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Cardiac vagal control and children's adaptive functioning: A meta-analysis

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Abstract

Polyvagal theory has influenced research on the role of cardiac vagal control, indexed by respiratory sinus arrhythmia withdrawal (RSA-W) during challenging states, in children's self-regulation. However, it remains unclear how well RSA-W predicts adaptive functioning (AF) outcomes and whether certain caveats of measuring RSA (e.g., respiration) significantly impact these associations. A meta-analysis of 44 studies (n = 4,996 children) revealed small effect sizes such that greater levels of RSA-W were related to fewer externalizing, internalizing, and cognitive/academic problems. In contrast, RSA-W was differentially related to children's social problems according to sample type (community vs. clinical/at-risk). The relations between RSA-W and children's AF outcomes were stronger among studies that co-varied baseline RSA and in Caucasian children (no effect was found for respiration). Children from clinical/at-risk samples displayed lower levels of baseline RSA and RSA-W compared to children from community samples. Theoretical/practical implications for the study of cardiac vagal control are discussed.

Keywords

Cardiac vagal tone; RSA withdrawal; children; meta-analysis; adaptive functioning

Over the last twenty years a significant body of work across developmental and clinical psychology has identified self-regulation skills, particularly emotion regulation, as critical for children's adaptive functioning across various domains including behavioral, social, and cognitive/academic (Baumeister & Vohs, 2004; Blair, 2002; Calkins & Fox, 2002; Graziano, Reavis, Keane, & Calkins, 2007; Shaw, Keenan, Vondra, Delliquadri, & Giovannelli, 1997). While definitions vary, most researchers agree that emotion regulation involves efforts to modulate emotional arousal in a way that facilitates adaptive functioning (Calkins, 1997; Garber & Dodge, 1991; Keenan & Shaw, 2003). Given the importance of emotion regulation for children's adaptive functioning, it is not surprising that researchers have attempted to identify biological markers associated with emotion regulation. Of interest to the current paper is the maturation of the parasympathetic branch of the autonomic nervous system (PNS) which has been identified as a critical factor in supporting the development of

increasingly sophisticated biobehavioral regulation processes (Calkins, 2007; Porges, 2007). Specifically, cardiac vagal tone—an index of the parasympathetic influence on the heart—has emerged as a psychophysiological marker for emotion regulation in both children and adults (Beauchaine, 2001; Calkins, 2007; Grossman & Taylor, 2007; Porges, 2007; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996).

Respiratory sinus arrhythmia (RSA), a component of heart rate variability, has emerged as a non-invasive measure of the functional output of the vagal pathways on the heart. RSA, under controlled respiratory conditions, is relatively uninfluenced by variations in sympathetic activity, and provides a sensitive index of cardiac vagal tone, even when alterations in parasympathetic activity are small (Grossman, Stemmler, & Meinhardt, 1990). Polyvagal Theory (Porges, 1995; 2003a; 2003b; 2007) is regarded as the most influential model in differentiating the relation between vagal tone during steady states (i.e., baseline vagal tone) and vagal reactivity (i.e., vagal regulation) in response to environmental challenges. Baseline measures of vagal tone represent an organism's ability to maintain homeostasis and the potential responsiveness of that organism. During such restful periods, the vagus exerts an inhibitory influence on the heart acting as a "brake" by increasing vagal output to the sino-atrial (SA) node of the heart and limiting sympathetic influences which contributes to a steady slow heart rate. On the other hand, during stressful periods, the vagal "brake" is disengaged resulting in a decrease in vagal output to the SA node of the heart and thus contributing to an increase in heart rate (Porges et al., 1996).

Individual differences in the regulation of the vagal "brake" are assessed by measuring changes in vagal tone from baseline to an attention-demanding or challenging state. Vagal regulation can refer to a suppression in RSA during a challenging state (i.e., vagal tone decreases from baseline to challenging task, indicative of a positive vagal regulation score) or to an augmentation in RSA (i.e., vagal tone increases from baseline to challenging task, indicative of a negative vagal regulation score). According to Polyvagal theory, however, successful vagal regulation is marked by RSA suppression or withdrawal, which is thought to facilitate an organism's ability to cope with challenging states by mediating metabolic output via heart rate increases (Porges, 2003a, 2007; Porges et al., 1996). Indeed, research has shown that greater levels of RSA withdrawal are associated with better self-regulation and active coping skills as well as observed emotion regulation during frustrating/stressful tasks (Degangi, Dipietro, Greenspan, & Porges, 1991; Gentzler, Santucci, Kovacs, & Fox, 2009; Huffman et al., 1998). What remains unclear, and of interest to the current paper, is the extent to which vagal or RSA withdrawal contributes to more complex adaptive functioning outcomes and whether RSA withdrawal predicts certain outcomes better than others.

Vagal Withdrawal and Social Functioning

Perhaps the most widely cited area of adaptive functioning in which the role of vagal withdrawal has been implicated is within the social domain. As noted by Porges (2003a), social interactions arguably require considerable neural and physiological involvement due to the range of tasks required for a successful interaction (e.g., ability to maintain eye contact/gaze with another person, attend to his/her vocalizations/language, interpret his/her

vocalizations/language, observe his/her facial expressions, and discern the other person's overall affect and intent, as well as the ability to successfully initiate your own appropriate verbal and non-verbal responses in an appropriate amount of time). Porges' Social Engagement System highlights that the vagal system, which originally served as a neural circuit for controlling fight or flight amygdalar mechanisms on the sympathetic nervous system and the stress response via the hypothalamic-pituitary-adrenal (HPA) system, over time became integrated with the nuclei that controls the muscles of the face and head (2003b). Subsequently, a well-regulated and calm visceral state may contribute to better control of facial/head muscles that enables complex facial gestures, vocalizations, social gesturing, and orientation, which are thought of as important behaviors for engaging in social communication.

Despite the theoretical link between RSA withdrawal and social functioning, most of the empirical research has focused only on baseline RSA. For example, children with Autism Spectrum Disorders (ASD) have been observed to have low baseline RSA compared to healthy controls (Ming, Julu, Brimacombe, Connor, & Daniels, 2005; Patriquin, Scarpa, Friedman, & Porges, 2011; Vaughan Van Hecke et al., 2009). Similarly within non-ASD samples and as noted by Beauchaine (2001), high levels of baseline RSA have been associated with uninhibited behavior, assertiveness, sociability, and social competence. However, significantly less research has examined the link between RSA withdrawal and social competence. Examining this link is particularly important to solidify the engagementdisengagement function of the vagal brake as it relates to socially relevant behaviors versus a general level of responsiveness indexed by baseline RSA. Additionally, the results of the few studies that have examined the link between RSA withdrawal and social functioning have been mixed. For instance, in a sample of kindergarteners, Graziano and colleagues (2007) found that higher levels of RSA withdrawal (which is calculated by subtracting children's RSA score during a challenging task from children's RSA score during a resting or baseline task) were associated with higher social preference scores. On the other hand, Blair (2003) found an inverse relation between RSA withdrawal and social competence as reported by teachers. Hence, both theoretical and empirical reasons highlight the importance of conducting a meta-analytic review to more accurately determine the viability of vagal withdrawal as a physiological mechanism important for social engagement.

Vagal Withdrawal and Externalizing Behavior Problems

Vagal withdrawal is also thought to facilitate metabolic and regulatory processes important for attention and behavioral control strategies. Children with externalizing behavior problems such as aggression, hyperactivity, and inattention are more likely to have emotion regulation and behavioral control difficulties such as impulsivity (Gilliom & Shaw, 2004; Keenan & Shaw, 2003). A pattern of physiological dysregulation in the form of both lower sympathetic activity and lower levels of vagal withdrawal may underlie children with externalizing behavior problems' ability to cope with stress and challenging situations (Mezzacappa et al., 1997; Pine et al., 1998). Indeed, a fair number of studies have found that children with externalizing behavior problems display a more blunted vagal response to challenge (Beauchaine, 2001; Boyce et al., 2001; Calkins & Dedmon, 2000; Musser et al., 2011). On the other hand, some studies have failed to find a link between RSA withdrawal

and externalizing problems (Beauchaine, Gatzke-Kopp, & Mead, 2007; Eisenberg et al., 2012; Erath, Tu, & El-Sheikh, 2011) with such a link further attenuated by the presence of co-occurring internalizing problems (Calkins, Graziano, & Keane, 2007) or only occurring in the presence of a moderating environmental factor such as attachment status (Willemen, Schuengel, & Koot, 2009).

