



Heart rate variability is associated with emotion recognition: Direct evidence for a relationship between the autonomic nervous system and social cognition

Daniel S. Quintana^{a,b}, Adam J. Guastella^b, Tim Outhred^a, Ian B. Hickie^b, Andrew H. Kemp^{a,c,*}

^a SCAN Research & Teaching Unit, School of Psychology, University of Sydney, Australia

^b Brain and Mind Research Institute, University of Sydney, Australia

^c CADE Clinic, Discipline of Psychiatry, Sydney Medical School, University of Sydney, Australia

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ABSTRACT

It is well established that heart rate variability (HRV) plays an important role in social communication. Polyvagal theory suggests that HRV may provide a sensitive marker of one's ability to respond and recognize social cues. The aim of the present study was to directly test this hypothesis. Resting-state HRV was collected and performance on the Reading the Mind in the Eyes Test was assessed in 65 volunteers. HRV was positively associated with performance on this emotion recognition task confirming our hypothesis and these findings were retained after controlling for a variety of confounding variables known to influence HRV – sex, BMI, smoking habits, physical activity levels, depression, anxiety, and stress. Our data suggests that increased HRV may provide a novel marker of one's ability to recognize emotions in humans. Implications for understanding the biological basis of emotion recognition, and social impairment in humans are discussed.

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1. Introduction

Impairments in the ability to understand and interpret social information are commonly observed in a variety of psychopathologies including; major depressive disorder (MDD), autism spectrum disorders (ASD), and alcohol use disorders (Baron-Cohen et al., 2000; Demenescu et al., 2010; Hasin et al., 2007). The perception, interpretation and generation of responses to the intention, dispositions and behaviors of others are known as social cognition (Green et al., 2008), and deficits in these processes may underpin social impairment. The recognition of facial expressions and the ability to infer the likely mental states of other people are an important feature of social cognition and this ability may predict functional social capacity beyond more traditional neurocognitive assessments that index working memory, psychomotor speed, and attention (Bora et al., 2006). While research on the biological basis of social cognition has highlighted the importance of neural circuitry in the medial frontal cortex (Amodio and Frith, 2006), theories also propose a role for the autonomic nervous system (Appelhans and Luecken, 2006). This study aims to directly test the hypothesis that HRV is related to social cognition.

Porges' polyvagal theory (Porges, 2007) proposes that the mammalian autonomic nervous system (ANS) has evolved to support the survival, reproduction and social engagement of the species. An important feature of this theory is the bidirectional influence of the brain on the body (through the nucleus ambiguus) and the body on brain (via afferent feedback to the nucleus tractus solitarius). The most recent development of the human ANS in our phylogenetic history is the myelinated vagus nerve, which facilitates engagement with the environment through its inhibitory influence on the sinoatrial node (i.e., the heart's pacemaker). When an individual is threatened, vagal tone is inhibited, triggering a suite of responses that promotes survival (e.g., increased blood flow to the limbs). By contrast, when the surrounding environment is deemed safe, the "vagal brake" is applied, promoting social behavior and homeostatic functions. The application of the vagal brake slows the heart rate (due to tonic vagal influences on the sinoatrial node), encouraging social interaction. Poor control of the vagal brake may hinder social interaction, as survival behaviors increase sympathetic nervous system's activity. The polyvagal theory proposes that optimal social interaction, which includes the recognition of emotion in faces, is facilitated by a calm physiological state (Porges, 2003). Thus, efficient control of the vagal brake and the ANS allows for rapid engagement and disengagement with others.

ANS function can be indexed non-invasively by heart rate variability (HRV), a measure of beat-to-beat temporal changes in the heart rate. High frequency (HF) HRV represents a rhythmic fluctuation of the heart rate in the respiratory frequency band and has been demonstrated

* Corresponding author at: School of Psychology, Brennan MacCallum Building (A18), The University of Sydney, NSW 2006, Australia. Tel.: +61 2 9351 7585; fax: +61 2 9036 5223.

E-mail address: andrew.kemp@sydney.edu.au (A.H. Kemp).

to be an index of parasympathetic control and vagal tone (Berntson et al., 1997). A number of studies have reported reduced HRV in a range of psychiatric illnesses including depression, anxiety, and alcohol use disorders (Kemp et al., 2010, 2012a; Ingjaldsson et al., 2003; Quintana et al., in press-b). As reduced HRV is an index of poor ANS regulation, it may also contribute to the poor social relationships that have been reported in these psychiatric illnesses (Baron-Cohen et al., 2000; Demenescu et al., 2010; Hasin et al., 2007). Prior research has provided some support for this proposal; studies on children with autism have reported poor ANS function, indexed by HRV, relative to those without ASDs (Van Hecke et al., 2009). However, only one study has suggested a relationship between HRV and emotion recognition. In that study, ASD children with low HRV were slower in recognizing emotions in comparison to ASD counterparts with high HRV (Bal et al., 2010). The Reading the Mind in the Eyes Test (RMET; Baron-Cohen et al., 2001) has been used to index emotion recognition aptitude. This test requires participants to determine what someone is thinking or feeling based on images of the eye region. Poor performance in the RMET has been associated with a number of disorders including autism (Baron-Cohen et al., 2001) and depression (Lee et al., 2005) suggesting that emotion recognition may play a role in the etiology and maintenance of these disorders. The use of this test has also been extended to healthy populations (Domes et al., 2007).

