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Review

Development of cardiac autonomic balance in infancy and early childhood: A possible pathway to mental and physical health outcomes

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ABSTRACT

Cardiac autonomic balance (CAB), defined as the relative influences of the sympathetic (SNS) and parasympathetic (PNS) nervous systems on the heart at rest, is a well-established biomarker of mental and physical health in adulthood (Kemp & Quintana, 2013). SNS and PNS functioning that, jointly, determine CAB, mature and stabilize between gestation and age five (Alkon, Boyce, Davis, & Eskenazi, 2011), co-developing with capacity to regulate distress during challenge and social engagement (Porges & Furman, 2011). This review integrates existing work in developmental, clinical, and medical sciences to propose a theoretical model of CAB development from gestation through early childhood and its putative relations with later functioning. By age five, CAB may reflect biological embedding of regulatory strategies that lay the groundwork for risk or resilience: The same profiles of SNS and PNS functioning associated with limited regulatory support in infancy and exposure to early adversity predict poor mental and physical health problems in adulthood (e.g., Beauchaine, 2001; Oosterman et al., 2010; Suurland, van der Heijden, Smaling, et al., 2017). In three key questions, we identify areas of consensus and remaining gaps in existing work to guide the next generation of research on early CAB development as a possible pathway from early experiences to mental and physical health outcomes.

Introduction

The theory of biological embedding posits that children's early environments get under the skin to affect physical and mental health later in life (Shonkoff, Boyce, & McEwen, 2009). One likely site of this embedding, cardiac autonomic balance (CAB[1]), reflects the relative influences of the sympathetic (SNS) and parasympathetic (PNS) nervous systems on the heart at rest. The SNS and PNS functioning thought to produce CAB (Berntson, Cacioppo, & Quigley, 1991) appears to stabilize by age five, following rapid SNS and PNS maturation from gestation through the first years of life (Alkon, Boyce, Davis, & Eskenazi, 2011; DiPietro et al., 2004; Massin & von Bernuth, 1997). During this sensitive period, when components of CAB are co-developing with capacity for emotion regulation and social engagement (Porges & Furman, 2011), children's physiological and emotional abilities to recover from distress are both thought to be scaffolded by caregiver support and hindered by exposure to adversity (Busuito & Moore, 2017; Leerkes, Blankson, & O'Brien, 2009). Because the SNS and PNS are central regulators of emotional reactivity and recovery during challenge and also of most visceral organs and systemic responses such as inflammation (Hall, 2015; Lim, Kim, Lee, & Namgung, 2016; Porges, 2007), their

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[1] Abbreviations: CAB = cardiac autonomic balance; SNS = sympathetic nervous system; PNS = parasympathetic nervous system; PEP = pre-ejection period; LF-HRV = low-frequency heart rate variability; RSA = respiratory sinus arrhythmia; HF-HRV = high-frequency heart rate variability.

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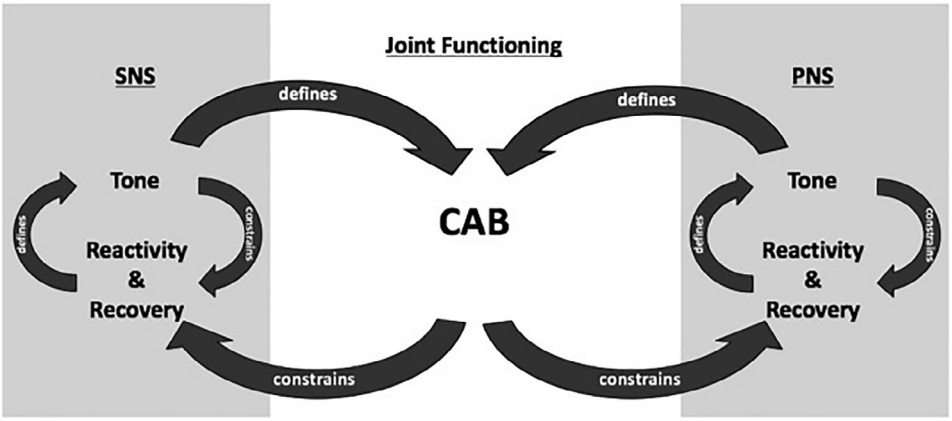

Fig. 1. CAB develops as a function of SNS and PNS reactivity and recovery.

calibration by supportive or adverse conditions may influence both psychological and physical functioning.

