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Intersections between cardiac physiology, emotion regulation and interpersonal warmth in preschoolers: Implications for drug abuse prevention from translational neuroscience

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ABSTRACT

Background: Early childhood is characterized by dramatic gains in emotion regulation skills that support social adjustment and mental health. Understanding the physiological substrates of healthy emotion regulation may offer new directions for altering trajectories toward initiation and escalation of substance abuse. Here, we describe the intersections between parasympathetic and sympathetic tone, emotion regulation and prosocial behavior in a high-risk sample of preschoolers.
Method: Fifty-two 3–6 year old children completed an assessment of attention regulation in response to affective stimuli. Cardiac respiratory sinus arrhythmia, an index of parasympathetic tone, and pre-ejection period, a marker of sympathetic activation, were recorded at rest and while children engaged in social interactions with their mothers and an unfamiliar research assistant. Mothers reported on children's emotional reactivity and prosocial behavior.
Results: Controlling for age and psychosocial risk, higher parasympathetic tone predicted better attention regulation in response to angry emotion and higher levels of prosocial behavior, whereas a reciprocal pattern of higher parasympathetic tone and lower sympathetic arousal predicted better attention in response to positive emotion and lower emotional reactivity. Children exposed to fewer risk factors and higher levels of maternal warmth were more able to sustain a high level of parasympathetic tone during interaction episodes.
Conclusions: Findings suggest that autonomic measures represent biomarkers for socio-emotional competence in young children. They also point to the importance of early experiences in the establishment of physiological regulation and the promise of family-based intervention to promote healthy emotion regulation and prevent substance dependence in high-risk populations.
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1. Introduction

In theories of developmental psychopathology, the strategies children use to overcome early developmental milestones become part of their personalities, guiding habitual responses to challenges across the lifespan. Children exposed to early adversity, including household stress, poverty, violence and maltreatment, are at increased risk for psychiatric morbidity, early drug use and substance dependence (Blanco et al., 2013; Chassin et al., 2013; Enoch, 2011; Sitnick et al., 2014). Moreover, higher levels of childhood adversity predict greater levels of dependence in adult substance users (Banducci et al., 2014). To understand heterogeneity in these outcomes and enhance preventative strategies, it is necessary to take a lifespan approach, focusing on the etiological mechanisms that progressively canalize some children's development along these poor trajectories while other children remain resilient. Here, we focus on a critical developmental skill that typically begins to develop in early childhood, the ability to manage and effectively respond to emotion.

Emotion regulation is a multi-dimensional construct incorporating both the ability to modulate one's own emotional arousal and intensity, and the recognition of and socially appropriate response to others' emotions (Thompson, 1994). Theories of emotion reg-

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ulation stress the importance of both bottom-up processing of emotional cues and top–down regulation of attention toward these cues (Cole et al., 1994). That is, both the *experience* of emotion and *use of strategies* to regulate emotions reflect adaptive responses of the organism to his/her environment (Kim and Cicchetti, 2010). Emotion regulation is also an important dimension of interpersonal competence, allowing an individual to gauge and adjust his/her level of emotional expressiveness according to social demands and expectations (Denham et al., 2003; Jones et al., 2013). Indeed, deficits in emotion regulation are a hallmark of psychopathology and, as emphasized throughout this volume, invariably accompany substance dependence (Aldao et al., 2010; Berking et al., 2011; Dorard et al., 2008).

The preschool years are a time of dramatic improvement in children's ability to regulate their emotions (Kopp, 1989). During these years, youngsters shift from being primarily co-regulated in the context of close caregiver–child interactions to showing increased capacity for autonomous regulation (Cole et al., 1994). They become more proficient at recognizing expressions such as anger, fear and surprise (Smith and Walden, 1998). They also make gains in language skills that enable them to label emotions and better articulate and understand feedback regarding their own and others' emotional states. Between 3 and 4 years of age, children become able to successfully navigate tasks that involve taking the perspectives of others (Carlson et al., 2013; Wimmer and Perner, 1983). Notably, the preschool period is also characterized by marked growth in higher-order cognitive control competencies (e.g., working memory, inhibitory control) that allow children to manage and coordinate attentional and behavioral responses to competing neural and sensory inputs (Clark et al., 2012; Garon et al., 2008). The convergence of these new skills enables children to implement complex strategies for managing emotion that foster their ability to engage in socially appropriate, empathic peer interactions by the time they reach kindergarten (Denham et al., 2003; Stansbury and Sigman, 2000).

