Biological Psychology 107 (2015) 69–75

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

The association between heart rate reactivity and fluid intelligence in children

Yu Gao[a,b,*], Deborah Borlam[a], Wei Zhang[b]

[a] Department of Psychology, Brooklyn College of the City University of New York, Brooklyn, NY, United States
[b] The Graduate Center of the City University of New York, New York, NY, United States

ARTICLE INFO

Article history:
Received 29 August 2014
Accepted 7 March 2015
Available online 14 March 2015

Keywords:
Heart rate
Respiratory sinus arrhythmia
Fluid intelligence
Child

ABSTRACT

This study aimed to examine (a) whether findings of increased cardiovascular reactivity in relation to cognitive ability seen in infants, young adults and the elderly can be extended to middle childhood and (b) which specific aspect(s) of intelligence is related to cardiovascular reactivity. We examined cardiovascular activity in 340 8- and 9-year-old children during a number judgment task and measured fluid and crystallized IQ using the WISC-IV (Wechsler, 2003). Regression analyses revealed that heart rate (HR) reactivity was positively associated with fluid intelligence and perceptual reasoning in particular, after controlling for the effects of sex, age, task performance, social adversity, and resting HR. Intelligence scores were not associated with respiratory sinus arrhythmia (RSA) reactivity. Findings are consistent with prior literature in infants and older populations and for the first time suggest that the association between HR reactivity and cognitive ability is specific for fluid reasoning.

1. Introduction

The association between cardiovascular reactivity and cognitive ability has received scant attention (see review by Ginty, Phillips, Der, Deary, & Carroll, 2011a, 2011b). Furthermore, the literature is conducted mostly with adults and infants, and few studies focus on typically developing elementary school-aged children. For example, Backs and Seljos (1994) administered to 24 participants (12 female, 12 male, mean age = 22 years) a continuous memory task varying in memory load (one or three items) and temporal demand (inter-stimulus interval of 2, 3, or 4 s), and found that as memory load and temporal demand increased, good performers, those whose error rate was below the median of the sample, had a smaller decrease in heart period, while poor performers, those whose error rate exceeded the median of the sample, had a larger decrease in heart period. In another study, Wright, Kunz-Ebrecht, Iliffee, Foese, and Steptoe (2005) administered two standardized verbal paired-associates recall tasks and a Matrix Reasoning task to 139 participants (ages 65–80 years), and measured heart rate (HR) before, during, and after each task. They found that greater memory in the verbal paired-associates task was related to more effective post-task recovery of HR.

Recently, Ginty et al. (2011a) in a sample of 1647 participants, ages 24, 44, and 63, measured HR before, during, and after the paced auditory serial addition test (PASAT). In the PASAT, participants heard a series of single-digit numbers and were instructed to add sequential number pairs while keeping the second number of the pair in memory to add to the next number. HR reactivity was calculated as the difference between baseline HR and HR during the PASAT. They found that higher HR reactivity was correlated with a higher IQ score assessed five and 12 years later and less of a decline between follow-up assessments. In another report, Ginty et al. (2011b) linked general intelligence, simple reaction time, and subsequent cardiovascular reactivity in 409 55-year-olds with HR reactions to an acute mental arithmetic task 7 years later. They found that low HR reactivity was characteristic of those with relatively low cognitive ability. Taken together, the researchers concluded that the low HR reactivity–low cognitive ability association is bidirectional, and robust, because associations withheld following adjustment for a wide range of potentially confounding variables including baseline cardiovascular activity, socio-demographics, body mass index, medication status, and stress task performance (Ginty, Phillips, Roseboom, Carroll, & Derooij, 2012). Given that certain brain regions, including the striatum and ventromedial prefrontal cortex, are critically involved in

* Corresponding author at: Department of Psychology, Brooklyn College, 5401 James Hall, 2900 Bedford Avenue, Brooklyn, NY 11210, United States.
Tel.: +1 718 951 5000x6033.
E-mail addresses: yugao@brooklyn.cuny.edu (Y. Gao), deborah.borlam@gmail.com (D. Borlam), wzhang2@gc.cuny.edu (W. Zhang).