Vagal Withdrawal and Cognitive/Academic Problems

Negative emotionality is known to interfere with higher order cognitive processes such as executive functioning (Blair, 2002; Posner & Rothbart, 2007). The physiological mechanism responsible for such interference remains relatively understudied in children, although there is a well-documented overlap in the brain structures (e.g., anterior cingulated cortex and orbitofrontal cortex) responsible for regulating both emotions and higher order cognitive processes (Bush, Luu, & Posner, 2000; Levesque et al., 2004). A child with good emotion regulation skills who has a history of using such physiological system efficiently during challenging or stressful situations should theoretically have an even easier time recruiting the orbitofrontal cortex for higher order cognitive functions during less stressful situations. Initial studies do show that children with higher vagal withdrawal scores, indicative of better emotion regulation, perform better on cognitive and academic tasks (Blair & Peters, 2003; Katz & Gottman, 1997; Quas, Bauer, & Boyce, 2004). Once again, however, these findings are equivocal as some studies do not find such an association (Quas, Carrick, Alkon, Goldstein, & Boyce, 2006) or find a more quadratic association (Marcovitch et al., 2010). Hence, it may be more adaptive for children to have a lower RSA withdrawal response to less emotionally based cognitive or academic tasks which may free up metabolic resources for attention and memory processes important for the task at hand. Children that may perceive a cognitive or academic task as threatening or high in stress may overly engage and disengage the vagal brake or sustain such RSA withdrawal for an unnecessary period of time. Chronic periods of unnecessary regulation can lead to increases in stress and be maladaptive (Schubert, Lambertz, Nelesen, Bardwell, Choi, & Dimsdale, 2009). Given the mixed empirical findings and possible non-linear association between RSA withdrawal and children's cognitive/academic functioning, a meta-analytic review would help determine the role of vagal withdrawal as a physiological mechanism important for cognitive/academic functioning.

Vagal Withdrawal and Internalizing Problems

The role of vagal withdrawal in contributing to internalizing problems is perhaps the least understood and examined adaptive functioning domain. Some researchers have suggested that an extreme vagal withdrawal response contributes to a sense of over vigilance and one in which the individual is paying too much attention to potential threats in the environment. Such an over reactivity contributes to physical and cognitive internalizing symptoms such as stress/anxiety and worry (Thayer & Lane, 2000). On the other hand, some researchers have argued that low reactivity (i.e., low vagal withdrawal) would restrict an individual's ability to cope with a stressful situation and/or differentiate such stress from non-stressful (i.e., baseline or resting) times (Schmitz, Kramer, Tuschen-Caffier, Heinrichs, & Blechert, 2011). Indeed, findings are mixed on whether higher vagal withdrawal scores relate to lower

(Gentzler et al., 2009; Pearson et al., 2005; Schmidt, Fox, Schulkin, & Gold, 1999) or higher (Boyce et al., 2001; Hastings, Sullivan, et al., 2008; Hinnant & El-Sheikh, 2009) levels of internalizing symptoms.

Measurement Issues Associated with RSA

There is a significant debate over the methodology that is required to accurately measure children's RSA as an estimate of vagal tone (see Allen, Chambers, & Towers, 2007; Denver, Reed, & Porges, 2007; and Grossman & Taylor, 2007 for thorough reviews). Studies vary on how RSA is quantified with some using spectral analysis (Miskovic, Schmidt, Georgiades, Boyle, & MacMillan, 2009; Scheinin et al., 1999; Wolff, Wadsworth, Wilhelm, & Mauss, 2012) while others use time-domain peak valley analysis (El-Sheikh & Whitson, 2006; Hinnant & El-Sheikh, 2009; Willemen et al., 2009) or the Porges adaptive polynomial filter method (Calkins et al., 2007; Graziano, Keane, et al., 2007; Hastings, Nuselovici, et al., 2008; Porges et al., 1996). The Society for Psychophysiological Research's Task Force committee concluded that no single measure for quantifying RSA can be viewed as the gold standard as each of approaches offers advantages and disadvantages (Berntson et al., 1997). The main source of debate is regarding how much respiration confounds RSA as an estimate of cardiac vagal tone. Proponents of the peak-to-valley method and using respiratory parameters as covariates in statistical analyses assume a causal relation between respiration and RSA whereas proponents of using either respiratory frequency or global frequency bands associated with breathing rates to identify frequency component in the heart rate spectrum assume a parallel relation (Denver et al., 2007).

One line of evidence offered by Grossman and Taylor (2007) indicate that across 20 studies and regardless of method used to derive RSA, respiration rates and tidal volume significantly affect RSA magnitude. Additionally, frequency domain methods such as spectral analysis are less affected by respiration rates compared to methods that assess the amplitude of RSA oscillations (Grossman, van Beek, & Wientjes, 1990). Grossman and Taylor (2007) along with Allen and colleagues (2007) also argue that statistically controlling for respiratory parameters as covariates in between subjects designs (e.g., ANCOVAs) does not "solve" the problem of the impact of respiration on RSA. The use of ANCOVAs is problematic for various reasons including that the associations between respiratory measures and RSA are much stronger within individuals versus between individuals (Ben Lamine et al., 2004). The use of ANCOVAs may also create spurious group effects or remove an actual effect of interest (see Miller & Chapman, 2001). A better option is to regress RSA against respiration variables and use the residuals as an index of vagal tone (Grossman et al., 1991).

On the other hand, Denver and colleagues (2007) offer evidence that while respiration frequency strongly relates to the *frequency* of RSA, it minimally impacts the *amplitude* of RSA (2–10% of variance). They also show evidence that a time domain method that extracts only the heart rate variability within a defined band of breathing frequencies (i.e., Porges adaptive filter method), is equivalent to spectral analyses. In addition, Denver and colleagues (2007) show across a review of 13 studies that statistically adjusting for respiration parameters including tidal volume or respiration frequency did not change any of

the results. More recently, an analysis by Lewis and colleagues (2012) comparing the Porges adaptive filter method, peak-to-through method, and spectral analysis methods (which were all highly correlated) showed that the frequency band (.12–.40 Hz) used in the Porges adaptive filter method to define RSA in adults can accurately capture respiration rates (less than 1% of individual breaths fell outside this frequency band). More importantly, compared to the other two methods, the Porges adaptive filter method was significantly more sensitive to vagal mechanisms (effect sizes were reported as more than 3 times greater than the other two methods) as evidenced through a glycopyrrolate infusion. It remains unclear; however, the extent to which the associations between RSA withdrawal and *children's* adaptive functioning outcomes differ between studies that actually measure respiration versus those that use normative rates (i.e., frequency bands such as Porges adaptive polynomial filter method).

Another important measurement issue to consider when examining RSA withdrawal is whether one should control for baseline or resting levels of RSA. As a marker of potential responsiveness, baseline RSA impacts the magnitude of RSA withdrawal that may occur during challenging situations (Beauchaine, 2001; Calkins, Graziano, Berdan, Keane, & Degnan, 2008; El-Sheikh, 2005; Graziano, Keane, et al., 2007; Porges, 2007). The law of initial values also suggests that participants with higher baseline levels of a physiological measure have a greater potential for decreases in that measure (Lacey & Lacey, 1962; Wilder, 1956). However, as pointed out by Beauchaine (2001) studies have varied in terms of whether baseline RSA levels are co-varied when examining links between RSA withdrawal and adaptive functioning outcomes.

Lastly, studies vary in terms of which types of challenging tasks are used to derive RSA withdrawal values ranging from cognitively challenging tasks to more socially oriented or negative mood/stress inductions. While some studies have demonstrated that cognitively or frustrating challenging tasks incur greater RSA withdrawal levels compared to positive or neutral mood induction tasks (Calkins et al., 2007; Moore, 2009; Musser et al., 2011), it is not clear whether the type of challenging task actually affects any potential associations with adaptive functioning outcomes. This is a particularly important area to investigate as the adaptive nature of RSA withdrawal may be contingent in the context children are in. For example, while a stressful or threat perceiving context may call for a reduction or suppression of RSA in order to active cardiac activity and mobilize metabolic resources to deal with the stress/threat, a more positive or threat free context may not require prolonged decreases in RSA and in fact augmentation of RSA may be more adaptive (Hastings, Nuselovici, et al., 2008).

Goals of the Current Meta-Analysis

In summary, while vagal withdrawal has emerged as a biological marker for children's emotion regulation abilities, it remains unclear the extent to which it equally predicts various adaptive functioning domains. From a developmental psychopathology perspective, it is important to understand whether vagal withdrawal deficits act as a broad risk factor for various maladaptive outcomes or only certain ones. It is also important to note that several caveats for measuring RSA has been recently highlighted (Allen, Chambers, & Towers,

2007; Denver, Reed, & Porges, 2007; and Grossman & Taylor, 2007) which may impact associations between RSA withdrawal and adaptive functioning including the measurement of respiration, co-varying baseline RSA, as well as the type of challenging task used to derive RSA withdrawal.

