*	-0.13	0.10	0.14	**0.52**
Parent-Report Impulsivity	-0.12	0.06	0.09	*0.19*	0.04	**0.29**	**0.27**	**-0.28**	0.00	-0.02
Teacher-Report Impulsivity	-0.08	0.11	-0.05	*0.19*	0.03	**0.42**	**0.39**	*-0.19*	-0.10	-0.13
Observer-Report Impulsivity	**-0.23**	**0.23**	-0.05	0.00	0.09	**0.42**	**0.53**	-0.10	0.04	**-0.29**

Note. $p < .05$ is bold; $p < .10$ is italic.

Table 4

Principal Components Analysis: Communalities, Eigenvectors, and Percent Variance Explained

	Communalities					
Variable	EC	Task EC	Shyness	Impulsivity	Externalizing	Anxiety
Bird & Dragon	0.35	0.59				
Knock Tap	0.47	0.54				
Gift Wrap	0.54	0.66				
CPT Detectability	0.49					
Parent-Report EC	0.47					
Teacher-Report EC	0.41					
Parent-Report Shyness			0.50			
Teacher-Report Shyness			0.62			
Observer-Report Shyness			0.48			
Parent-Report Impulsivity				0.54		
Teacher-Report Impulsivity				0.64		
Observer-Report Impulsivity				0.55		
Teacher-Report Externalizing					0.79	
Observer-Report Externalizing					0.79	
Parent-Report Anxiety						0.46
Teacher-Report Anxiety						0.44
Observer-Report Anxiety						0.52
First Eigenvector	2.73	1.79	1.60	1.74	1.58	1.42
Percent Variance Explained	46%	60%	53%	58%	79%	47%

Table 5

Correlations among Demographic Variables, Component Scores, and Physiological Variables

		1	2	3	4	5	6	7	8	9	10
1	Female	–	-0.14	**0.20**	0.04	-0.02	*-0.18*	**-0.29**	-0.13	-0.11	0.15
2	Age		–	**0.44**	**0.48**	-0.16	*0.17*	0.12	0.10	0.16	-0.08
3	EC[1]			–	**0.87**	*-0.18*	-0.09	**-0.26**	-0.03	0.13	-0.09
4	Task EC[1]				–	*-0.20*	0.13	-0.07	-0.04	0.12	-0.15
5	Shyness[1]					–	**-0.46**	-0.07	**0.43**	-0.08	*-0.18*
6	Impulsivity[1]						–	**0.57**	**-0.23**	-0.01	0.17
7	Externalizing[1]							–	**0.25**	-0.02	0.01
8	Anxiety[1]								–	0.12	0.02
9	Baseline RSA									–	0.00
10	RSA Suppression										–

Note. $p < .05$ is bold; $p < .10$ is italic. [1] indicates a component score.

Table 6

Results of Hierarchical Multiple Regression Analyses Predicting Effortful Control from Baseline RSA and Shyness

	Set 1: Demographics			Set 2: Main Effects			Set 3: Interaction			Set 4: Interaction with Sex		
	b	*t*		*b*	*t*		*b*	*t*		*b*	*t*	
Intercept	-0.21			-0.21			-0.20			-0.20		
Age	0.77	5.64	***	0.70	5.08	***	0.72	5.28	***	0.69	4.97	***
Female	0.52	2.89	**	0.54	3.03	**	0.53	3.02	**	0.52	2.99	**
RSA				3.96	2.10	*	3.21	1.70	†	3.69	1.64	
Shyness				-0.12	-1.35		-0.13	-1.47		-0.02	-0.18	
RSA X Shyness							4.22	2.14	*	3.12	1.25	
Sex X RSA										-1.82	-0.42	
Sex X Shyness										-0.21	-1.24	
Sex X RSA X Shyness										3.23	0.78	
r^2	0.28			0.33			0.36			0.38		
Change in Model Fit	$D_m = 18.17$, $p < .001$			$D_m = 3.26$, $p < .05$			$D_m = 4.59$, $p < .05$			$D_m = .69$, *ns*		