http://dx.doi.org/10.1016/j.biopsycho.2015.03.006
0301-0511/

cognitive functioning (Busato, Prins, Elshout, & Hanmaker, 2000; Dweck, 1986) and HR reactivity (Carroll, Lovallo, & Phillips, 2009; Carroll, Phillips, & Lovallo, 2011; Lovallo, 2011), it was argued that central motivational dysregulation, as supported by both regions, may contribute to both cognitive ability and HR reactivity (Ginty et al., 2011a, 2011b). However, one limitation of the prior literature was that it was based on either adults (Backs & Seljos, 1994; Ginty et al., 2011a, 2011b, 2012) or infants (DeGangi, DiPietro, Greenspan, & Porges, 1991); none of the studies tested school-age children using a comprehensive battery of cognitive tests. The first goal of the present study was to build on and extend prior literature through the assessment of cardiovascular activity in relation to cognitive functioning and intelligence in typically developing school-age children from diverse ethnic backgrounds. We aimed to determine whether the same patterns of findings observed in infants and adults may also be present in children. It was predicted that large HR reactivity to a stress task would be associated with better cognitive functioning and higher IQ scores.

The second goal was to gain a better understanding of the specificity of these relationships by examining the different categories of intelligence. Intelligence is a multifaceted construct, and it reflects a variety of measurable skills. For example, fluid and crystallized intelligence have been considered by many intelligence theories as two major categories of cognitive abilities, subserved by different parts of the brain (e.g., Colom et al., 2009; see review by Blair, 2006). Fluid intelligence refers to inductive and deductive reasons, skills to solve new problems on the spot and the ability to learn new things (Cattell, 1971), and it is thought to be largely influenced by neurological and biological factors; crystallized intelligence refers to knowledge and skills that one accumulated by applying one's fluid ability in different areas (Cattell, 1971), and it is primarily influenced by environmental and sociocultural factors (e.g., Rindermann, Flores-Mendoza, & Mansur-Alves, 2010).

Findings from both imaging research and clinical neuropsychological research have linked the prefrontal cortex (PFC) with fluid intelligence. In addition, neural circuitry including the superior parietal temporal and occipital cortex, and subcortical regions such as the striatum are also involved (Crone et al., 2009; Duncan et al., 2000; Gray, Chabris, & Braver, 2003; Jung & Haier, 2007; Lee et al., 2006; Olesen, Westerberg, & Klingberg, 2004). In contrast, crystallized intelligence has been found to be much less affected by the damage to PFC (Waltz et al., 1999). Meanwhile, research has shown that complex and interconnected cortical and subcortical regions including the medial PFC, insular, anterior cingulate, amygdala, striatum, and the cerebellum, are involved in HR reactivity (Carroll et al., 2009, 2011; Critchley, 2003; Critchley, Corfield, Chandler, Mathias, & Dolan, 2000; Critchley et al., 2003; Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Gianaros, Van Der Veen, & Jennings, 2004; Lovallo, 2011; Wong, Masse, Kimmerly, Menon, & Shoemaker, 2007). Taken together, it was expected that increased HR reactivity would be strongly associated with fluid but not crystallized intelligence.