The goal of the current study is to conduct a meta-analysis to examine a) the magnitude of the associations between RSA withdrawal and children's adaptive functioning outcomes, b) determine any differences in the magnitude of these associations according to adaptive functioning domain, and c) determine the extent to which measurement issues related to RSA (i.e., respiration rates, co-varying of baseline RSA, type of challenging task) impacts the association between RSA withdrawal and adaptive functioning outcomes. The only meta-analyses conducted as it relates to RSA has been linking baseline RSA with depression in adults (Rottenberg, 2007) or baseline RSA and childhood outcomes (Beauchaine, 2001). Based on Polyvagal and the Social Engagement System (2003b, 2007; 1996) along with significant research showing a strong association between emotional control and behavioral control (Keenan & Shaw, 2003), we expected that the strongest associations between RSA withdrawal and adaptive functioning outcomes would occur within the social competence and externalizing behavior functioning domains. Given the neurobiological overlap between emotion and cognitive regulation (Bush et al., 2000), we also expected a positive association between RSA withdrawal and children's cognitive/academic outcomes. We did not expect a strong association between RSA withdrawal and internalizing symptoms given contradicting views on whether children with internalizing symptoms overregulate (i.e., extreme RSA withdrawal) or have difficulty coping with stress (i.e., poor RSA withdrawal). Lastly, given the caveats of measuring RSA, we expected stronger associations between RSA withdrawal and children's adaptive functioning outcomes in studies that measured children's respiration, co-varied baseline RSA, and used more cognitively based challenging tasks.

Method

Literature Review

We conducted a comprehensive search for empirical research regarding the relation between RSA withdrawal and children's adaptive functioning outcomes over the last 25 years (since the early publications leading to Polyvagal theory), using PsychINFO (1986–2012), Science Citation Index Expanded (1986–2012), Social Sciences Citation Index (1986–2012), Arts & Humanities Citation Index (1986–2012), Google Scholar (1986–2012), and MEDLINE (1986–2012). The terms used in the search included RSA withdrawal, RSA suppression, RSA reactivity, vagal reactivity, vagal regulation, vagal suppression, vagal control, vagal withdrawal, vagal tone, cardiac autonomic regulation, physiological regulation, parasympathetic flexibility, and heart rate variability. These terms were crossed with terms related to children's adaptive functioning, including social functioning, social competence, peer relations, behavior problems, disruptive behavior, externalizing problems, internalizing problems, anxiety, depression, cognitive functioning, executive functioning, neurocognitive functioning, academic functioning, and school functioning. In addition to the database search, references used in identified studies and review articles were surveyed to identify other potentially relevant studies. Due to the extensive number of studies identified

through database search and study ancestry, unpublished data were not utilized for the present analyses.

Inclusion and Exclusion Criteria

Forty-four studies satisfied the inclusion criteria. Publication years of the identified studies ranged from 1992 to 2012. Our inclusion criteria were liberal in terms of the design of the studies as the main goal of this meta-analysis was to determine the magnitude of any associations between RSA withdrawal and children's adaptive functioning outcomes. Studies had to report an RSA withdrawal variable which means that RSA values had to be calculated during a baseline period as well as during a challenging task. Studies could either compare RSA withdrawal scores between a clinical (e.g., children displaying clinically elevated behavioral problems) and a control group (e.g., children displaying normative levels of behavior problems) or use correlational methods to examine concurrent or longitudinal associations between RSA withdrawal and adaptive functioning outcomes among a large community sample or at-risk group (e.g., Head Start). In addition, sufficient statistical data to allow the calculation of effect sizes had to be present (e.g., correlational tables, regressions, test statistics such as t-test, ANOVA, etc.). Articles written in languages other than English were excluded.

Additionally, since our focus was on four main adaptive functioning outcomes (i.e., externalizing problems, internalizing problems, social problems, and cognitive/academic problems), over 60 articles examining relations between RSA withdrawal and other outcomes were excluded. For example, articles which examined RSA withdrawal and children's health outcomes such as obesity (Graziano, Calkins, Keane, & O'Brien, 2011), immune response (Cacioppo, 1994), asthma (Miller, Wood, Lim, Ballow, & Hsu, 2009) or epilepsy (Harnod et al., 2008) were excluded. We also excluded articles examining the link between RSA withdrawal and sleep (El-Sheikh & Buckhalt, 2005), substance exposure (Hickey, Suess, Newlin, Spurgeon, & Porges, 1995; Sheinkopf et al., 2007) or parenting factors (Blandon, Calkins, Keane, & O'Brien, 2010; Calkins & Johnson, 1998; Mills-Koonce et al., 2009; Oosterman & Schuengel, 2007). Articles that solely examined the stability of RSA withdrawal (Bornstein & Suess, 2000; El-Sheikh, 2005), or changes in RSA withdrawal associated with treatment (Beauchaine, Gartner, & Hagen, 2000; Graziano, Bagner, Sheinkopf, Vohr, & Lester, 2012) were also excluded. Lastly, we also excluded articles that examined the association of RSA withdrawal and temperamental indices of emotional responses (Calkins, Dedmon, Gill, Lomax, & Johnson, 2002). Because we were interested in only children's adaptive functioning, any article in which the mean and/or range of age was over 18 was excluded.

Coding of Moderators

Studies were coded for several demographic and methodological features. Two judges (first and second authors) independently coded studies. Interjudge reliability was assessed via intraclass correlation coefficients (ICC) for continuous codes, and via kappas (κ) for categorical codes. When a discrepancy was found, both coders independently reviewed the study again and decided whether they would retain their original code or modify it.

Remaining discrepancies were resolved through discussion between coders. The reliability between coders was excellent (all ICC values > .90 and κ values = 1.00).

Demographic variables—We coded studies for average age of sample, gender (% male), ethnicity (% Caucasian), time lag (time in years between RSA measure and adaptive functioning outcome), type of sample (community/healthy, n = 27 vs. clinic/at-risk population such as Head Start or comparison of community/healthy and clinic/at-risk groups, n = 18). We also coded studies for type of measurement of adaptive functioning used such as parent report, observational measure or peer report, teacher report, or multiple reports.

Measurement of RSA—As noted in the introduction, several caveats of measuring RSA have been recently recognized (Grossman & Taylor, 2007) which may impact any potential associations between RSA withdrawal and adaptive functioning outcomes. Hence, we coded studies for a) whether children's respiration rates were actually measured (n = 12), estimated based on norms (n = 25) or not even mentioned (n = 8) as well as b) whether baseline RSA was co-varied in analyses of RSA withdrawal (n = 17) or not co-varied (n = 26). Additionally, we coded the type of challenging task used to derive RSA withdrawal scores: negative mood induction tasks such as listening to an argument (n = 13), cognitive tasks such as a solving a puzzle or memory game (n = 9), social tasks such as being rejected by a peer (n = 9), positive mood induction tasks (n = 2), and finally studies that used multiple types of tasks (n = 11).

Computation of Effect Sizes

For the Effect Size (*ES*) metric, Pearson's *r* was used because of the correlational nature of most of the relevant studies. *ES* estimates were attained primarily from correlations between RSA withdrawal and adaptive functioning outcomes. However, when correlations were not provided, Pearson's *r* was estimated from other available data sources, including group comparisons (t-tests), analyses of variance (ANOVAs), or means and standard deviations for extreme or tertiary groups assigned according to a criteria (e.g., comparing children with clinically elevated externalizing behavior problems versus those with normal rates of externalizing behavior problems). All effect size estimates and all transformations from other data sources to Pearson's *r* were calculated according to the formulas provided in Lipsey and Wilson (2001). Negative *ESs* in the present meta-analysis indicated negative associations between RSA withdrawal and adaptive functioning difficulties (e.g., externalizing problems, social problems, internalizing problems, cognitive/academic problems).

Forty-four studies with adequate meta-analytic information were identified, yielding ESs for externalizing problems (24 studies, total n = 3,331), internalizing problems (18 studies, total n = 1,697), social problems (15 studies, total n = 1,969), and cognitive/academic problems (10 studies, total n = 1,025). In studies in which two or more pertinent dependent variables were used, such as two different measures of externalizing behavior problems or two different reporters, the average correlation was used. All averaged measures used in the current study were judged by both coders as being of approximately equal validity.

Additionally, effect sizes from studies that used the same sample for investigating outcomes within the same domain (e.g., Sijsema et al., 2011 and Shoulberg et al., 2011 as well as Blair & Peters, 2003 and Blair, 2003) were also averaged. All study references appear in Appendix A.

Data Analysis

Primary analyses were conducted using a random effects model approach (Hedges & Vevea, 1998). This approach was chosen to reflect the likelihood that individual studies would produce ESs different from other studies in the analysis. All ESs were transformed to z-scores using Fisher's r to z transformation. After aggregation, ESs were transformed again to rs for comparison. To estimate the size of the effects, we adopted Cohen's criteria: small = . 10, medium = .30, large = .50. As a result of the large number of studies included, we used a minimum alpha level of .01 (two-tailed tests).