In this way, biological embedding evident in CAB by age five may point to a mechanism linking early environments with pervasive public health problems such as depression and cardiovascular disease (see Beauchaine, 2001; Kemp & Quintana, 2013 for reviews). Profiles of CAB associated with health in adulthood, marked by greater PNS than SNS influence on the heart at rest (Cacioppo et al., 1994), may be promoted by the ability to recover following distress. Beginning in middle-childhood (Korkushko, Shatilo, Plachinda, & Shatilo, 1991), CAB characterized by low SNS and high PNS tones is considered advantageous for two reasons: It reflects a high and appropriate degree of PNS inhibition of the heart in the absence of threat, facilitating regenerative processes and rest, and it theoretically provides the organism with space for dynamic PNS reactivity (Hall, 2015; Thayer & Brosschot, 2005). Conversely, low resting PNS tone places the regulatory burden on the SNS, such that mobilization requires more metabolically costly SNS reactivity that may delay recovery (Porges, 2007). Profiles of CAB associated with disease and disorder, marked by high SNS and low PNS tones at rest, may develop due to this protracted fight or flight responding, contributing to allostatic load (McEwen, 1998; Thayer & Brosschot, 2005). In this way, strategies for reacting to and recovering from distress developed in early childhood may have far-reaching influences on adult health.

The current paper lays out a theoretical model for the early development of CAB by integrating existing theory and empirical work on the function, development, and clinical implications of concurrent SNS and PNS functioning. We propose that early experiences calibrate CAB, which is strongly predictive of mental and physical health in adulthood, by supporting or hindering children's developing ability to recover from challenge (Fig. 1). Because, according to this model, the stable CAB observed by age five develops from SNS and PNS reactivity and recovery, we review not only the relatively small body of work that has examined CAB directly—that is, the relative influence of the SNS and PNS on the heart at rest—but studies that have examined both cardiac SNS and PNS reactivity and recovery (sometimes referred to herein as "dual-branch functioning" or "dual-branch processes" for simplicity) during early childhood. Examination of this dual-branch functioning is necessary to understanding CAB development, as the SNS and PNS are theorized to play different roles in response to stress or social engagement (Porges, 2007), and, although they operate as a conjoint system, may not operate or develop reciprocally (Berntson et al., 1991). We include discussion of work on single-branch functioning only where it lends relevant supplementary evidence. Although three papers have reviewed topics related to the early development of CAB (Beauchaine, 2001; Propper & Holochwost, 2013; Shields, 1983), to our knowledge, none have synthesized existing work on the dual-branch processes contributing to CAB development and elucidated their possible implications for health and mental health in later childhood and adulthood.

We provide supporting evidence for our model and direction for future work in three key questions about the early development of CAB and its possible role linking early experiences with risk or resilience:

1. How has CAB been conceptualized and measured, and what are the most promising definitions and measures for use in developmental science moving forward?
2. What is known about the normative maturation of and environmental contributors to SNS and PNS determinants of CAB?
3. Does CAB reflect a mechanism linking early experiences with later mental and physical health outcomes?

Terminology

Before entering into these questions, it is necessary to establish a common language for accurately discussing the diverse literature reviewed here.

Autonomic balance vs. cardiac autonomic balance

Autonomic balance refers to the relative influences of the SNS and PNS on the organism at rest (Eppinger & Hess, 1915). For reasons discussed in more detail in the coming section on conceptualization and measurement (Question 1), we distinguish *cardiac*