Note. † $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. RSA = Baseline RSA

Table 7

Results of Hierarchical Multiple Regression Analyses Predicting Anxiety from Shyness and Baseline RSA

	Set 1: Demographics		Set 2: Main Effects			Set 3: Interaction			Set 4: Interaction with Sex		
	b	*t*	*b*	*t*		*b*	*t*		*b*	*t*	
Intercept	0.09		0.07			0.08			0.08		
Age	0.13	0.80	0.22	1.50		0.23	1.55		0.26	1.70	†
Female	-0.23	-1.08	-0.16	-0.87		-0.17	-0.90		-0.16	-0.83	
Shyness			0.46	5.02	***	0.46	4.95	***	0.36	2.70	**
RSA			2.63	1.30		2.29	1.12		1.65	0.68	
Shyness X RSA						2.04	0.94		2.20	0.79	
Female X Shyness									0.21	1.10	
Female X RSA									1.95	0.41	
Female X Shyness X RSA									-0.39	-.08	
r^2	0.02		0.24			0.25			0.26		
Change in Model Fit	D_m = 1.04, *ns*		D_m = 12.95, $p < .001$			D_m =.89, *ns*			D_m = .43, *ns*		

Note. † $p < .10$; ** $p < .01$; *** $p < .001$. RSA = Baseline RSA

Table 8

Results of Hierarchical Multiple Regression Analyses Predicting Externalizing Behavior from Impulsivity and Baseline RSA

	Set 1: Demographics			Set 2: Main Effects			Set 3: Interaction			Set 4: Interaction with Sex		
	b	*t*		*b*	*t*		*b*	*t*		*b*	*t*	
Intercept	0.22			0.15			0.13			0.10		
Age	0.13	0.84		0.01	0.08		0.02	0.12		0.00	0.00	
Female	-0.55	-2.78	**	-0.38	-2.23	*	-0.33	-1.95	†	-0.39	-2.33	*
Impulsivity				0.54	6.27	***	0.54	6.44	***	0.70	6.93	***
RSA				-0.81	-0.44		-1.36	-0.75		-0.06	-0.03	
Impulsivity X RSA							-4.11	-2.12	*	-5.40	-2.36	*
Female X RSA										-1.58	-0.38	
Female X Impulsivity										-0.45	-2.58	*
Female X Impulsivity X RSA										4.04	0.96	
r^2	0.09			0.36			0.39			0.44		
Change in Model Fit	$D_m = 4.62$, $p < .01$			$D_m = 19.71$, $p < .001$			$D_m = 4.50$, $p < .05$			$D_m = 2.71$, $p < .05$		

Note. † $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. RSA = Baseline RSA