Heterogeneity analyses were also conducted to determine whether ESs were more heterogeneous than would be expected due to sampling error alone. The measure I^2 is a modification of Cochrane's Q test (Cochran, 1954) which measures whether the ratio of variation that exceeds chance, thereby accounting for the number of studies utilized in meta-analysis with more accuracy (Higgins & Thompson, 2002). Values for I^2 range from 0 to 1; an I^2 of 0% indicates no heterogeneity, whereas I^2 s of 25%, 50%, and 75% represent low, moderate, and high heterogeneity, respectively (Higgins, Thompson, Deeks, & Altman, 2003). For variables with moderate to high heterogeneity, potential moderators to the ES were identified using weighted least squares regression procedures (Hedges, 1994). Finally, file drawer analyses were conducted following Hedges and Olkin's (1985) approach to determine the number of studies that would be necessary to reduce the mean effect to a negligible level.

Results

Primary Analyses

Study identification information, coded categories, and *ESs* representing the relation between RSA withdrawal scores and children's adaptive functioning outcomes can be found in Table 1. The relation between RSA withdrawal and measures of children's externalizing problems had a weighted *ES* of r = -.16 (95% CI = -.19 to -.12, p = .001), indicating a small negative effect. Similarly, the relation between RSA withdrawal and measures of children's internalizing problems had a weighted *ES* of r = -.16 (95% CI = -.21 to -.12, p = .001), also indicating a small negative effect. Lastly, the relation between RSA withdrawal and measures of children's cognitive/academic problems also had a weighted *ES* of r = -.16 (95% CI = -.10 to -.22, p = .001), indicating a small negative effect. These results indicate that greater RSA withdrawal levels were associated with fewer externalizing, internalizing, and cognitive/academic problems. In contrast, a non-significant relation between RSA withdrawal and measure of children's social functioning problems was found, indicating that RSA withdrawal is not associated with social functioning across studies (r = .06, 95% CI = -.10 to -.01, ns).

Heterogeneity and Moderation Analyses

The measure I^2 was used to assess whether ESs were more heterogeneous than would be expected due to sampling error alone. Values for I^2 range from 0 to 1; an I^2 of 0% indicates no heterogeneity, whereas I^2 s of 25%, 50%, and 75% represent low, moderate, and high heterogeneity, respectively (Higgins et al., 2003). Once heterogeneity was identified, potential moderators to the ES were identified using weighted least squares regression procedures for continuous variables. Results of heterogeneity and moderator analyses are presented in Table 1.

The I^2 values for the RSA withdrawal relations with the adaptive functioning outcomes indicated moderate heterogeneity for externalizing, internalizing, and social problems (54%, 54%, and 71%, respectively). The I^2 values for academic/cognitive performance did not exceed 50%, suggesting relatively low heterogeneity. Hence, demographic moderators were tested only for externalizing, internalizing, and social problems. Demographic moderators included average age, gender (% male), ethnicity of sample (% Caucasian), time lag (time in years between RSA measure and adaptive functioning outcome), and type of sample (community vs. clinic).

Regression analyses indicated that ethnicity of sample was significantly associated with the average strength of the relation between RSA withdrawal and externalizing problems ($\beta = -$. 62, p < .01). This indicates that the association between RSA withdrawal and externalizing problems is stronger (more negative) among studies which had a sample containing a high percentage of Caucasian children. A t-test also indicated a significant difference in the strength of the relation between RSA withdrawal and social problems according to type of sample, t = -2.67, p < .05. Specifically, the association between RSA withdrawal and social problems was significantly more negative among studies with a community/healthy sample (M = -.14, SD = .16) versus studies with a clinically/at-risk sample (M = .16, SD = .28). Hence, while greater levels of RSA withdrawal was associated with fewer social problems among community/healthy children the reverse was true for clinically/at-risk children where greater levels of RSA withdrawal was associated with more social problems. No other significant demographic moderators were identified.

In terms of measurement issues, it is important to note that we found significant associations between baseline RSA and RSA withdrawal (r = .427, p < .05) as well as child age (r = .422, p < .05). Hence, according to the studies we reviewed, children with higher baseline RSA experienced greater levels of RSA withdrawal while baseline RSA values also increased as a function of children's age. An ANCOVA, controlling for ethnicity and type of sample, was also conducted in which the between group variables were a) co-varying of baseline RSA (yes or no), b) inclusion of respiration rates (actual measurement versus use of normative rates), and c) type of challenging task used to derive RSA (cognitive, social, negative mood/stressor, and multiple tasks). The dependent variable was the average weighted ES across adaptive functioning outcomes. This analysis (graphically depicted in Figure 1) indicated a significant effect for co-varying baseline RSA, F(1, 21) = 6.16, p = .02. Specifically, studies that co-varied baseline RSA had stronger associations between RSA withdrawal and adaptive functioning outcomes, M = -.19, SE = .03, compared to studies that did not co-vary

baseline RSA, M = -.09, SE = .04. Measurement of respiration rates (versus using normative rates) did not significantly impact the magnitude of the ESs (p = .70) nor did type of challenging task (cognitive, social, negative mood/stressors, multiple tasks) used to derive RSA withdrawal scores (p = .08). Of note, probing of this marginal significant finding indicated that studies which used negative mood/stressor tasks obtained larger RSA withdrawal to adaptive functioning associations compared to studies that used cognitive tasks to derive RSA withdrawal scores, p = .041. This may suggest that mood/stress induction tasks are tapping a key element of RSA withdrawal that elucidates its influence on adaptive outcomes. No other differences among tasks were found.

Lastly, to further probe the differential association between RSA withdrawal and social functioning outcomes for studies with clinically/at-risk samples, we coded mean levels of baseline RSA as well as RSA withdrawal (out of the 44 studies we examined, 29 provided enough descriptive information for this analysis). As seen in Figure 2, it is important to note that children from community/healthy samples had significantly higher levels of baseline RSA (weighted M = 6.26, SD = 1.50) compared to children from clinically/at-risk samples (weighted M = 6.09, SD = .88), F(1, 2003) = 11.30, p < .001. In terms of RSA withdrawal, and after controlling for baseline RSA, children from community/healthy samples had marginally higher levels of RSA withdrawal (weighted M = .27, SD = .51) compared to children from clinically/at-risk samples (weighted M = .20, SD = .27), F(1, 1342) = 3.61, p = .058. Finally, the association between baseline RSA and RSA withdrawal was significantly higher among children from clinically/at-risk samples (r = .36) compared to children from community/healthy samples (r = .20), F(1, 2976) = 250.50, p < .001.

File Drawer Analysis

To account for the bias toward publishing or submitting only significant findings, we conducted a file drawer analysis. This statistic examines the number of studies with null findings that would need to exist to bring the significant ESs of relations to less than p=.01. According to Rosenthal (1995), if only a few studies with null results are needed to change the significance level of a finding, then this finding is susceptible to the "file drawer threat," indicating that the finding is not reliably significant. Results of File Drawer analyses are provided in Table 1. In the case of RSA withdrawal and externalizing problems, the file drawer analysis indicated over 100 studies necessary to overturn significant findings. Similarly, in the case of RSA withdrawal and internalizing problems, the file drawer analysis indicated 65 studies would be necessary to overturn significant findings. However, for RSA withdrawal and academic/cognitive performance and social functioning problems, considerably fewer studies would be necessary to reduce results to non-significance (10 and 32, respectively), suggesting that these varied findings are less likely to remain stable as new research emerges.

Discussion

Given emerging research over the last 20 years regarding the importance of the parasympathetic branch of the autonomic nervous system (ANS), as indexed by cardiac vagal control or RSA withdrawal, in children's emotion regulation development, we sought

to determine the extent to which such a biological marker is associated with more complex adaptive functioning outcomes across domains. We also sought to examine measurement issues that have recently been highlighted (Grossman & Taylor, 2007; Denver et al., 2007; Allen et al., 2007) when studying RSA withdrawal. Our research questions were examined via a meta-analysis of 44 studies, the first to our knowledge that has focused on RSA withdrawal in children.

