



## Resting parietal EEG asymmetry and cardiac vagal tone predict attentional control



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### ARTICLE INFO

#### Article history:

Received 4 April 2012

Accepted 12 February 2013

Available online 28 February 2013

#### Keywords:

Attentional control  
Parietal EEG asymmetry  
Vagal tone

### ABSTRACT

The present study explores both resting cortical EEG asymmetry and vagally-mediated heart rate variability (HRV), as an index for vagal tone, as physiological correlates of self-reported attentional control in a sample of 53 healthy young adults. Regression analyses indicate that higher vagally-mediated HRV and lower right-sided parietal activity in the  $\beta_2$  frequency range (20–30 Hz) are significant predictors of larger attentional control. Results are in line with some of the basic features of the neurovisceral integration model and stress the role of parietal areas in attentional control capabilities, thus aiming to consider attentional control as a trait-like disposition.

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### 1. Introduction

Attentional control refers to the cognitive ability to regulate attentional allocation and is considered a key component for effective emotion regulation. In fact, low attentional control and/or difficulties in disengaging attention have been linked to increased self-focused emotion regulation strategies such as perseverative thinking (Armstrong et al., 2011; Koster et al., 2011). Further, attentional control has been reported to moderate the relationship between negative affectivity and anxious and depressive symptomatology (Sportel et al., 2011) and also between negative affectivity and an attentional bias to threatening stimuli (Derryberry and Reed, 2002; Helzer et al., 2009; Lonigan and Vasey, 2009). Recent studies using non-emotionally laden tasks (Bishop, 2009; Moriya and Tanno, 2009; Pacheco-Unguetti et al., 2010, 2011) have pointed out that attentional biases in anxiety could reflect a much broader dysregulation of attentional control that influences general attentional processing. Therefore, if attentional control is a trait-like disposition influencing not only emotion regulation processes but also performance during non-emotional attentional tasks, it seems reasonable to think that individual differences in self-reported attentional control could be reflected in specific patterns of resting cardiac and EEG activity.

According to the neurovisceral integration model (Thayer et al., 2012; Thayer and Lane, 2000, 2009) and related theories (i.e. Beauchaine, 2001; Friedman, 2007; Porges, 1992, 1995, 2007), heart rate variability (HRV) can be considered as a marker for dynamic regulation of autonomic activity.

Variability of heart rate is primarily mediated by the two branches of the autonomic nervous system (sympathetic and parasympathetic), which keep the degree of HRV relatively high. From a dynamical systems perspective, variability in biological systems is thought to be important because phase transitions often occur at certain critical values when variability is high. Previous works have shown that vagal influences on cardiac control are much faster than sympathetic influences (Thayer and Lane, 2000). Thus, when fast vagal modulation is decreased, the ability to organize an appropriate response according to environmental demands worsens, and this might involve both a less adequate response and a reduced capacity to sustain attention to task-relevant stimuli, in parallel with an HRV reduction in the time domain.

Resting HRV (and also state and phasic), has been associated with emotion regulation capabilities and also with several cognitive processes, such as attention modulation. These are considered to underlie emotional regulation, as they are necessary to flexibly respond to a changing context. For instance, high resting HRV facilitates orienting response and maintains sustained attention toward discrete stimuli, which is critical to adequately respond to environmental demands. In line with these claims (e.g. Appelhans and Luecken, 2006; Thayer and Brosschot, 2005), positive associations between low resting HRV, reduced emotion regulation capabilities and poor attentional control have been reported.

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However, research about how HRV is related to attentional control has mostly been conducted under a laboratory conditions where HRV measures are taken prior to, during, and after an experimental attentional task (e.g. during a continuous performance task, see Hansen et al., 2009, or during a Stroop test, see Johnsen et al., 2003). In this way, researchers can study the predictive power of HRV on task performance as well as changes in HRV that could be induced by the task itself and/or by emotions related to task performance (e.g. vagal tone suppression).

In addition to this widely used study design, where on-line attentional processes are the main aim of the study, attentional control can also be understood as a trait-like disposition and can thus be evaluated through questionnaires; we call this “self-reported attentional control”. To our knowledge, only one study to date has considered the associations between self-reported attentional control and resting HRV (Healy, 2010). Healy assessed HRV at rest and used a questionnaire (the Attentional Control Scale, Derryberry and Reed, 2002) to evaluate the participants’ self-reported attentional control, without including any experimental task. He reported a positive association between vagally-mediated HRV at rest and self-reported attentional control in healthy undergraduate students: higher vagal tone was related with higher self-reported scores in attentional control. A similar questionnaire and design were used in the present study.

