Biological Psychology 123 (2017) 83–93

Contents lists available at ScienceDirect

Biological Psychology

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

The moderating influence of heart rate variability on stressor-elicited change in pupillary and attentional indices of emotional processing: An eye-Tracking study

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ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form 20 October 2016
Accepted 26 November 2016
Available online 1 December 2016

Keywords:
Attentional bias
Eye-tracking
Heart rate variability
Mood induction
Pupil
Emotion regulation

ABSTRACT

Low resting heart rate variability (HRV) is associated with a broad array of negative psychosocial outcomes. Recent theoretical explications of HRV suggest it is an autonomic marker of emotion regulation capacity, but limited research has examined its relationship with emotional information processing indices. The present study utilized eye-tracking methodology to test HRV's theorized role as a marker of emotion regulation capacity in a non-clinical sample. Attentional biases towards threatening, dysphoric, and positive emotional information as well as affective modulation of pupil size were assessed before and after a stress induction. Low resting HRV marginally predicted larger increases in attentional bias towards positive emotional stimuli from pre to post-stress induction and significantly predicted decreased pupil dilation to positive stimuli after the stress induction only; exploratory analyses suggested that this pattern might reflect an unsuccessful attempt at anxious mood repair. HRV was unrelated to negative emotional information processing. Findings are consistent with existing theories of HRV's psychological significance and suggest a specific association with altered positive emotional processing under acute stress.

1. Introduction

Low parasympathetically-mediated heart rate variability (HRV) has emerged as a robust correlate of negative psychosocial outcomes across multiple domains (e.g., presence of psychopathology, poor self-regulation, decreased emotion recognition ability; Beauchaine & Thayer, 2015; Quintana, Guastella, Outhred, Hickie, & Kemp, 2012; Segerstrom & Nes, 2007). Resting HRV, a measure of the variability in an individual's beat-to-beat intervals while in a resting state, is thought to index parasympathetic influence on the heart and has been linked with psychosocial functioning in non-clinical and clinical samples (Beauchaine, 2015; Beauchaine & Thayer, 2015; Ottaviani et al., 2016). Recent reviews of the HRV literature suggest that low HRV may confer risk for poor psychosocial functioning because it is a marker of emotion dysregulation, which is implicated in most forms of psychopathology (Beauchaine, 2015; Beauchaine & Thayer, 2015). Elucidating the specific mechanisms through which low HRV operates is a critical step towards enhancing our understanding of low HRV's broad associations with negative psychosocial outcomes.

Converging evidence suggests that low HRV is associated with negative psychosocial outcomes because it is a peripheral marker of emotion dysregulation. Specifically, HRV is linked to the connectivity between the PFC and subcortical regions (Beauchaine & Thayer, 2015; Thayer, Hansen, Saus-Rose, & Johnsen, 2009) which plays an important role in adaptive emotional responses to stressors (Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). This hypothesis stems from evidence demonstrating 1) inhibitory pathways from the PFC to the parasympathetic nervous system (PNS), 2) a positive relationship between HRV and executive functioning tasks, and 3) neuroimaging evidence linking greater HRV with greater PFC functioning (see Beachaine & Thayer, 2015 and Thayer et al., 2009 for reviews). Thus, theories of the psychological significance of HRV emphasize the regulation of emotional responding (i.e., PFC-subcortical connectivity) as central to the relationship between HRV and psychopathology (e.g., Appelhans & Luecken, 2006; Beauchaine, 2015; Thayer et al., 2009), but more research is needed to understand the specific mechanisms through which HRV influences maladaptive emotional responding.

HRV may be linked with emotion dysregulation via its influence on emotional information processing. Within cognitive models

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http://dx.doi.org/10.1016/j.biopsycho.2016.11.013
0301-0511/

of affective psychopathology, information processing abnormalities are closely tied to maladaptive emotional responding (Beck & Clark, 1988). Specifically, exaggerated processing of negative emotional information and decreased processing of positive emotional information have been implicated in multiple forms of affective psychopathology (Armstrong & Olatunji, 2012). One well-established behavioral index of maladaptive emotional information processing is attention bias (MacLeod, Mathews, & Tata, 1986; Leppänen, 2006). Negative attention bias (NAB) refers to preferential attentional processing of negatively-valenced (i.e., threatening, dysphoric) relative to neutral information, whereas positive attention bias (PAB) refers to preferential processing of positively-valenced relative to neutral information. Increased NAB and decreased PAB are believed to be indices of dysfunctional corticolimbic circuitry (see Gibb, McGeary, & Beevers, 2016 for a review) and have been linked with anxiety/depressive symptoms in non-clinical and clinical samples (Armstrong & Olatunji, 2012; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007; Peckham, McHugh, & Otto, 2010). Given the putative role of corticolimbic circuitry in HRV and attention bias as well as their established associations with emotion dysregulation, low HRV may be related to increased NAB and decreased PAB.

