



Anxiety, attention, and decision making: The moderating role of heart rate variability



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ABSTRACT

The current exploratory research examined whether high frequency heart rate variability (HF-HRV) modulates the association between anxiety and (1) executive attentional control during situations involving neutral stimuli, in which the distractor stimuli are in conflict with the target stimulus, and (2) risk aversion in decision making. Forty-five participants (21 with low and 24 with high trait-anxiety) performed a modified version of the Attention Network Test to measure attentional control, and the Balloon Analog Risk Task to measure risk aversion. HF-HRV was recorded during a rest period before completion of the tasks. Results showed that individuals with high anxiety and low HF-HRV have worse attentional control in the face of conflicting information as well as greater risk aversion, in comparison with individuals with both high anxiety and high HF-HRV or low anxiety (regardless of HF-HRV). HF-HRV was positively associated with attentional control and negatively associated with risk aversion. Furthermore, a strong negative association was observed between attentional control and risk aversion. These results suggest that HF-HRV modulates the influence of anxiety on both attentional control to neutral stimuli, and risk aversion in decision making. Greater HF-HRV appears to fulfill a protective role in highly anxious individuals. The associations observed also suggest that executive control of attention plays a relevant role in decision making. These results support the relevance of the autonomic nervous system in sustained cognition and are in accordance with theories in which vagal-mediated heart rate variability is taken as an indicator of prefrontal cortex inhibitory influences.

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1. Introduction

Individuals with high anxiety focus their attention preferentially on negative information (MacLeod and Mathews, 1988; Mogg and Bradley, 1999), and have greater difficulty than individuals with low anxiety in disengaging attention from threatening information (see Fox et al., 2005, for a review). Several studies have emphasized the role of attentional control functions in anxiety, referred to the voluntary control exercised by the anterior attention network in situations that require the resolution of stimulus or responses to conflicts (Posner and Dehaene, 1994). Biases to potentially threatening stimuli are associated with alterations in attention control capacity (Eysenck et al., 2007). The advantage of quickly detecting hazards and responding effectively to them can become a disadvantage for anxious people, given that they activate their alert mechanisms in the face of ambiguous or negative information that is irrelevant to most individuals. This negatively affects their performance in various tasks. Moreover, recent

studies also suggest a lower attentional control in highly anxious individuals with respect to the processing of non-threatening stimuli (Pacheco-Unguetti et al., 2009, 2010; Ortega et al., 2012).

Attentional control capacity can be viewed as an effortful self-regulatory dimension (Derryberry and Reed, 2002). Effortful control constrains overly reactive emotions and plays a significant role in disengaging from threatening cues and engaging with safety ones (Park et al., 2012). According to Derryberry and Reed (2002), anxious individuals with poor effortful control exhibited attentional biases favoring threatening stimuli, whereas anxious individuals with good effortful control were capable of shifting their attention away from threatening stimuli and engaging with safety stimuli. Lonigan and Vasey (2009) also found an interaction between negative affectivity and effortful control on attentional biases favoring negative information in children. Therefore, an individual's ability to regulate the location of attention can modulate the extent to which attention is directed to either threatening (Cisler and Koster, 2010; Peers and Lawrence, 2009), or non-threatening stimuli (Ortega et al., 2012; Pacheco-Unguetti et al., 2010).

One promising physiological correlate of attentional control is heart rate variability (HRV), an index of autonomic control of the heart that is related to cardiovascular and emotional disorders (Gillie and Thayer,

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2014; Gorman and Sloan, 2000; Pittig et al., 2013). HRV reflects oscillations in the interval (ms) between consecutive heartbeats which result mainly from parasympathetic (vagal) inputs to the heart via the sinoatrial node (Berntson et al., 1997; Reyes del Paso et al., 2013). Vagal cardiac tone has been repeatedly linked to attentional and emotional control (e.g., Duschek et al., 2009, 2013; Hansen et al., 2003; Porges, 1995).

The part of the HRV spectrum more often related to vagal-mediated influences is the high frequency band (HF, from .15 to .40 Hz); the HRV is linked to respiration (i.e., respiratory sinus arrhythmia) (Berntson et al., 1997). Parasympathetic influences are essential for the successful adaptation of the organism to changing environmental demands (Porges, 1995; Reyes del Paso et al., 2009; Thayer and Lane, 2000). Reduction of vagal control (i.e., decreased HF-HRV) could indicate a lack of ability to respond flexibly to changing demands, reducing the range of possible options and thus limiting the ability of individuals to generate appropriate responses and inhibit inappropriate ones.

In accordance with the neuro-visceral integration model (Friedman, 2007; Thayer et al., 2009; Thayer and Lane, 2000) HF-HRV is taken as an index of attentional-emotional regulation that is hypothesized to be related to tonic inhibitory influences from the prefrontal cortex to sub-cortical structures. A low HF-HRV can be interpreted in this context as indicating a dysregulation of this inhibitory network, which can lead to sub-cortical disinhibition with greater arousal and a more rigid and defensive-biased attentional-cognitive pattern (Thayer et al., 2009).