Within the externalizing domain, lack of self-control has long been conceptualized as a core feature of children who display significant behavioral problems such as those diagnosed with Attention-Deficit/Hyperactivity Disorder (ADHD) and Oppositional Defiant Disorder (Barkley, 1997; Keenan & Shaw, 2003). Due to observations that children with externalizing behavior problems also display greater emotion regulation difficulties compared to their peers (Graziano, McNamara, Geffken, & Reid, 2011; Hill, Degnan, Calkins, & Keane, 2006; Walcott & Landau, 2004), more recent psychopathology models of ADHD, for example, have argued that an emotion regulation perspective may offer a better understanding of its etiology (Martel, 2009). Previous physiological research had highlighted children with externalizing problems as having overall low reactivity as measured primarily through the sympathetic nervous system (SNS) via both electrodermal activity and lower baseline heart rate levels (see meta-analysis by Lorber, 2004). Our meta-analysis elucidates potential etiological mechanisms by finding that a physiological regulatory function in the PNS, as indexed by RSA withdrawal, is also compromised in children with externalizing problems. Specifically, lower levels of RSA withdrawal were linked to more externalizing behavior problems. We also found that children from clinical/at-risk samples (i.e., which primarily comprised of children who were categorically assigned as having significant externalizing behavior problems or having a diagnosis) had significantly lower absolute levels of baseline RSA as well as RSA withdrawal compared to children from community/healthy samples. This suggests that while externalizing problems may be associated with low baseline sympathetic arousal in general, there may be quite a bit more to the story regarding the cofunctioning of SNS and PNS systems. The empirical data summarized here appear to support the possibility that greater RSA withdrawal contributes to the allocation of metabolic resources. Specifically, increases in heart rate may facilitate the use of attentional abilities, which in turn may aid children in controlling both their behaviors and emotions during challenging states.

Past research had suggested two different perspectives on the physiological functioning of children with internalizing problems. One perspective indicated that children with internalizing problems physiologically overregulate which contributes to their symptoms (Thayer & Lane, 2000) while another perspective highlighted that internalizing problems are also a function of physiological dysregulation (Schmitz et al., 2011). The results of our meta-analysis provide clear support for the latter view in that greater levels of RSA withdrawal were associated with fewer internalizing symptoms. However, it is important to not fully discount the fact that the overwhelming number of studies we reviewed only examined a linear relationship between RSA withdrawal and internalizing problems. It is still possible that a quadratic association between RSA withdrawal and internalizing problems exists such that a moderate level of regulation is optimal. Additionally, it may also be the case that the overregulation hypothesized to be part of the internalizing problem

domain takes place in a more cognitively based way (e.g., worry) versus a primarily physiological reaction. Another plausible scenario that needs further research is the context in which such regulation occurs. It may be the case that children with internalizing problems overregulate during less threatening situations while underregulate during more challenging situations.

Within the cognitive/academic domain, a significant amount of research has linked better emotion regulation with optimal academic outcomes including school readiness (Graziano, Reavis, et al., 2007) as well as cognitive processes such as executive functioning (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Blair, 2002). Children with emotional and behavioral control difficulties also perform worse on cognitive tasks and have worse academic outcomes (Holmes et al., 2010; Massetti et al., 2008; Masten et al., 2005). Our findings are consistent with such literature by documenting a significant link between a biological marker for self-control and children's cognitive/academic functioning. From a physiological perspective such link is not surprising given the significant overlap in the brain structures (e.g., ACC and orbitofrontal cortex) that facilitate the regulation of both emotions and higher order cognitive processes (Bush et al., 2000). Efficient emotion regulation allows greater metabolic resources to be used for attentional control purposes and areas of the prefrontal cortex that are essential for cognitive functioning and subsequently academic success. Despite our findings, it is important to note that more research is needed linking RSA withdrawal to cognitive/academic outcomes given our file drawer analysis.

Similar to the internalizing domain, further examination of potential quadratic effects is needed, especially given a recent study showing that moderate levels of RSA withdrawal was associated with more optimal executive functioning (Marcovitch et al., 2010). In fact, the overwhelming number of studies we reviewed only examined a linear association between RSA withdrawal and children's adaptive functioning outcomes. While Polyvagal theory does not explicitly state a potential quadratic association between RSA withdrawal and children's adaptive functioning outcomes, it does highlight the importance of the vagus nerve in physiologically engaging and disengaging with the environment depending upon the level of challenge presented. When interpreting within this engagement and disengagement of the vagal break, then it is reasonable to expect that the timing and level of challenge in the environment will shape the pattern of the RSA withdrawal, and not necessarily in a linear way. Future research should examine both linear and non-linear patters of RSA withdrawal and how they map onto types of challenges in the environment as optimal levels of RSA withdrawal may differ according to the context the child is in.

The most surprising and noteworthy aspect of our study was the lack of a significant overall association between RSA withdrawal and children's social functioning. This finding is counter to what one would expect based on Polyvagal theory and the Social Engagement System, outlined by Porges (2003b). While the evolutionary and neuroanatomical evidence supporting the role of the vagus nerve in the nuclei that controls the muscles of the face and head is well-established, empirical data is vastly missing on: a) whether a well-regulated and calm visceral state actually contributes to better control of facial/head muscles that enables complex facial gestures, vocalizations, social gesturing, and orientation, and b) whether

subtle individual differences in the Social Engagement System actually contribute to children's social competence.

Despite our non-significant finding across studies, moderation analyses suggested that the relation between RSA withdrawal and social functioning was very different across populations. The ES between RSA withdrawal and social problems was negative (adaptive) in community/healthy samples (M = -.14, SD = .16) but positive (maladaptive) in clinically/at-risk samples (M = .16, SD = .28). Thus, the question appears to be not whether RSA withdrawal is associated with improved social functioning, but for whom. Why RSA withdrawal is associated with poor social functioning in clinical/at-risk populations is unclear, although there are several possible explanations. First, it is important to acknowledge the difficulty in extrapolating biological and psychological processes that tend to be examined within normative samples to high-risk groups (Beauchaine, 2001). While our mixed findings are unlikely the result of smaller sample sizes for children from clinical/atrisk samples (44% of studies we reviewed contained clinical/at-risk samples), high-risk groups undoubtedly have more complex psychological and biological deficits that contribute to their impairment. As such, one possibility is that the direct effects of RSA withdrawal are masked by other, more powerful influences on social functioning, such as significant clinical impairment. Additionally, given that the vast majority of our clinical/at-risk samples consisted of children displaying disruptive behavioral disorders (e.g., ADHD and/or high levels of aggression), it is possible that the more dysfunctional structural and neurochemical functioning implicated with such disorders (e.g., abnormalities in the mesoaccumbens dopamine pathway; Volkow et al., 2009) blunts the PNS's response to stress via a lack of reciprocity with the SNS's response, which has recently been shown to contribute to greater externalizing problems (see El-Sheik et al., 2009).

It is important to note that all studies that we reviewed used a broad measure of social functioning whether reported by parents, teacher, or peers. Social functioning is a complex and broad construct that is influenced by numerous factors. While some factors may be etiologically and theoretically linked to RSA withdrawal such as the finding that children with worse behavioral control have lower social preference scores (Hoza et al., 2005; Mrug, Hoza, Pelham, Gnagy, & Greiner, 2007), others such as physical attractiveness are not linked to self-control and yet have long been associated with social preference (Coie, Coppotelli, & Dodge, 1982). Further research needs to be conducted to truly examine any subtle effects of RSA withdrawal on voice control, eye contact, and facial movements that are hypothesized by the Social Engagement System. As it stands, however, the phylogenetic contributions to social behavior outlined by Polyvagal Theory have little empirical support for individuals with other significant clinical impairment.

Other moderation analyses failed to find any significant associations between child age or gender and the associations between RSA withdrawal and children's adaptive functioning outcomes. These null findings are noteworthy as only a handful of studies have suggested that gender may moderate RSA and adjustment links (Eisenberg et al., 1995) and even fewer studies have suggested that RSA (either baseline levels or withdrawal levels) relate to adjustment differently at different ages (Beauchaine et al., 2007; Gentzler, Rottenberg, Kovacs, George, & Morey, 2011). It is important to note that our meta-analysis could not

examine gender or age differences as they relate to absolute levels of baseline RSA and RSA withdrawal. While studies tend to show that baseline levels of RSA increase across development (Calkins & Keane, 2004; Hinnant, Elmore-Staton, & El-Sheikh, 2011) less work has examined the extent to which levels of RSA withdrawal change with time. In terms of gender, most studies find that boys and girls exhibit similar levels of baseline RSA and RSA withdrawal (Gentzler et al., 2011; Graziano, Keane, et al., 2007). Hence, despite potential age differences, and to a lesser extent gender differences, in the magnitude of RSA, it appears that at least the links between RSA and children's adjustment outcomes work similarly for boys and girls across development.