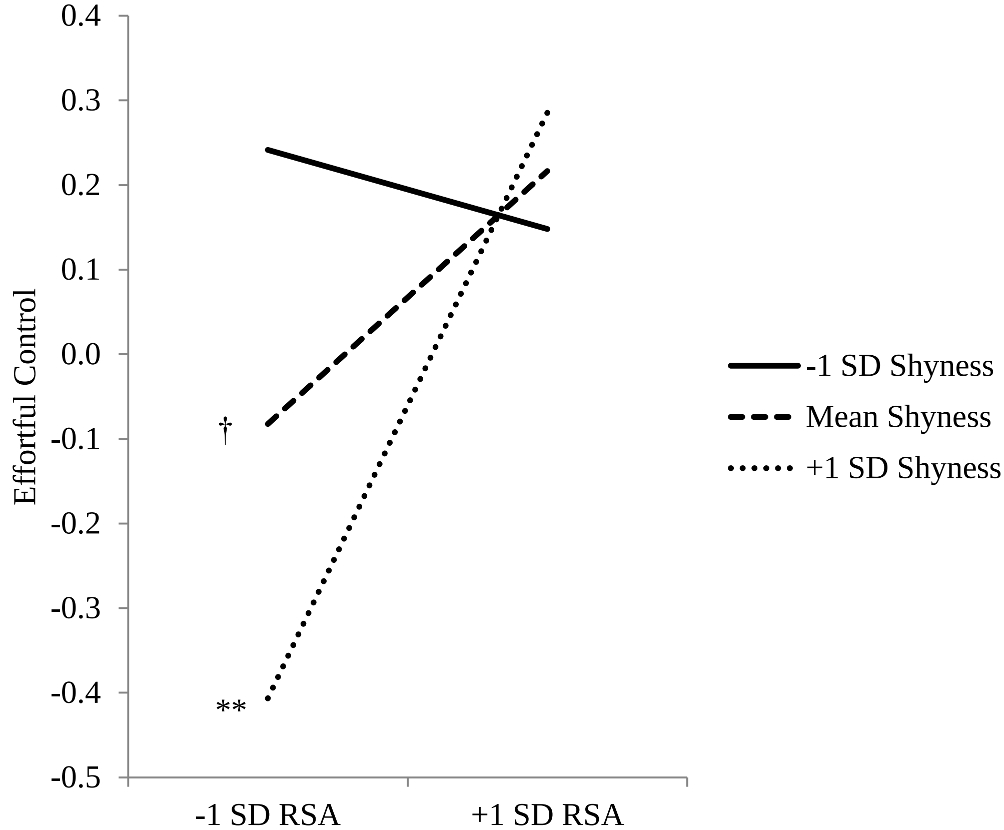
Table 9

Results of Hierarchical Multiple Regression Analyses Predicting Task Effortful Control from Shyness and Residualized RSA Suppression

	Set 1: Demographics			Set 2: Main Effects			Set 3: Interaction			Set 4: Interaction with Sex		
	b	*t*		*b*	*t*		*b*	*t*		*b*	*t*	
Intercept	-0.07			-0.07			-0.05			-0.08		
Age	0.81	5.93	***	0.76	5.50	***	0.78	5.67	***	0.79	5.80	***
Female	0.16	0.89		0.18	0.96		0.19	1.06		0.23	1.25	
Shyness				-0.17	-1.83	†	-0.19	-2.07	*	-0.13	-1.02	
ΔRSA				-4.33	-0.96		-5.62	-1.24		-8.30	-1.55	
Shyness X ΔRSA							7.82	1.70	†	2.24	0.36	
Female X Shyness										-0.18	-0.97	
Female X ΔRSA										9.54	1.05	
Female X Shyness X ΔRSA										15.13	1.61	
r^2	0.27			0.30			0.33			0.38		
Change in Model Fit	$D_m = 17.39$, $p < .001$			$D_m = 1.77$, *ns*			$D_m = 2.87$, $p < .10$			$D_m = 1.78$, *ns*		

