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Review article

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 ($n = 4996$ 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.

Contents

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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.

1. 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 engagement–disengagement function of the vagal brake as it relates to socially relevant behaviors vs. 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, Keane, and Calkins (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.

2. 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