In terms of measurement issues associated with RSA, our meta-analysis highlights the importance of co-varying baseline levels of RSA when examining RSA withdrawal. Specifically, stronger associations between RSA withdrawal and children's adaptive functioning outcomes emerge when co-varying those initial starting values provided by baseline RSA. The law of initial values predicts that higher physiological baseline functioning facilitates greater physiological response during challenges (Lacey & Lacey, 1962; Wilder, 1956). However, previous research with clinical samples suggest that some children may have high starting baseline RSA values but have difficulty suppressing RSA during challenging states (Degangi et al., 1991). Our results show moderate levels of association between baseline RSA and RSA withdrawal levels although this association also varied as a function of sample type. Interestingly, children from clinical/at-risk samples had lower levels of baseline RSA and RSA withdrawal compared to children from community/ healthy samples. Baseline RSA is thought to represent a general responsiveness measure as it provides a ceiling on how much withdrawal a child can engage in during challenging situations. Hence, it appears that the more severe clinically/at-risk sample of children not only have greater physiological regulation difficulties in terms of their ability to withdrawal RSA but also start out at a disadvantage in terms of their overall ability to react and respond to environmental demands. Additionally, the higher association between levels of baseline RSA and RSA withdrawal among children from clinical-at-risk samples versus children from community/healthy samples suggest lower variability or flexibility in their physiological system's response to stress/challenge, even when considering varying baseline levels.

It is also important to note that recent studies show that the interaction between baseline RSA and RSA withdrawal is what predicts various outcomes, not just the independent examination of baseline RSA and RSA withdrawal (see El-Sheikh, Hinnant, & Erath, 2011; Hinnant & Erath, 2009). For example, in the context of experiencing marital conflict, only boys with lower baseline RSA *and* who experienced an augmentation of RSA (rather than a withdrawal) during a challenging task demonstrated an elevated risk for increasing delinquent behavior over time (El-Sheikh et al., 2011). On the other hand, a combination of lower baseline RSA *and* higher RSA withdrawal predicted later internalizing symptoms among early elementary school age children (Hinnant & El-Sheikh, 2009). While the examination of interaction effects between baseline RSA and RSA withdrawal and children's adaptive functioning show promise, more research is needed with clinical

populations given the difficulties in extrapolating psychophysiological findings from normative samples (Beauchaine, 2001).

Despite the debate over how to account for respiration when estimating vagal tone from RSA (Allen, Chambers, & Towers, 2007; Denver, Reed, & Porges, 2007; Grossman & Taylor, 2007), we did not find any differences in the magnitude of the associations between RSA withdrawal and adaptive functioning outcomes among studies that actually measured children's respiration rates (e.g., using peak-to-valley method) versus those that used normative levels (e.g., Porges adaptive polynomial filter method). Hence, consistent with Denver and colleagues (2007), our findings indicate that the predictive validity of RSA towards various outcomes does not change as a function of how respiration is accounted for. It is important to note that our findings cannot speak to whether studies that used normative levels of respiration rates obtained less accurate estimates of vagal tone compared to those that actually measured children's respiration, especially given the short-comings of using ANOVAs when examining differences (Allen et al., 2007). While the use of precise respiration rates may indeed lead to more pure measurements of RSA as an estimate of vagal tone, it is significantly more practical within the child literature to use normative rates of respiration during RSA calculations versus subjecting children to wearing a respiration band which may cause extra artifacts from the child touching the band.

There was also significant variability in terms of which challenging tasks researchers use to derive RSA withdrawal. These tasks ranged from frustration, cognitive, social, positive, sensory oriented tasks, while some studies used multiple tasks. The magnitude of the link between RSA withdrawal and children's adaptive functioning outcomes did not appear to vary as a function of the type of challenging task used, although there was a trend suggesting that negative/stress tasks obtained higher Effect Sizes compared to more cognitive oriented tasks. However, it is important to point out that very few studies used positive tasks (e.g., a game of peek-a-boo with a puppet; positive emotion-laden film clip) or compared regulation across types of task. This may be an important area for future research given a recent study showing that children with ADHD overregulate during positive tasks and underregulate during more stressful tasks (Musser et al., 2011). It will be important to replicate such pattern with other samples as well as children with other difficulties such as those displaying internalizing behavior problems. Examining such regulation during positive tasks may also yield information on children's reward sensitivity and surgency, important constructs that have been implicated in various psychological disorders (O'Brien & Frick, 1996; Tripp & Alsop, 2001; Volkow et al., 2009).

In summary, this study marks the first meta-analysis to confirm the role of cardiac vagal control, as measured via RSA withdrawal, in contributing to children's adaptive functioning across externalizing, internalizing, and cognitive/academic domains. Although we found evidence for the role of vagal regulation in the social behavior of healthy children (as predicted by the Social Engagement System outlined by Polyvagal Theory), we found the opposite to be true for clinical/at-risk populations, suggesting that the vagal "brake" does not uniformly enhance social functioning across all children. Additionally, children from clinical/at-risk samples displayed lower absolute levels of baseline RSA and RSA withdrawal compared to children from community/healthy samples. Despite the recent

caveats about measuring RSA, it appears that using normative rates of respiration versus actual measurement of respiration does not affect the link between RSA withdrawal and adaptive functioning outcomes nor does the type of challenging task used to derive RSA. Co-varying baseline RSA during analyses does strengthen the associations between RSA withdrawal and adaptive functioning outcomes.

In terms of limitations, our file drawer analyses highlighted the importance of further empirical work on the link between RSA withdrawal and children's social problems and cognitive/academic outcomes given the small number of studies conducted within those domains. While we examined certain measurement issues associated with RSA, we were not able to examine whether the task length or length of the baseline period affected any of the findings. Respiration rates vary with age (Bar-Haim, Marshall, & Fox, 2000), and this needs to be considered when determining the minimum length of RSA estimation as well as whether the length of RSA estimation impacts associations between RSA withdrawal and adaptive functioning. Additionally, it is important to recognize that we were not able to distinguish the extent to which our findings are a function of higher absolute levels of RSA withdrawal versus lower levels of RSA withdrawal or more importantly RSA augmentation. RSA or vagal augmentation represents a heighten parasympathetic response (i.e., increase in RSA during a challenging task versus baseline rather than a decrease that is typically seen and measured as RSA withdrawal) that has been suggested as being associated with hypervigilance and representative of an endophenotype of children at risk for more serious behavior or conduct problems (Katz, 2007). It will be important for future research to examine RSA withdrawal not only in a continuous manner but also in terms of whether children simply suppressed RSA during challenge or augmented RSA. It may be the case then that an augmentation of RSA is a better indicator of physiological dysfunction rather than lower levels of RSA withdrawal. Additionally and consistent with findings from Blair & Peters (2003) and as suggested by Hastings and colleagues (2008), it may be the case that the adaptive nature of either vagal augmentation or withdrawal is contingent on the context and demands the child is facing. Future work should attempt to examine the direction of children's RSA reactivity across multiple contexts as well as ecologically valid settings such as the school or home rather than in the laboratory.

Given that our moderation analyses indicated that the strongest associations between RSA withdrawal and children's externalizing outcomes were among studies with a higher percentage of Caucasian as participants, this could be a function of the power to detect an effect given the small number of minority children participating in research of this nature. Alternatively, some recent studies have documented differences among African-American children versus Caucasian children. For example, Hinnant and colleagues (2011) found that African-American children had higher levels of baseline RSA compared to Caucasian children but did not experience growth in baseline RSA over a two year period. Graziano and colleagues (2011) found that a cardiovascular profile characterized by lower levels of RSA withdrawal and heart period represented a significant risk factor for the development of obesity, but only for African-American children. The adult cardiovascular literature has also documented that African-Americans tend to show higher rates of hypertension and cardiovascular disease and display lower autonomic regulation compared to Caucasian adults (Cossrow & Falkner, 2004; Sloan et al., 2008). It is important to note that there is a

lack of studies examining actual rates of RSA withdrawal among children from different ethnicities/race, although the few studies available have not found any significant differences (Graziano, Calkins, et al., 2011; Graziano, Keane, et al., 2007; Matthews, Salomon, Kenyon, & Allen, 2002; Stifter & Corey, 2001). Future psychophysiological research would do well to include more diverse samples to determine whether this finding remains. It will be particularly important to study Latino children, given that they are the largest minority group in the U.S., comprising of more than 25% of children 5 years of age or younger (U.S. Census Bureau, 2009).

However, it is most important to note that the ESs of our significant associations were quite small in nature. This highlights the limitations of current physiological work in our field as researchers tend to examine widely different biological markers independently; some studies only focus on examining electrodermal activity, others on PNS measures such as RSA, others on EEG symmetry, and still others on SNS measures such as pre-ejection period (PEP) or cortisol. As pointed out by Beauchaine (2001), in order for our field to move forward and obtain a better understanding of the biological/physiological factors that contribute to children's adaptive functioning outcomes and/or common psychopathologies, researchers need to measure, analyze, and integrate multiple physiological systems at once. For example, research by El-Sheik and colleagues (2009) demonstrated that co-activation or co-inhibition of the PNS and SNS predicted greater externalizing behavior problems associated with marital conflict while reciprocal action of the PNS and SNS served as a protective factor. Equally important and demonstrated by El-Sheik and colleagues (2009) is the need for research to continue to examine how environmental and contextual factors interact with children's physiology to predict adaptive functioning outcomes. For example, children displaying less RSA withdrawal to a stressful event only showed elevated conduct problems in the context of a violent home environment (Katz, 2007). Greater levels of RSA withdrawal are also more strongly associated with reductions in stress reactivity in the context of higher social support (Wolff et al., 2012). These more complex analyses that incorporate multiple biological markers (and more accurately mirror the way the nervous system operates) as well as interactions with contextual and environmental factors will increase the understanding of how various psychological disorders develop and ultimately inform more targeted preventative and treatment strategies.