A higher HF-HRV has been linked to more effective strategies for regulating emotion and attention and a faster recovery of the basal state (McEwen, 2000). A lower HF-HRV is associated with worse regulation strategies and the development of mental disorders (Thayer and Brosschot, 2005), especially anxiety (Pittig et al., 2013). According to this hypothesis, individuals with higher HF-HRV (greater vagal control) perform better on executive level, attention span, working memory, processing speed and decision making (Causse et al., 2011; Hansen et al., 2003, 2009; Quintana et al., 2012). At the emotion-regulation level, high HF-HRV is associated with a more flexible and differentiated emotion-modulated startle reflex, while individuals with lower HF-HRV tend to exhibit potentiated startle to neutral and even pleasant foregrounds, indicating aberrances in emotional processing (Ruiz-Padial et al., 2003; Ruiz-Padial and Thayer, 2014). A low HF-HRV predicts the development of post-traumatic stress disorder (PTSD) after a traumatic event, as well as greater symptom severity (Gillie and Thayer, 2014; Shaikh al arab et al., 2012). In adolescents, reduced autonomic flexibility (i.e., lower HF-HRV) predicts levels of anxiety (Greaves-Lord et al., 2010). Park et al. (2013b) found faster attentional engagement to fearful faces in lower vs. higher HF-HRV participants. Miskovic and Schmidt (2010) proved that HF-HRV (in combination with prefrontal electroencephalogram asymmetry) predicted attentional bias to social threats in healthy individuals. Nevertheless, some results do not confirm the neuro-visceral integration model (Britton et al., 2008; Drucaroff et al., 2011; Hovland et al., 2012), and recent studies have shown that there is a need to revise the theory by narrowing and circumscribing its hypothesis, in order to better capture cognitive-visceral interrelations (Jennings et al., 2015).

Some studies suggest that HF-HRV can modulate the relationship between anxiety and attention to fearful and threatening stimuli. In a study performed under flight-like conditions, Bornas et al. (2005) found that anxious individuals with a fear of flying, but with high HF-HRV, directed their attention to the task and reported similar anxiety levels as the non-anxious group. Cacia et al. (2012) also found that HF-HRV moderates the relationship between trait anxiety and disengagement bias to fearful stimuli. High anxiety participants with low HF-HRV showed disengagement bias but this was not observed in anxious participants with high HF-HRV. Melzig et al. (2009) studied the startle response elicited by the threat of receiving an electric shock in people with symptoms of panic disorder and

found that those with low HF-HRV had exaggerated startle responses relative to those with high HF-HRV.

Research on the modulatory effect of HF-HRV on cognitive bias to neutral stimuli is scarce. Using fearful and neutral faces as distractors, Park et al. (2013a) found that individuals with low HF-HRV showed difficulties in inhibiting the negative influence of both types of distractors, while in the high HF-HRV group interference was observed only from the fearful faces. In conclusion, individuals with low HF-HRV tended to concentrate more on ambiguous-threatening information, were less able to disengage attention from irrelevant stimuli, failed to recognize safety cues and showed a lower habituation rate to novel and neutral stimuli, displaying a hypervigilance-like state (Thayer et al., 2009).

Taking the above evidence together, it can be postulated that HF-HRV may modulate the relationship between trait anxiety and attentional biases. However, the available evidence about this moderating influence has been gathered using emotionally driven stimuli. To date, no study has used neutral stimuli. Thus, a relevant question that remains poorly studied and deserves further research is whether the moderating influence of HF-HRV on anxiety-related attentional biases could also be observed during tasks using neutral stimuli.

Trait anxiety may influence an individual's ability to make risky decisions. Highly anxious individuals are likely to try to avoid risk (Maner et al., 2007). Several studies describe risk avoidance patterns in anxiety (Mitte, 2007; Miu et al., 2008; Ortega et al., 2012). Because the ability to control and regulate emotions is involved in decision-making, it is relevant to consider whether HF-HRV modulates the effect of anxiety on risk avoidance, as some studies seem to suggest (Fenton-O'Creevi et al., 2012). If low HF-HRV is related to poorer emotional regulation and difficulty in controlling attention, it could be hypothesized that it is also related to higher risk avoidance. Low HF-HRV would increase the impact of anxiety on decision-making, and the conflict between risk-taking and negative assessment by the individual of what could happen, because he/she would focus more on the negative emotions anticipated to result from a poor outcome.

The aim of this study was to analyze the way HF-HRV interacts with trait anxiety to modulate how individuals inhibit distracting information in a conflict situation involving neutral stimuli, as well as their ability to take risks during decision-making. As a secondary objective, we will assess the relationships between attentional control and risk aversion in decision-making. It was hypothesized that: (1) Individuals with high trait anxiety and low HF-HRV will manifest an attentional control bias when the distractor stimuli are in conflict with the target stimulus, compared to those with high trait anxiety but high HF-HRV; (2) Individuals with high trait anxiety and low HF-HRV will exhibit greater risk avoidance than those with high trait anxiety but high HF-HRV; (3) In individuals with low trait anxiety, we hypothesize no differences as a function of HF-HRV either in the appearance of attentional bias or risk avoidance. Furthermore, these individuals would not differ from those with a high trait anxiety and high HF-HRV; and (4) greater attentional control would be associated with lower risk aversion.

2. Method

2.1. Participants

The initial sample of the study included 200 first year Psychology students. Participants were selected and assigned to one of the following two groups according to their trait anxiety scores: the low trait anxiety group (LTA), with scores below 12 ($\leq$ percentile 10) on the Trait scale of the State-Trait Anxiety Inventory (STAI-T) ($n = 21$, 11 females and 10 males), and the high trait anxiety group (HTA), with scores above 28 ($\geq$ percentile 80) on STAI-T ($n = 24$, 14 females and 10 males) (see Table 1). The Beck Depression Inventory (BDI) and the Social Desirability Scale (SDS) (see below) were used like a control

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