Moreover, research involving cardiac responses and attentional control can be enriched by introducing measures of brain activity. Heart and the brain are bidirectionally connected: the neurovisceral integration and related models consider that vagally-mediated HRV can inform about how this heart–brain system works (e.g. Thayer et al., 2012). In brief, these models consider that a poor tonic inhibition of the amygdala mainly by the medial prefrontal cortex, and in conjunction with other cortical regions, is associated with both a disinhibition of sympathoexcitatory circuits and with a predisposition to chronic threat perception (negative bias). This dysregulated central–peripheral integration results in reduced levels of complex neurogenic rhythms and lower HRV. Neuroimaging studies support this view (see the meta-analytic review by Thayer et al., 2012) and a growing body of literature (e.g. Bishop, 2007; Hartley and Phelps, 2010; Sandi and Richter-Levin, 2009) identifies the amygdala–prefrontal circuit to underlie several forms of emotion regulation, conditions of fear, and attentional and interpretative biases. That is, impoverished prefrontal cortex functioning has been found to be associated with attentional control, which is also observed when facing non emotionally-laden tasks (e.g. Bishop, 2009).

However, the role of other brain regions, such as the parietal cortex, has also been widely reported in the study of attentional and executive control. For instance, Posner, Rothbart and colleagues claimed that parietal brain areas are critically involved in attentional capabilities (Posner and Rothbart, 2009; Posner et al., 2007). In fact, thanks to a wide variety of neural measurement techniques, the importance of parietal regions in attentional control has been recognized. Interestingly, several works have reported right-sided lateralized activity to be related with impaired attentional capabilities (e.g. Kanai et al., 2011; Kanwisher and Wojciulik, 2000; Li et al., 2010; Mevorach et al., 2006, 2009; Wojciulik and Kanwisher, 1999).

The EEG-based research has also shown parietal (and other regions’) beta band power (13–30 Hz) to be associated with attentional processes (e.g. Deiber et al., 2007; Barry et al., 2007; Schutter et al., 2001). For instance, the study by Schutter et al. (2001) found that an increased parietal right-sided beta activity at baseline was associated with a larger number of avoidant responses to angry facial expressions. More recently, Stewart et al. (2011), in their study on EEG asymmetry and major depressive disorder, stated that research on that topic had basically been focused on the prefrontal

and anterior cingulate cortices, and that the parietal cortex was also involved in the attentional and executive deficits observed in depression.

To our knowledge, very few studies have simultaneously explored the potential associations of both EEG asymmetries and cardiac responses with attentional processes, and none has to date focused on parietal asymmetries. Hofmann et al. (2005), simultaneously measured frontal EEG asymmetry and autonomic responses during the experimental induction of worry, a form of repetitive negative thinking that has been related to enhanced attentional engagement with threat and/or impaired attentional disengagement from it (e.g. Cisler and Koster, 2010; Hirsch et al., 2011). The authors recorded frontal EEG activity, heart rate, respiratory sinus arrhythmia (the degree of ebbing and flowing of heart rate during the respiratory cycle that results from increases in vagal efference during exhalation, which decelerate heart rate, and decreases in vagal efference during inhalation, which accelerate heart rate), and skin conductance level during a relaxation phase, during worrying, and during varying degrees of threat imminence. Their findings suggest that worrying is associated with higher left frontal brain asymmetry, a lower cardiac vagal tone, and larger electrodermal activity, when compared with fearful anticipation. The authors interpreted that worrying is not a mere state of fearful anticipation and thus differs from fearful activation in its degree of threat impending. This is consistent with evidence that shows different types of anxiety to be associated with distinct physiological markers.

Miskovic and Schmidt (2010) studied the influences of the central and peripheral nervous system on attentional bias to threatening faces. They found that frontal right EEG alpha asymmetry and low vagal tone, taken together, predicted up to 37% of the variability in attentional bias (vigilance) for angry faces. Interestingly, frontal EEG asymmetry and vagally-mediated HRV were not significantly correlated. Their results provided preliminary evidence that two well-established psychophysiological trait-like markers predict biased attention toward social threat.

To date, no previous work has examined the simultaneous association between asymmetrical parietal EEG activity and vagally-mediated HRV (both at rest) with self-reported trait-like attentional control. The purpose of the current study was to investigate how these cortical and autonomic outputs are associated to self-reported attentional control.

Based on the literature reviewed and the rationale described above, it was hypothesized that vagally-mediated HRV at rest, right-sided frontal asymmetry as indexed by higher beta band power (both in beta 1 (13–20 Hz) and beta 2 (20–30 Hz)), and right-sided parietal asymmetry also indexed by higher beta band (both in beta 1 (13–20 Hz) and beta 2 (20–30 Hz)), independently as well as taken together, would predict a significant amount of the variability in self-reported attentional control.

## 2. Methods

### 2.1. Participants

Eighty-three undergraduate students gave written consent for neurophysiological recording at the Neurodynamics and Clinical Psychology Laboratory. All procedures performed were approved by the Bioethics Committee of the University. Participants were asked to inform about neurological, psychiatric, and cardiovascular disorders, and medical conditions such as diabetes. One participant was excluded due to a history of epilepsy. All participants were asked to refrain the consumption of alcohol, drug use, and caffeinated beverages from four hours until participation in the study. Regarding EEG analyses, ten subjects were excluded because impedance criteria (see below) were not met. Nine participants were excluded due to the presence of too many artifacts (changes in voltage larger than 100  $\mu$ V). To maintain consistency across the data, five left-handed participants were not included in this study. After excluding the above-mentioned participants, EEG recordings from 58 right-handed subjects proved to be valid for analyses. For heart rate analyses, ECG signals from eight participants were excluded due to

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