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The association of cardiac vagal control and executive functioning – Findings from the MIDUS study

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ABSTRACT

Cardiac vagal control (CVC), an index of parasympathetic contribution to cardiac regulation, has been linked to enhanced executive functioning (EF). However, findings to date have been based on small or unique samples. Additionally, previous studies assessed the CVC–EF link only during rest or recovery period from a cognitive challenge, but not during both states. In the present study, data on 817 socio-economically diverse participants were obtained from the Midlife Development in the United States (MIDUS) study. As part of this study, participants completed cognitive tests, including EF, along with laboratory-based measures of CVC during rest and following recovery from a cognitive challenge. Regression analyses adjusting for respiratory rate revealed no effect of CVC at rest or during recovery on a global index of EF. However, exploratory post-hoc analyses of the components of the global EF index revealed a significant association between faster vagal recovery and better attention-switching and response inhibition abilities, as indexed by faster reaction time to the mixed SGST. This association remained significant after controlling for demographic, clinical (BMI, diseases and medications altering cardiac autonomic functioning, etc.), and health behavior covariates (Beta = .148, $p = .010$). Our findings suggest that future studies may need to investigate the links of CVC to specific EF abilities, rather than global measures of EF. Additionally, our results highlight the importance of assessing CVC during both rest and recovery from a cognitive challenge. The authors discuss the putative neurobiological underpinning of this link, as well as suggestions for future basic and clinical research.

1. Introduction

Cardiac vagal control (CVC) reflects the input of the parasympathetic branch of the autonomic nervous system (ANS) to cardiac regulation. CVC is commonly measured using heart rate variability (HRV), an analysis of periodic beat-to-beat changes in heart rate that tend to aggregate in different frequency bands. The high-frequency band is thought to reflect fluctuations in vagal-cardiac traffic, and previous studies found that it correlates with CVC (Berntson et al., 1997). Enhanced CVC, as characterized by greater vagal reactivity and faster vagal recovery from psychological stressors, has been linked with greater ANS flexibility and an improved ability to respond to stressors (Sloan et al., 1994; Thayer and Fischer, 2009) and return to homeostasis (McEwen, 2000; Mezzacappa et al., 2001). Similarly, evidence suggests that low levels of resting CVC are associated with impaired self-regulation in both children and adults (Beauchaine, 2001; Calkins et al., 2007). Thus, CVC is an important target of investigation as it contributes to self-regulation, organization of physiological resources, and response selection in the face of challenges (McEwen, 2000).

Consistent with this view, in healthy adults greater CVC has been associated with enhanced executive functioning (EF), as well as better attention, working memory, and processing speed. In

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particular, Hansen et al. (2003) reported that among 51 male navy sailors divided to High vs. Low resting CVC (as indexed by HRV), individuals with higher CVC displayed better working memory, faster reaction time, more correct responses, and fewer attention errors. This pattern was evident only for components of the task where EF was involved. In an elegant follow-up study of 37 male sailors, CVC as indexed by HRV was found to increase with fitness training and decrease when the physical training was discontinued, with changes in cognitive performance correlating with the HRV fitness-related changes (Hansen et al., 2004). A number of other small-sample studies reported similar results, linking CVC (as indexed by HRV) to working memory, EF, and attention control (Albinet et al., 2010; Hansen et al., 2009; Schellekens et al., 2000; Middleton et al., 1999; Vincent et al., 1996). However, these findings are not universal – a large study of 5375 middle-age adults did not find associations between CVC and cognitive functioning, including EF (Britton et al., 2008). This inconsistency in findings may be due to different cognitive domains and/or different aspects of EF being assessed, a point acknowledged by Britton et al. (2008). Another explanation may be rooted in that previous studies have typically examined CVC during either rest or recovery from a cognitive challenge, but not during both.

While a number of studies support the link between higher CVC and performance on EF tasks, most studies to date have examined relatively small samples or participants with distinct backgrounds (i.e., highly-trained military personnel), bringing into question the generalizability of the findings. The only large-sample study published to date included individuals from relatively narrow occupational and SES backgrounds. This sample had relatively limited representation of low SES participants (Britton et al., 2008), an important limitation as we have previously reported that CVC at rest is associated with SES (Sloan et al., 2005). Additionally, Britton et al. (2008) assessed CVC during rest only, and did not evaluate the potential impact of medications on CVC. To the best of our knowledge, no study to date has investigated the link between EF and CVC at rest and in response to recovery from a cognitive challenge in a large representative sample. Thus, our primary aims are 1) to assess the putative link between CVC and EF in a large, socioeconomically diverse sample representative of the general population; and 2) to examine whether EF performance is differentially associated with CVC at rest vs. during the subsequent recovery period.