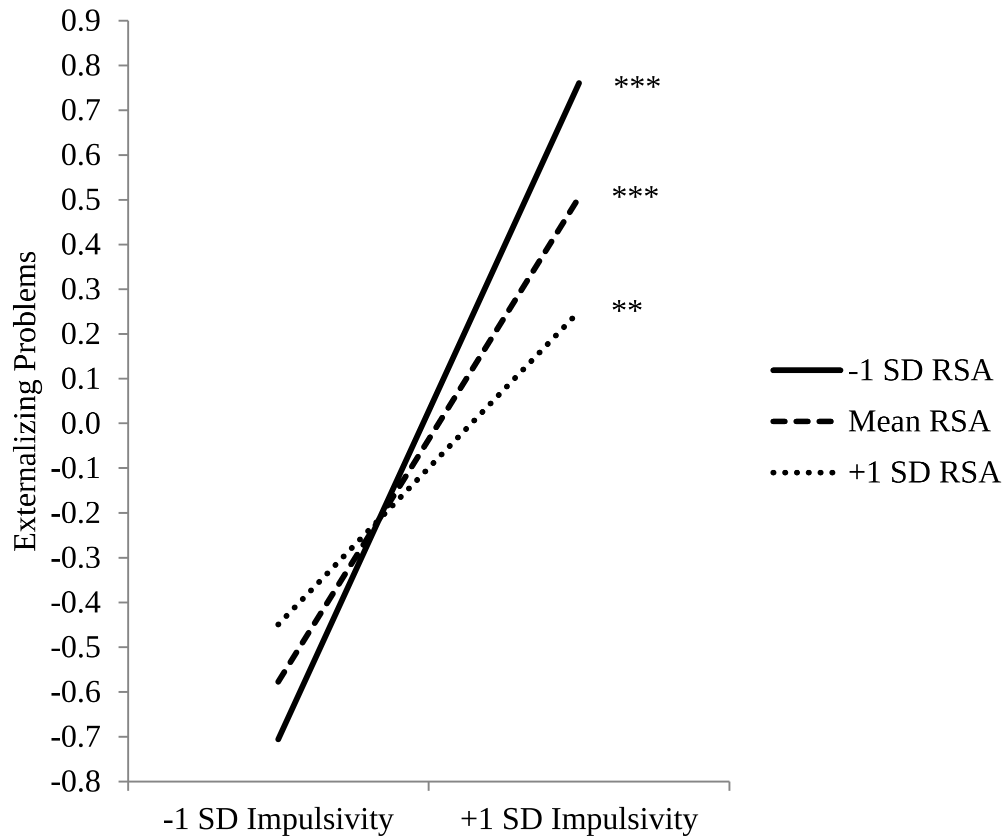
Note. † $p < .10$; * $p < .05$; *** $p < .001$. ΔRSA = Residualized RSA suppression.

Figure 1. Simple Effect of Baseline RSA on Effortful Control at Varying Levels of Shyness



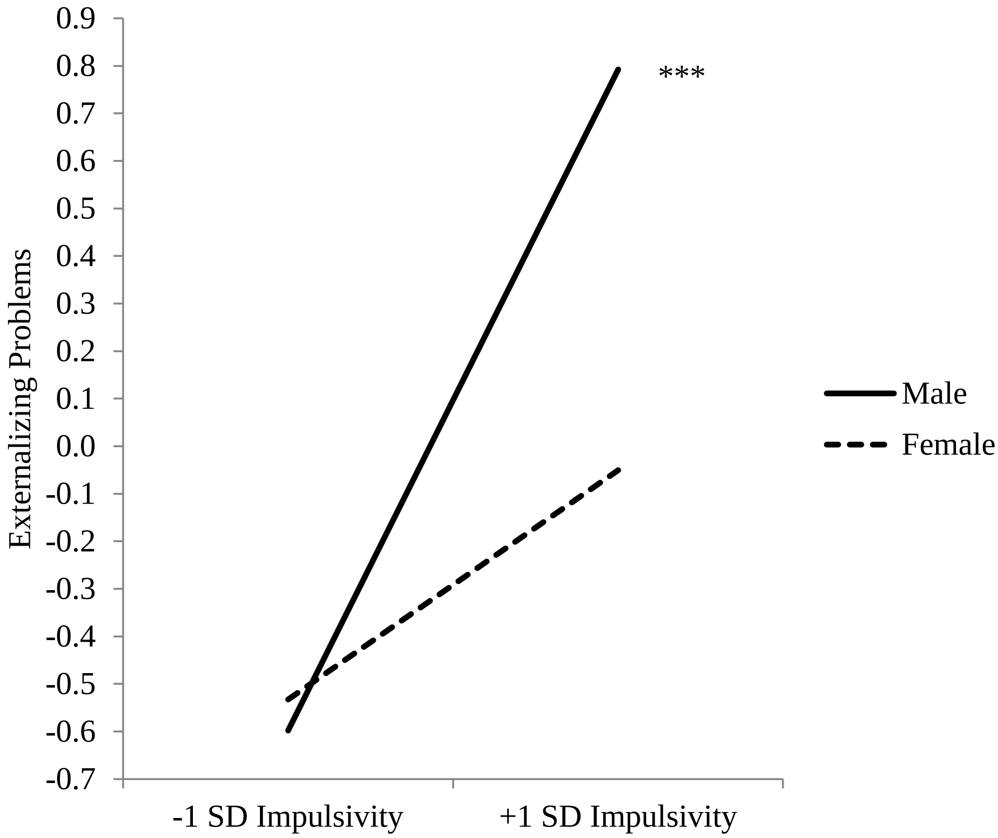
Note. ** $p < .01$. † $p < .10$.