To date, the relationship between emotion recognition and HRV has not been examined in healthy adult participants. The aim of the present study therefore was to examine the relationship between HRV and social cognition, indexed by performance on the RMET, in healthy adult participants taking into consideration other factors that have been demonstrated to influence HRV: sex (Ryan et al., 1994; Sztajzel et al., 2008), BMI (Karason et al., 1999), smoking habits, (Hayano et al., 1990) physical activity (Rossy and Thayer, 1998), depression (Kemp et al., 2010, 2012a), anxiety (Thayer et al., 1996), and stress (Dishman et al., 2000). We hypothesized that HF HRV would be positively associated with emotion recognition accuracy as operationalized by the RMET.

2. Materials and methods

2.1. Participants

Sixty-five volunteers (35 females, 30 males; mean age \pm SD, 20.91 \pm 6.16) were recruited from a pool of undergraduate students. Participants received university course credit for their participation and gave written informed consent in accordance with Australian National Health and Medical Research Council guidelines. The University of Sydney Human Research Ethics Committee provided ethical approval for this research (Protocol Number 02–2011/13368). Exclusion criteria included a self-reported history of psychiatric illness or any other serious medical condition (e.g., diabetes; cardiovascular disease). Participants were also excluded if they reported current use of antidepressants. In order to prevent any confounding influences of other substances on psychophysiological functioning, participants were asked to abstain from caffeine, cigarettes, alcohol and illicit substances on the day of testing.

2.2. Instruments

Participants completed the RMET (Baron-Cohen et al., 2001) in order to index emotion recognition aptitude. Participants are presented with 36 images of the eye region of different faces, provided four options for each image (e.g., playful) and are instructed that they should answer each response as quickly as possible. We note that the RMET was originally developed to measure social cognition in adults with autism spectrum disorders (Baron-Cohen et al., 2001) and that prior research has shown that university students perform at ceiling levels on the easy items of this test (Baron-Cohen et al.,

2001; Domes et al., 2007). Consequently, we calculated a score weighted for difficulty (RMET_{diff}) based on performance norms in university students (Baron-Cohen et al., 2001). Items that are more difficult were given more weighting than easy items. For example, 8.7% of the university students provided an incorrect response for item 9 of the RMET – the easiest item – thus we multiplied item 1 scores by 1.087. In contrast, item 19 (the hardest item) was multiplied by 1.417 to reflect its difficulty as 41.7% of the university students incorrectly respond to this item (Baron-Cohen et al., 2001). This approach is analogous to previous research that has divided the RMET into easy and difficult items (Domes et al., 2007; Guastella et al., 2010), but takes into account responses on all items.

Additional questionnaires completed by participants included the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) and the Depression Anxiety and Stress scales (DASS-21; Lovibond and Lovibond, 1995). The IPAQ is a 9-item questionnaire that assesses the energy cost of physical activities by calculating a Metabolic Equivalent Task (MET) score. In this questionnaire participants are asked how much time they devote to physical activities over a range of intensities. In a 12-country validation study, the IPAQ demonstrated acceptable levels of criterion validity (Spearman's p of 0.30) and repeatability (Spearman's p of 0.76; Craig et al., 2003). The DASS is a 21-item questionnaire that comprises three subscales indexing depression, anxiety and stress, which have demonstrated Cronbach's alphas of .94, .87, and .91 respectively (Antony et al., 1998).

Interbeat intervals (IBI) were measured for 5 min via the Polar RS800CX (Polar Electro Oy, Kempele, Finland) heart rate monitoring system at 1000 Hz, which wirelessly receives HR data from a chest-strap (two-lead) worn by participants. Although there has been some debate regarding the validity of Polar monitors to measure R–R intervals (Quintana et al., in press-a; Wallén et al., 2012), research has demonstrated that Polar monitors can be used interchangeably with ECGs in healthy volunteers (Weippert et al., 2010). In their study, Weippert et al. (2010) recorded R–R intervals using a Polar monitor and an ECG simultaneously. Intra-class correlation coefficients and the Bland–Altman limits of agreement method demonstrated excellent agreement between the Polar monitor and ECG.

2.3. Procedure

All participants were tested in the morning (0900–1200 h). Participants completed a questionnaire that measured demographic information, along with the IPAQ and DASS and the RMET. Height and weight were also measured to calculate BMI. Following these tasks participant's IBIs were recorded for 5 min while they were relaxed in a seated position after a resting period of 5 min. Participants were breathing spontaneously during the recording period; respiration rate does not affect HRV in resting state recordings (Denver et al., 2007).

2.4. Data analysis

Raw data was extracted as a text file and imported into Kubios (version 2.0, 2008, Biosignal Analysis And Medical Imaging Group, University of Kuopio, Finland, MATLAB). Samples were filtered with the low automatic filter and visually inspected for artifacts by a single investigator (DSQ); data quality was high, consistent with resting-state recording conditions. Kubios was then used to calculate HF HRV (0.15–0.4 Hz; normalized units) using the Fast Fourier transform. As the total power of the spectral signal is heterogeneous from person to person, it has been recommended that HF data should be presented as normalized values (Pagani et al., 1986). The HF band of frequency domain is influenced almost exclusively by parasympathetic activity and has been argued to be an index of vagal tone (Akselrod et al., 1981; Lane et al., 2009). In addition, HF HRV is largely unaffected by sympathetic blockade by propranolol (Berger et al., 1989) indicating that HF reflects a valid index of parasympathetic

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