Another cardiovascular measure that has been correlated with cognitive functioning is respiratory sinus arrhythmia (RSA). In contrast to HR, which is influenced by both the sympathetic and parasympathetic nervous systems, RSA is a measure of parasympathetic nervous system-linked cardiac activity, and reflects the variability of HR across the respiration cycle due to the influence of the vagus nerve on the sinoatrial node (SA) (Beauchaine, 2001; Grossman, Van Beek, & Wientjes, 1990). RSA typically decreases (e.g., RSA suppression) during stressors and engagements that require increases in attention, and this process reflects the ability to maintain the internal homeostatic balance in responses to stressors and to sustain attention to the changes in the environment (Porges, 1991). Typically, change in RSA from baseline to task is described as RSA reactivity, with low reactivity indicating smaller than average decreases (or even augmentation) in RSA from baseline, and large reactivity indicating greater than average decreases (withdrawal) in RSA. Low RSA reactivity is proposed to reflect inactive engagement and ineffectively coping with stressors (Beauchaine, 2001; Porges, 2007), whereas large RSA reactivity is postulated to be associated with better cognitive performance and higher intelligence. Since HR is greatly influenced by both sympathetic and parasympathetic nervous systems (Beauchaine, 2001) whereas RSA is an index of parasympathetic functioning, examining RSA in relation to intelligence will help us determine the predominant driving factor for the intelligence–HR reactivity association.

Findings from empirical studies on the relationship between RSA and cognitive performance are mixed. DeGangi et al. (1991) measured the RSA of 35 infants during sensory and cognitive challenges, and found that greater decreases of RSA during mental testing were related to higher functional levels. Duschek, Muckenthaler, Werner, and Reyes del Paso (2009) reported a trend toward better attention capacity in individuals with stronger decreases in RSA in 60 college students. In contrast, Staton, El Sheikh, and Buckhalt (2009) failed to find a significant relationship between RSA reactivity and cognitive performance on a set of standardized tests examining fluid intelligence (e.g., working memory and cognitive efficiency) in a group of elementary school-age children.

In the current study, three hundred and forty 8–9-year old boys and girls from the community were administered a number judgment task while HR and RSA were assessed at rest and during the task. In this task, children determined if the number on the screen was higher or lower in value than the previous one, and it was expected that the task performance would be associated with fluid intelligence scores. Children's intelligence was assessed using four subtests of the Wechsler Intelligence Scale for Children (WISC), the most widely used intelligence and neuropsychological assessment in children. Based on prior literature, it was hypothesized that large HR reactivity would be associated with better cognitive performance and higher IQ scores, and these associations would be specific to fluid intelligence. Due to mixed findings, we did not form any specific hypothesis on the relationship between RSA reactivity and IQ scores.

2. Method

2.1. Participants

Data were collected as part of the Healthy Childhood Study, an ongoing longitudinal study examining the development of behavioral problems in middle childhood. The sample consisted of 8- and 9-year old boys and girls (mean age = 9.06, *SD* = 0.60) living in Brooklyn, New York. Within the study area, fliers soliciting enrollment were placed in recreation centers, libraries, churches, and other community centers. Targeted mailings were also sent to parents of 8–9-year-old children living in the geographic catchment area. Children with a diagnosed psychiatric disorder, intellectual disability, or a pervasive developmental disorder were excluded. The initial sample consisted of 340 subjects, 164 of whom were male (48.2%), with ethnic breakdown as follows: 11% Hispanic, 21% Caucasian, 52% Black, 2% Asian, and the remaining 14% of mixed/other. Compared to the ethnic distribution in the Kings County or New York population (http://quickfacts.census.gov/qfd/states/36000.html), our sample consisted of more African Americans and people with more than one race.

Caregiver participants were primarily biological mothers of the children (86.4%), although other relatives were also interviewed, including biological fathers (10.8%), or other relatives (2.8%). Fifty-nine percent of the children were living with both biological parents and 29% were living alone with their biological mother. Among the remaining families in which the biological parents were not living together (because of separation, divorce, or death of the parent), the majority of these (9%) were remarried to a partner at the time of testing. Thus, the majority of the children lived in two-parent households, although 2% of the children did live in a single-parent household with no other adult in the home. The remainder of the children (1%) resided with a single parent as well as one or more other adults (mostly grandparents).

Median family income was $43,200, which is slightly lower than the median income in Kings County (average median = $45,215) of the state of New York between 2008 and 2012 (http://quickfacts.census.gov/qfd/states/36/36047.html). Maternal and paternal education levels, measured as years of schooling, were