Figure 2. Simple Effect of Impulsivity on Externalizing Problems at Varying Levels of Baseline RSA.



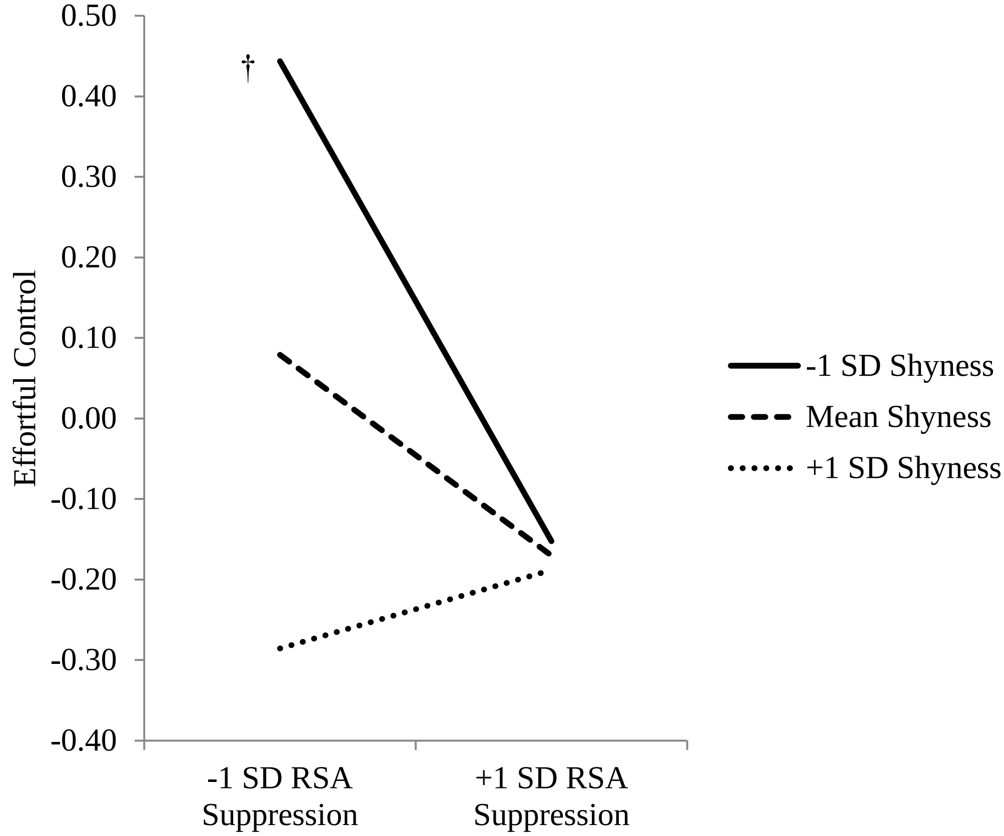
Note. ** p < .01; *** p < .001.

Figure 3. Simple Effect of Impulsivity on Externalizing Problems for Girls and Boys



Note. *** *p* < .001.

Figure 4. Simple Effect of RSA Suppression on Effortful Control at Varying Levels of Shyness.



Note. † $p < .10$.

APPENDIX

QUESTIONNAIRE MEASURES

Teglasi's adaptation of the short form of the CBQ for teachers is available upon request from Samuel Putnam (sputnam@bowdoin.edu).

Child Behavior Questionnaire (Parent Version):

Instructions and Rating Scale

On the next pages you will see a set of statements that describe children's reactions to a number of situations. We would like you to tell us what this child's reaction is likely to be in those situations. There are of course no "correct" ways of reacting; children differ widely in their reactions, and it is these differences we are trying to learn about. Please read each statement and decide whether it is a "true" or "untrue" description of this child's reaction within the past six months.

