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Integrating affective and cognitive correlates of heart rate variability: A structural equation modeling approach

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ABSTRACT

High frequency heart rate variability (HRV) is a measure of neurocardiac communication thought to reflect predominantly parasympathetic cardiac regulation. Low HRV has been associated empirically with clinical and subclinical levels of anxiety and depression and, more recently, high levels of HRV have been associated with better performance on some measures of executive functioning (EF). These findings have offered support for theories proposing HRV as an index measure of a broad, self-regulatory capacity underlying aspects of emotion regulation and executive control. This study sought to test that proposition by using a structural equation modeling approach to examine the relationships of HRV to negative affect (NA) and EF in a large sample of U.S. adults ages 30s–80s. HRV was modeled as a predictor of an NA factor (self-reported trait anxiety and depression symptoms) and an EF factor (performance on three neuropsychological tests tapping facets of executive abilities). Alternative models also were tested to determine the utility of HRV for predicting NA and EF, with and without statistical control of demographic and health-related covariates. In the initial structural model, HRV showed a significant positive relationship to EF and a nonsignificant relationship to NA. In a covariate-adjusted model, HRV's associations with both constructs were nonsignificant. Age emerged as the only significant predictor of NA and EF in the final model, showing inverse relationships to both. Findings may reflect population and methodological differences from prior research; they also suggest refinements to the interpretations of earlier findings and theoretical claims regarding HRV.

1. Introduction

Autonomic and neuroendocrine mechanisms associated with negative emotion have been implicated in the development of mental and physical health problems (Brooks et al., 2011; Glick et al., 1965). Although the focus has been on sympathetic adrenomedullary activity associated with emotional volatility (Kreibig, 2010), a growing body of work examines parasympathetic nervous system influences on heart rate variability (HRV) thought to reflect emotion regulation (Berntson et al., 1997; Levy, 1990). High HRV, taken in this work to indicate greater parasympathetic (vagal) tone, is viewed as a possible marker for cardioprotective processes, whereas low HRV/less parasympathetic tone is considered a potential risk factor for cardiovascular disease (CVD), adverse cardiac events, and all-cause mortality (Dekker et al., 1997, 2000; Tsuji et al., 1994, 1996).

Inverse relationships have been reported between HRV and symptoms of anxiety and depression in physically healthy individuals (Friedman, 2007; Rottenberg, 2007). Both anxiety and depression are considered possible risk factors for CVD and other physical health problems (Gianaros and Sheu, 2009; Rozanzki et al., 1999; Suls and Bunde, 2005). There are also reports of positive relationships between HRV and executive functioning (EF; reviewed in Thayer et al., 2009), cognitive control processes that support planning and execution of goal-directed activity. These inverse associations with negative affect (NA) and its sequelae, and positive associations with EF, are consistent with theories conceptualizing HRV as a measure of bidirectional neurocardiac communication that reflects adaptive mechanisms of affective and cognitive self-regulation (Bates and Buckman, 2013; Benarroch, 1997; Berntson et al., 2007).

The present study addressed several questions that emerge from the work outlined above by using structural equation modeling (SEM) to examine simultaneously the relationships of HRV to both NA and EF. A large, nonclinical sample of U.S. adults permitted a test of the HRV–NA relationship in individuals predominantly without anxiety or mood disorders or clinical CVD. It also afforded the opportunity to examine associations among HRV, NA, and EF across a broad age range. In addition, employing SEM allowed a more comprehensive representation of EF compared with most prior studies of its relationship to HRV.

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1.1. Associations of HRV with anxiety and depression

Among the anxiety disorders, panic and post-traumatic stress disorders have shown the strongest relationships with low HRV, while less consistent results have been found for generalized anxiety disorder and phobias (Friedman, 2007). In nonclinical samples, low HRV has been associated with biased attention toward threat (Miskovic and Schmidt, 2010) and delay in disengaging attention from threat (Cocia et al., 2012). These cognitive responses have been linked to anxiety disorders, but are not measures of anxiety (Clark, 1999). In other research, low resting HRV has been found to predict exaggerated startle response under threat of shock (Melzig et al., 2009) and increased startle magnitude following neutral stimuli (Ruiz-Padial et al., 2003). These findings have been discussed in terms of anticipatory anxiety. However, while startle modulation has validity for measuring neurobiological aspects of emotion, it is not itself a measure of subjective NA. With regard to trait anxiety, which is a marker for chronic NA, an inverse association with HRV has been shown in medical patients (e.g., Kogan et al., 2012), but findings in physically healthy individuals have been inconsistent (Bleil et al., 2008; Dishman et al., 2000; Fuller, 1992; Virtanen et al., 2003; Watkins et al., 1998).

Turning to HRV's relationship to depressive symptoms, much of the research has been conducted in CVD patients (e.g., Carney et al., 2001; Stein et al., 2000), raising the possibility that CVD confounds or moderates this association (Kemp et al., 2010). Studies of HRV and depression in physically healthy participants have shown more mixed and modest findings than the HRV–anxiety literature (Kemp et al., 2010; Rottenberg, 2007). Major considerations regarding the discrepancies include: (1) some antidepressant medications affect HRV, (2) unmeasured cardiovascular factors may be linked to both HRV and depression, and (3) unmeasured comorbid anxiety may account for effects on HRV. To our knowledge, only one study has examined HRV's relationship to symptoms of both anxiety and depression in a large community sample. Bleil et al. (2008) reported that in young and middle-aged adults ($N = 653$) depression and anxiety each independently predicted HRV and contributed to the higher-order latent variable of negative affect, which also predicted HRV.