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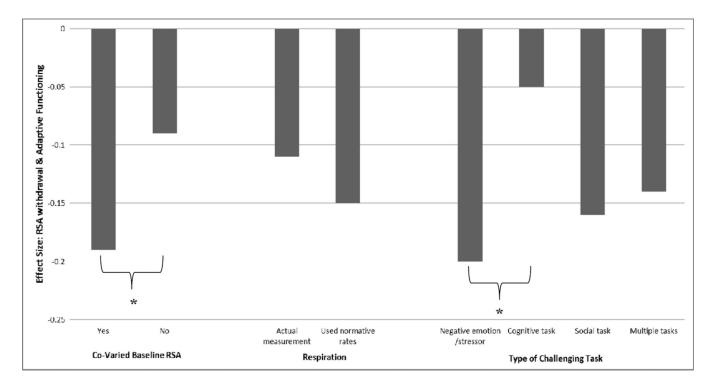


Figure 1. Summary of Moderation Analyses for RSA Measurement Variables. Note. * p < .05. Overall ANOVA for Type of Challenging Task comparison: F(1, 21) = 2.62, p = .078.

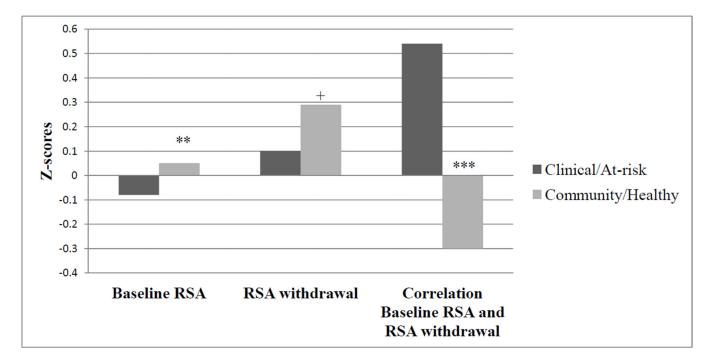


Figure 2. Summary of Moderation Analyses for Sample Type Note. + p < .06, ** p < .01, *** p < .001.

Table 1Effect Sizes across measures of adaptive functioning

	Externalizing Problems	Internalizing Problems	Social Problems	Cognitive/Academic Problems
Weighted Mean ES	16	16	06	16
Cohen's Criteria	Small	Small		Small
95% CI	19 to12	21 to12	10 to01	22 to10
Number of Effects Sizes	25	18	15	10
Total N across Studies	3,331	1,697	1,969	1,025
Range of Effects Sizes	55 to .10	48 to .07	44 to .42	32 to02
t	-9.09***	-6.78***	-2.63	-5.16***
File Drawer Analysis	113	65	30	30
I^2	54%	54%	73%	39%
Nature of Moderation	а		b	

Note.

^{***} p < .001.

a. Stronger negative (adaptive) association between RSA withdrawal and externalizing problems among studies which had a sample containing a high percentage of Caucasian children.

b. Association between RSA withdrawal and social problems was significantly more negative (adaptive) among studies with a community/healthy sample versus studies with a clinically/at-risk sample.

Appendix A

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Coded Qualities and Weighted Effect Sizes of Studies of RSA Withdrawal and Children's Adaptive Functioning Outcomes

Demographic Variables	Demographic Variables	graphic Variables					RSA Measurement Variables	riables			
	Mean Age in Years	% of sample Male	% of sample Caucasian	Time Lag in Years	Sample Type	Type of Task used for RSA	Controlled for baseline RSA	Respiration Rates	Adaptive Functioning Domain Measured	Effect Size	Z
	29.6	52	74	2.0	Community/Healthy	negative emotion/stressor	Yes	Yes, actual measurement	Externalizing (P) Internalizing (P)	11 29	133
	2.50	49	29	0	Community/Healthy vs. Clinic/At-Risk groups	multiple tasks	Yes	Yes, via estimated norms	Externalizing (O)	28	66
	9.90	52	80	0	Community/Healthy	negative emotion/stressor	Yes	Yes, actual measurement	Externalizing (P) Internalizing (P)	30 34	75
	7.00	88	91	0	Community/Healthy	negative emotion/stressor	No	Yes, actual measurement	Externalizing (P) Internalizing (P)	11	4
	4.50	57.00	96.00	3.00	Community/Healthy	positive/reward task	No	Yes, via estimated norms	Externalizing (P) Social Problems (P) Cognitive/Academic (O)	31 08 25	56
	.67	50.00	100.00	2.25	Community/Healthy	cognitive task	^o Z	No information provided	Externalizing (P) Internalizing (P) Social Problems (P)	50 45 42	24
	5.00	43.00	100.00	3.00	Community/Healthy	positive/reward task	Yes	No information provided	Cognitive/Academic (O)	18	56
Graziano, P., Keane, S., & Calkins, S. (2007)	5.50	46.00	67.00	0.	Community/Healthy vs. Clinic/At-Risk groups	multiple tasks	Yes	Yes, via estimated norms	Externalizing (M) Social Problems (O)	09	341
	5.50	47.00	67.00	0.	Community/Healthy vs. Clinic/At-Risk groups	multiple tasks	°Z	Yes, via estimated norms	Externalizing (P)	11	335
	3.50	48.00	53.20	0.	Community/Healthy vs. Clinic/At-Risk groups	multiple tasks	ON.	No information provided	Cognitive/Academic (O)	07	220
	4.75	45.00	00.69	0.	Clinic/At-Risk groups	cognitive task	No	Yes, actual measurement	Social Problems (T) Cognitive/Academic (T)	.40	42
	7.93	54.00	56.90	1.50	Community/Healthy vs. Clinic/At-Risk groups	negative emotion/stressor	Yes	Yes, via estimated norms	Internalizing (M)	36	65

				Demographic Variables	ic Variabl	es	RSA Me	RSA Measurement Variables	ıriables			
Study Mean % of % of Time Sa Age in sample sample Lag in Years Male Caucasian Years	% of % of Time sample sample Lag in Male Caucasian Years	% of Time sample Lag in Caucasian Years	Time Lag in ian Years		Sa	Sample Type	Type of Task used for RSA	Controlled for baseline RSA	Respiration Rates	Adaptive Functioning Domain Measured	Effects Size Size	Z Graziano
Calkins, S., & 2.00 46.00 63.00 2.00 Comm Keane, S. (2004) vs. Cling groups	46.00 63.00 2.00	63.00 2.00	2.00		Comn vs. Cli group	Community/Healthy vs. Clinic/At-Risk groups	multiple tasks	Yes	Yes, via estimated norms	Externalizing (P)	21	and Dere
Boyce, T., Quas, J., 6.50 40.00 100.00 .0 Comm Alkon, A., Smider, N., Essex, M., & Kupper, D. (2001)	40.00 100.00 .0	100.00	0.		Comm	Community/Healthy	multiple tasks	No	Yes, via estimated norms	Externalizing (M) Internalizing (M)	46 .07	tinko
Quas, J., Carrick, N., 6.30 55.00 52.00 .0 Comm Alkon, A., Goldstein, L., & Boyce, T. (2006)	55.00 52.00 .0	52.00 .0	0.	.0 Comm	Сопп	Community/Healthy	negative emotion/stressor	N _O	Yes, via estimated norms	Cognitive/Academic (O)	02	
Staton, L., El- 10.03 56.00 95.00 .0 Comm Sheikh, M., & Buckhalt, J. (2009)	56.00 95.00 .0	95.00 .0	0.	.0 Comm	Comm	Community/Healthy	cognitive task	Yes	Yes, actual measurement	Cognitive/Academic (O)	24	
Quas, J., Bauer, A., 5.16 54.00 71.00 .0 Comm & Boyce, T. (2004)	54.00 71.00 .0	71.00 .0	0.	.0 Соши	Comn	Community/Healthy	multiple tasks	No	Yes, via estimated norms	Cognitive/Academic (0)	18	
Obradovic, J., Bush, 5.32 52.00 43.00 .0 Comm N., Stamperdahl, J., Adler, N., & Boyce, T. (2010)	52.00 43.00 .0	43.00 .0	0.	.0 Comm	Comm	Community/Healthy	multiple tasks	Yes	Yes, via estimated norms	Externalizing (P) Social Problems (P) Cognitive/Academic (O)	10 .07 06	
Doussard-Roosevelt, 5.60 60.00 43.00 .0 Commu J., Montgomery, L., & Porges, S. (2003)	60.00 43.00 .0	43.00 .0	0.	.0 Commu	Commu	Community/Healthy	negative emotion/stressor	Yes	Yes, via estimated norms	Social Problems (O)	40	
Crowell, S., 15.30 .0 74.00 .0 Community. Beauchaine, T., WcCauley, E., groups. Smith, C., Stevens, A., & Sylvers, P. (2005)	.0 74.00 .0	74.00 .0	0:	.0 Commu vs. Clir groups	Commu vs. Clir groups	Community/Healthy vs. Clinic/At-Risk groups	negative emotion/stressor	°N	No information provided	Internalizing (M)	11	
Leary, A., & Katz, 5.00 66.00 88.00 4.00 Comm L. (2004)	66.00 88.00 4.00	88.00 4.00	4.00	00.	Comm	Community/Healthy	social task	No	Yes, via estimated norms	Social Problems (O)	03	
Hastings, P., 3.48 57.00 76.00 .83 Comm Nuselovici, J., Utendale, W., Coutya, J., McShane, K., & Sullivan, C. (2008)	3.48 57.00 76.00 .83	76.00 .83	· 83		Comm	Community/Healthy	social task	Yes	Yes, via estimated norms	Externalizing (P) Internalizing (P)	21 21	
Schmidt, L., Fox. N., 7.00 90.00 .0 Comm Schulkin, J., & Gold, P. (1999)	7.00 90.00 .0	0.	0.	.0 Comn	Comn	Community/Healthy	negative emotion/stressor	S S	No information provided	Internalizing (P)	31	36
Hastings, P., 3.50 46.00 74.00 .0 Comm Sullivan, C.,	46.00 74.00 .0	74.00 .0	0.		Comm	Community/Healthy	cognitive task	Yes	Yes, via estimated norms	Internalizing (P)	.03	$\frac{\mathcal{E}}{2}$ Page 31