2. Materials and methods

2.1. Participants

Data on 817 participants were obtained from The Midlife Development in the U.S. (MIDUS), a study of the behavioral, psychological, and social factors accounting for age-related variations in health and well-being in a national sample of middle-age Americans. The data for the current study are from the second wave of MIDUS II, a 9-year follow-up of the MIDUS I cohort. MIDUS II included five large studies that were separated in time. Assessments of EF and the CVC were parts of two different studies (the Cognitive Project and the Biomarker Project, respectively). Participants first completed the EF assessments (Cognitive Project) and then, after a time lag (1–61 months; average 24.18 +/− 14.09 months), took part in the CVC assessment (Biomarker Project).

2.2. Procedures and measures

2.2.1. Assessments of executive function and the Psychophysiology Protocol

The entire MIDUS II cognitive battery was administered in a telephone interview; a detailed description of the interview process is available elsewhere (Lachman and Tun, 2008; Lachman et al., 2009; Tun and Lachman, 2008). EF was evaluated based on the EF factor previously derived (Lachman et al., 2010) from the Brief Test of Adult Cognition (BTACT) and Stop & Go Switch Task (SGST, a subtest within the BTACT; Lachman and Tun, 2008; Lachman et al., 2009; Tun and Lachman, 2006). Briefly, this factor included backward counting (speed of processing), backward digit span (working memory), category fluency (verbal ability and speed), number series (fluid intelligence/reasoning) tasks from the BTACT, and the task-switching test from the SGST. SGST is a dual EF test that includes two single-task blocks and a mixed-task block that requires alternating between two tasks, engaging key executive control functions of attention-switching and inhibitory control. In the single-task blocks, participants give a verbal response as quickly as possible to the stimulus words "RED" and "GREEN"; the first block follows a "NORMAL" (congruent) response rule (say "STOP" to "RED", and "GO" to "GREEN"), then the second block follows a "REVERSE" (incongruent) response rule (say "GO" to "RED", and "STOP" to "GREEN"). In the mixed-task block, the cues "NORMAL" and "REVERSE" are given at unpredictable intervals, requiring the participant to switch between the congruent and incongruent response rules midway through the block. The mixed SGST task requires EF of both attention-switching and inhibitory control, and it is indexed by the average of the switch & non-switch trials (Tun and Lachman, 2008). While BTACT provided accuracy measures only, SGST provided both accuracy and latency (e.g., reaction time in ms) measures. For the computation of EF factor, attention-switching/response inhibition time was multiplied by −1 to indicate greater values represent faster response time. To demonstrate that the participant adequately understood and engaged in the task, a minimum of 75% task accuracy was required for inclusion of data.

The Psychophysiology Protocol was administered in the morning after a light breakfast with no caffeinated beverages. ECG electrodes were placed on the left and right shoulders, and in the left lower quadrant. Respiration bands were put on chest and abdomen. The participant was seated, and a keypad for responding to the stress tasks was secured in a comfortable position relative to the dominant hand. The stressors used included a mental arithmetic task (Turner et al., 1986) and the Stroop color–word conflict task. Importantly, these tasks were used only as a stressor, not as an EF measure. Both stressors were computer-administered and their order was counterbalanced. After receiving the instructions, participants practiced the stressor tasks. Next, there were a first calibration period (up to 10 min), checking signal quality (up to 10 min), and a second calibration period (up to 4.67 min). Next, the baseline functioning was measured for 11 min, followed by the first stressor, a recovery period, the second stressor, and the second recovery period. All stressor and recovery periods lasted 6 min (see Fig. 1).

CVC was evaluated using high-frequency (HF) power of HRV (Berntson et al., 1997). Following previously reported procedures (Shcheslavskaya et al., 2010), analog ECG signals were digitized at 500 Hz by a National Instruments A/D board and passed to a microcomputer for collection. The ECG waveform was submitted to an R-wave detection routine implemented by proprietary event detection software, resulting in an RR interval series. Errors in marking R-waves were corrected interactively following established procedures (Dykes et al., 1986). Natural log transformation was performed prior to the analysis. Chest and abdominal respiration signals were submitted to proprietary software that produced minute-by-minute means of respiratory rate (Crowley et al., 2011; Sloan et al., 2001).

2.2.2. Assessment of cardiac vagal control at rest and recovery

To obtain stable response estimates for each period (e.g., rest, challenge, recovery), and to enhance the reliability of our findings,