1.2. Association of HRV with executive functioning

Executive functions are defined as cognitive control mechanisms for maintaining task goals and flexibly implementing task rules (e.g., Miller and Cohen, 2001). One prominent theoretical framework for characterizing individual differences in EF describes a three-factor model comprising (1) monitoring and updating information in working memory, (2) task shifting, and (3) inhibition of prepotent responses (Miyake et al., 2000). Factor analyses have shown these three EF components to be intercorrelated yet separable facets of the same underling construct (Miyake et al., 2000).

Several studies reported associations between resting HRV and performance on tasks involving EF (Thayer et al., 2009). Among young, male Norwegian Navy personnel, high-HRV participants showed superior accuracy on a computerized, two-back working memory measure, and faster responding, with a trend toward better accuracy, on particular components of a continuous performance task (Hansen et al., 2003). Other studies using the same tasks and Navy population reported improved EF under stress only among low-HRV participants; also reported were coincident increases in HRV and improvements in EF task components after fitness training (Hansen et al., 2004, 2009). Similar to the latter finding, a study of older, sedentary adults found increased HRV and improvement on the Wisconsin Card Sorting Test only in the group assigned to an exercise regimen (Albinet et al., 2010).

This work provides initial support for a correlation between higher resting HRV and better performance on several tasks tapping facets of EF. However, the samples were relatively small ($N = 24$–65), predominantly male, and drawn from the extremes of the adult population in terms of age and physical fitness. Moreover, some continuous measures of HRV were dichotomized, and single-task or task-component measures reflect relatively narrow conceptualizations of EF. The present study aimed to clarify the HRV–EF relationship in a nonclinical adult population by (1) using a larger, more diverse sample than much prior research in this area; (2) treating HRV as a continuous variable; and (3) conceptualizing EF as a latent variable measured by a set of tasks tapping its major theorized components.

1.3. Relationship of age to HRV, NA, and EF

Age has a pervasive influence on HRV, NA, and EF, and is therefore an important factor in modeling their inter-relationships. There is a well-documented, inverse association between age and HRV (e.g., Kuo et al., 1999; O'Brien et al., 1986; Sinnreich et al., 1998; Voss et al., 2012). Age also is associated with a number of more firmly established CVD risk factors, including hypertension, heart disease, hypercholesterolemia, diabetes or hyperglycemia, body mass index (BMI), smoking, and low levels of physical activity (Davis et al., 2011; Lakatta and Levy, 2003); these factors have been linked in turn with low HRV (Thayer and Lane, 2007). Though research on age and adult anxiety and depression has yielded mixed results, studies controlling for risk factors (e.g., sex, education, marital status, socioeconomic status) generally have shown age-related declines in anxiety and depression risk (Jorm, 2000). EF has also shown an inverse association with age in research on age-related cognitive decline (e.g., Bryan and Luszcz, 2000; reviewed in Luszcz, 2011), though the picture is somewhat clouded by variations in the definition and measurement of EF (Luszcz, 2011). One source of ambiguity is the possibility that global, age-related declines in processing speed, rather than EF specifically, might better explain patterns of cognitive aging (Salthouse, 1996). On the other hand, processing speed and efficiency may be inherent to the EF construct (e.g., Albinet et al., 2012; Borella et al., 2011).

1.4. Aims and hypotheses

In a large, nonclinical adult sample spanning six decades of age (30s–80s), SEM was used to examine the relationships of resting HRV to NA and EF. We sought to extend prior work by representing HRV as a continuous variable, examining anxiety and depression as indicators of a latent NA construct, and modeling EF as a latent construct reflecting three component cognitive abilities. This represents the first effort to operationalize and test theories proposing HRV as an index of individual differences in a broad set of affective and cognitive self-regulatory processes (Appelhans and Luecken, 2006; Porges, 2011; Thayer and Lane, 2009). It was hypothesized that: (1) HRV would show an inverse relationship to NA and a positive relationship to EF; (2) NA and EF would have an inverse association; and (3) controlling for other prominent CVD risk factors, age would be inversely associated with HRV, NA, and EF, and contribute, in part, to their interrelationships.

2. Materials and methods

2.1. Participants

Data were drawn from the second wave of the Midlife in the United States (MIDUS) study (MIDUS II; 2002–2006), which collected biomedical, psychosocial, cognitive, and psychophysiological data from a large, diverse sample of U.S. adults ($N = 4975$) aged 33 to 84 years. MIDUS II included 9-year follow-ups of all four subsamples in MIDUS I: (1) a national random digit dialing (RDD) sample, (2) oversamples from 5 U.S. cities, (3) siblings of participants from the RDD sample, and (4) a national RDD sample of twin pairs. In addition, MIDUS II added an African-American subsample from Milwaukee, WI. To be eligible to participate, individuals had to be non-institutionalized English-speakers