				Demographic V	hic Variables	les	RSA Me	RSA Measurement Variables	riables			
	Study	Mean Age in Years	% of sample Male	% of sample Caucasian	Time Lag in Years	Sample Type	Type of Task used for RSA	Controlled for baseline RSA	Respiration Rates	Adaptive Functioning Domain Measured	Graziano Size	z
	McShane, K., Coplan, R., Utendale, W., & Vyncke, J. (2008) McShane, K., Coplan, R., Utendale, W., & Vyncke, J. (2008) McShane, K., Coplan, R., Utendale, W., & Vyncke, J. (2008) McShane, K., Coplan, R., Utendale, W., & Vyncke, J. (2008)	R., Utendi R., Utendi R., Utendi R., Utendi	ale, W., & 'ale, W	Vyncke, J. (20 Vyncke, J. (20 Vyncke, J. (20 Vyncke, J. (20	(800 (800 (800 (800)						and Derefi	
25	Scheeringa, M., Zeanah, C., Myers, L., & Putnam, F. (2004)			100.00	0.	Clinic/At-Risk groups	cognitive task	N _o	Yes, via estimated norms	Internalizing (P)	uko	124
26	Hinnant, B., & El- Sheikh, M. (2009)	89.8	44.00	00.69	2.00	Community/Healthy	multiple tasks	Yes	Yes, actual measurement	Externalizing (P) Internalizing (P)	09	176
27	El-Sheikh, M. (2001)	9.47	51.00	63.00	0.	Community/Healthy	negative emotion/stressor	Yes	Yes, actual measurement	Externalizing (M) Internalizing (M) Social Problems (O)	03 07 .05	216
28	El-Sheikh, M., Hinnant, B., & Erath, S. (2011)	8.23	49.00	64.00	3.00	Community/Healthy	cognitive task	No	Yes, actual measurement	Externalizing (P)	09	251
29	Blair, C. (2003)	4.75	45.00	00.69	0.	Clinic/At-Risk groups	cognitive task	No	Yes, actual measurement	Social Problems (T) Cognitive/Academic (O)	.40 23	42
30	Willemen, A., Schuengel, C., Koot, H. (2009)	13.57	100.00	100.00	0.	Clinic/At-Risk groups	negative emotion/stressor	No	Yes, via estimated norms	Externalizing (M) Internalizing (M)	13	66
31	Pearson, S., Alkon, A., Treadwell, M., Wolff, B., Quirolo, K., & Boyce, T. (2005)	7.40	47.00	100.00	0.	Clinic/At-Risk groups	multiple tasks	N _o	Yes, via estimated norms	Externalizing (P) Internalizing (P)	19	19
32	Keller, P., & El- Sheikh, M. (2009)	8.72	42.00	00.99	2.00	Community/Healthy	multiple tasks	Yes	Yes, via estimated norms	Externalizing (P)	09	54
33	Sijtsema, J., Shoulberg, E., Murray-Close, D. (2011)	12.47	0.	94.00	0.	Community/Healthy	social task	No O	Yes, via estimated norms	Social Problems (M)	12	119
34	Crowell, S., Beuchaine, T., Gatzke-Kopp, L., Sylvers, P., Mead, H., & Chipman- Chacon, J. (2006)	4.60	58.00	71.00	0.	Community/Healthy vs. Clinic/At-Risk groups	cognitive task	No	Yes, via estimated norms	Externalizing (P)	90.	38
35	Shoulberg, E., Sijtsema, J., & Murray-Close, D. (2011)	12.43	0.	94.00	0:	Community/Healthy	social task	°N	Yes, via estimated norms	Social Problems (M)	Page 32	119

				Demographic Variables	ic Variabl	sə	RSA Me	RSA Measurement Variables	riables			
	Study	Mean Age in Years	% of sample Male	% of sample Caucasian	Time Lag in Years	Sample Type	Type of Task used for RSA	Controlled for baseline RSA	Respiration Rates	Adaptive Functioning Domain Measured	Effects Size Size	z
36	Beauchaine, T., Katkin, E., Strassberg, Z., & Snarr, J. (2001)	13.40	100.00	100.00	0.	Community/Healthy vs. Clinic/At-Risk groups	social task	No	Yes, via estimated norms	Externalizing (P)	and Derefin	59
37	Schmitz, J., Kramer, M., Tuschen-Caffier, B., Heinrichs, N., & Blechert, J. (2011)	10.00	54.00	100.00	0.	Community/Healthy vs. Clinic/At-Risk groups	social task	No	Yes, via estimated norms	Internalizing (P)	42. gko	56
38	Musser, E., Backs, R., Schmitt, C., Ablow, J., Measelle, J., & Nigg, J. (2011)	8.00	48.00	66.67	0.	Community/Healthy vs. Clinic/At-Risk groups	negative emotion/stressor	No	Yes, actual measurement	Externalizing (P)	23	99
39	Erath, S., Tu, K., & El-Sheikh, M. (2011)	11.67	51.00	62.00	0.	Community/Healthy	social task	No	No information provided	Externalizing (M) Internalizing (S) Social Problems (M)	.100912	63
40	Stifter, C., Corey, J. (2001)	1.00	48.50	91.80	0.	Community/Healthy	cognitive task	No	Yes, via estimated norms	Social Problems (O)	32	136
41	Gazelle, H., & Druhen, M.(2009)	8.66	41.00	62.00	0.	Community/Healthy vs. Clinic/At-Risk groups	social task	No	Yes, via estimated norms	Externalizing (O) Internalizing (O) Social Problems (O)	07 .00 01	154
42	Eisenberg, N., Sulik, M., Spinrad, T., Edwards, A., Eggum, N., Liew, J., et al. (2012)	1.48	55.80	84.00	3.00	Community/Healthy	negative emotion/stressor	Yes	Yes, actual measurement	Externalizing (M)	.07	213
43	Liew, J., Eisenberg, N., Spinrad, T., Eggum, N., Haugen, R., Kupfer, A., et al. (2011)	1.48	55.80	84.00	1.00	Community/Healthy	negative emotion/stressor	Yes	Yes, actual measurement	Social Problems (O)	20	216
4	Haley, D., Grunau, R., Weinberg, J., Keidar, A., & Oberlander, T. (Haley, Grunau, Weinberg, Keidar, & Oberlander, 2010)	.50	47.76	80.00	0.	Community/Healthy vs. Clinic/At-Risk groups	cognitive task	No	No information provided	Cognitive/Academic (O)	31	67

Note. (P) = Parent report, (T) = Teacher report, (S) = Self-report, (0) = observational or peer report, and (M) = Multiple reporters. Example of negative emotion/stressor tasks = Child hearing an argument, frustration task, watching a sad video. Example of cognitive tasks = memory, executive functioning, problem solving, bayley developmental test. Example of social tasks = peer provocation, peer interactions. Examples of positive tasks = game of peek-a-boo with a puppet; positive emotion-laden film clip.