Theory and research suggest that the environment plays a critical role in shaping these emotional competencies (Blandon et al., 2008; Feng et al., 2008). In infancy, primary caregivers act as emotional regulators through their responses to infant cues (Stern, 1977). Early caregiver–child interactions provide a training ground for emotion recognition and modulation: parents model, shape and reinforce children's emotional responses and act as supports in times of emotional arousal (Eisenberg et al., 2009; Thompson, 1994; Tronick, 1989). Accordingly, sensitive, warm and responsive parenting is associated with more effective emotion regulation in young children, whereas harsh, negative and physically abusive parenting is associated with poor emotion regulation and dysregulated attention in the face of negative emotion (Calkins et al., 2001; Hastings et al., 2008; Maughan and Cicchetti, 2002; Pollak et al., 2005). More broadly, chronic exposure to environmental stress, unpredictability, and a negative emotional climate may lead children to develop ineffective or atypical regulatory strategies (Morris et al., 2007). Not only are children exposed to such stress more likely to encounter caregivers who provide models of ineffective emotion regulation, but chronic activation of physiological stress response systems may alter biological set-points for arousal, compromise the integrity of these systems, and condition atypical responses to emotional challenge or threat (Evans and English, 2002; Evans, 2003; Nederhof et al., 2015). In a recent neuroimaging study with adults, for example, childhood poverty was associated with reduced neural responses in brain regions that are central to emotion regulation—the dorso- and ventrolateral prefrontal regions (Kim et al., 2013). Importantly, the relation of childhood poverty to neural activation in these core emotional processing networks was mediated by chronic early stress exposure. Taken together, studies provide compelling evidence that a child's environment shapes his/her bio-behavioral responses to emotion, with cascading implications for social competence and mental health.

Although there is widespread recognition of the importance of emotion regulation for healthy development, the construct has proven difficult to measure at a behavioral level, particularly during the preschool period when children's regulatory skills are just emerging and emotional expression may fluctuate rapidly from one moment the next. Consequently, some researchers have employed physiological measures as indices of emotional arousal and regulation. In Porges' (1995) polyvagal theory, the distinct branches of the mammalian autonomic nervous system evolved to serve different adaptive needs. The sympathetic nervous system, Porges contends, is a phylogencally ancient system that theoretically mobilizes the body's resources for fight or flight. Pre-ejection period (PEP), a measure of the time window between the depolarization of the cardiac ventricles to the opening of the aortic valve, is thought to capture this sympathetic influence, with shorter PEP indicative of greater sympathetic activation and accelerated heart rate (Alkon et al., 2003; Stern et al., 2001). The parasympathetic system is a more recently evolved system that theoretically supports effective social engagement, warmth, and proximity through the regulation of attention and the control of muscles involved in facial expressions that facilitate social engagement and communication (Porges, 1998, 2001). Respiratory sinus arrhythmia (RSA), a measure of beat-to-beat variability in heart rate across the respiration cycle, provides an approximation of the parasympathetic influence of the vagus nerve on the heart. Via its connections to the heart's sinostriatal node, the myelinated vagus presumably is able to inhibit sympathetic activation, conserve metabolic resources, and promote calm and self-soothing in non-threatening contexts (Porges, 2007). Through dynamic engagement or withdrawal of vagal influence on heart rate, the parasympathetic system can respond quickly to changing demands for vigilance or socio-emotional engagement. Importantly, the vagus has numerous afferent and efferent inputs from areas in the limbic system and ventromedial frontal cortex that are fundamentally involved in emotion regulation (Berntson et al., 2007; Thayer and Lane, 2000).

Recent meta-analytic findings provide support for polyvagal theory, showing that higher resting RSA is associated with increased levels of empathy, positive emotional expression and sustained attention, whereas lower resting RSA is associated with higher levels of disruptive and aggressive behavior (Graziano and Derefinko, 2013). Moreover, in a few recent studies, these associations have proven quite specific, with RSA relating to children's emotional or reward-related regulation as opposed to measures of cognitive control in non-emotional contexts (Conradt et al., 2014). Although there has been considerably less attention to sympathetic influences on emotion regulation early in life, low sympathetic activation appears to confer risk for antisocial behavior, attention deficits and reward insensitivity (Beauchaine et al., 2013; Crowell et al., 2006; Muñoz and Anastassiou-Hadjicharalambous, 2011), whereas high sympathetic activation is associated with anxious and inhibited behavior (Scarpa et al., 1997).

Studies have seldom considered the additive or interactive influence of parasympathetic and sympathetic branches of the autonomic nervous system in young children, an important oversight given that the two systems can act independently and that both systems influence heart rate (Alkon et al., 2003; Cacioppo et al., 1994; Quigley and Stifter, 2006). Berntson et al. (1991) proposed that the autonomic system can act in one of five ways: (1) reciprocal parasympathetic activation is characterized by parasympathetic activation coupled with sympathetic withdrawal; (2) reciprocal sympathetic activation is the inverse of this; (3) co-activation involves activation in both parasympathetic and sympathetic systems; (4) co-inhibition involves decreased activ-

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