Extremely Untrue	Quite Untrue	Slightly Untrue	Neither True nor False	Slightly True	Quite True	Extremely True
O	O	O	O	O	O	O

Child Behavior Questionnaire: Attention Focusing Items

1. When practicing an activity, has a hard time keeping her/his mind on it.
2. Will move from one task to another without completing any of them. REVERSED
3. When drawing or coloring in a book, shows strong concentration
4. When building or putting something together, becomes very involved in what s/he is doing, and works for long periods.
5. Is easily distracted when listening to a story. REVERSED
6. Sometimes becomes absorbed in a picture book and looks at it for a long time.

Child Behavior Questionnaire: Inhibitory Control Items

1. Can wait before entering into new activities if s/he is asked to.
2. Prepares for trips and outings by planning things s/he will need.
3. Has trouble sitting still when s/he is told to (at movies, church, etc.). REVERSED
4. Is good at following instructions.
5. Approaches places s/he has been told are dangerous slowly and cautiously.
6. Can easily stop an activity when s/he is told "no."

Child Behavior Questionnaire: Attention Shifting Items

1. Is hard to get his/her attention when he/she is concentrating on something. REVERSED
7. Can easily shift from one activity to another.
8. Has a lot of trouble stopping an activity when called to do something else. REVERSED
9. Has an easy time leaving play to do another activity.
10. Has a hard time shifting from one activity to another. REVERSED
11. Is good at games with rules, such as card games.
12. Often doesn't seem to hear me when he/she is working on something. REVERSED
13. Needs to complete one activity before being asked to start on another one. REVERSED
14. Seems to follow his/her own direction, even when asked to do something different. REVERSED
15. Can easily leave off working on a project if asked.

Child Behavior Questionnaire: Shyness Items

1. Seems to be at ease with almost any person. REVERSED
2. Is sometimes shy even around people s/he has known a long time.
3. Sometimes seems nervous when talking to adults s/he has just met.
4. Acts shy around new people.
5. Is comfortable asking other children to play. REVERSED
6. Sometimes turns away shyly from new acquaintances.

Child Behavior Questionnaire: Impulsivity Items

1. Usually rushes into an activity without thinking about it.
2. Often rushes into new situations.
3. Takes a long time in approaching new situations. REVERSED
4. Is slow and unhurried in deciding what to do next. REVERSED
5. Tends to say the first thing that comes to mind, without stopping to think about it.
6. Is among the last children to try out a new activity. REVERSED

Anxiety and Externalizing Questionnaire: Instructions and Rating Scale

Please rate the extent to which the following items have been true of your child during the last three months.

Never	Almost Never	Sometimes	Often
O	**O**	**O**	**O**

Anxiety Items

1. Too fearful or anxious
2. Worrying
3. Nervous, high strung, tense
4. Nausea, feels sick
5. Self-conscious or embarrassed
6. Headaches
7. Feels he/she has to be perfect
8. Stomach aches or cramps
9. Shy or timid
10. Clings to adults or too dependent
11. Aches or pains
12. Can’t get his/her mind off certain thoughts/obsessions
13. Fears going to school
14. Fears he/she might do something bad
15. Fears certain animals, situations, or places other than school
16. Nervous movements or twitching

Externalizing Items

1. Argues.
2. Disobedient.
3. Easily upset, annoyed or irritated.
4. Starts fights with other kids.
5. Stubborn.
6. Breaks rules.
7. Teases other kids.
8. Whines and nags.
9. Swears.
10. Demands too much attention.
11. Threatens or bullies other kids.
12. Sneaky.
13. Cruel to animals.
14. Yells at others.
15. Physically harms other kids.
16. Talks back, sasses.
17. Breaks things on purpose.
18. Aggressive to adults.
19. Lies.
20. Takes things that belong to others.
21. Defiant towards adults.

22. Blames others for misbehavior.

23. Temper tantrums.