Pupillary responding to emotional stimuli is another index of affective processing that may be associated with HRV. Specifically, stimulus-elicited pupil dilation is thought to reflect arousal and accordingly covaries with sympathetic nervous system activity, with greater increases in pupil dilation to positive and negative relative to neutral emotional stimuli (Bradley, Miccoli, Escrig, & Lang, 2008; Partala & Surakka, 2003). Moreover, multiple studies have demonstrated that pupil dilation is indicative of increased cognitive load and greater allocation of attentional resources independent of the effects of arousal (Stanners, Coulter, Sweet, & Murphy, 1979; Urry, van Reekum, Johnstone, & Davidson, 2009; van Reekum et al., 2007). Consistent with the notion that pupil dilation reflects both emotional (i.e., autonomic arousal) and cognitive (i.e., covert attentional allocation) processes, greater sustained pupil dilation to negative personally-relevant information and dysphoric facial stimuli has been positively associated with individual differences in the propensity to engage in sustained, elaborative processing of negative affect (i.e., trait rumination; Duque, Sanchez, & Vazquez, 2014; Siegle, Steinhauer, Carter, Ramel, & Thase, 2003). Likewise, with regard to pupil dilation to positive emotional information, one study found that greater pupil dilation to high-reward food stimuli was significantly correlated with state food craving (Graham, Hoover, Ceballos, & Komogortsev, 2011), which has been conceptualized as a form of elaborative cognitive processing of reward cues (May, Andrade, Kavanagh, & Hetherington, 2012). Taken together, these data suggest that pupil dilation to emotional stimuli is indicative of sustained allocation of cognitive resources as well as autonomic arousal, and may, as with attention bias, at least partially reflect neural activity in prefrontal regions implicated in emotion regulation (e.g., Siegle, Steinhauer, Friedman, Thompson, & Thase, 2011). As such, resting HRV may be associated with pupillary responding to emotional information.

To our knowledge, no studies to date have investigated if HRV is associated with either attention bias or pupil dilation. However, there is indirect evidence to suggest a relationship between these indices of emotional processing and HRV. For instance, a number of studies have found low HRV to be associated with rumination (Ottaviani, Shapiro, Davydov, Goldstein, & Mills, 2009; Williams et al., 2015; Woody et al., 2014), which has been linked with greater attentional bias towards dysphoric stimuli as well as greater pupil dilation to negative stimuli (Duque, Sanchez, & Vazquez, 2014; Siegle, Steinhauer, Carter et al., 2003). Relevant experimental evidence also supports an association between low HRV and increased emotional processing of negative information. Krypotos, Jahfari, van Ast, Kindt, and Forstmann (2011) showed that individuals with low HRV demonstrated greater distractor interference on a response inhibition task only when distractors were of a negative, but not neutral, valence. The association between low HRV and reduced task performance in the context of task-irrelevant negative emotional stimuli suggests that HRV moderates the effects of distracting negative emotional stimuli on attention, potentially by increasing emotional processing of task-irrelevant negative information, resulting in decreased task engagement (Krypotos, Jahfari, van Ast, Kindt, & Forstmann, 2011). Low HRV has also been associated with greater spontaneous and unsuccessful suppression of a negative, personally-relevant intrusive thought, providing further evidence of HRV's role in maladaptive attentional processing of negative emotional information (Gillie, Vasey, & Thayer, 2015). Relatedly, a recent meta-analysis conducted by Ottaviani et al. (2016) found low HRV to be related to perseverative cognition symptoms which are defined by excessive attention towards repetitive, negatively-valenced thoughts. To summarize, extant indirect evidence suggests that low HRV should predict increased attentional bias towards negative emotional information as well as enhanced pupil dilation while viewing negative emotional stimuli, though to our knowledge this has never been explicitly tested.

With respect to positive emotional processing, multiple studies have found robust cross-sectional and prospective relationships between low HRV and depression (Jandackova, Britton, Malik, & Steptoe, 2016; Kemp et al., 2010; Vazquez et al., 2016), a disorder characterized in part by decreased attention bias towards positive stimuli and blunted reward processing (Armstrong & Olatunji, 2012; Heshmati & Russo, 2015). More pertinently, two recent studies suggest that low HRV might be specific to anhedonia compared to other symptoms of depression and anxious arousal (Sanders & Abaied, 2015; Vazquez et al., 2016). Thus, given data that suggests pupil dilation in response to reward cues reflects reward processing (Graham et al., 2011; Kennerley & Wallis, 2009; O'Doherty, Buchanan, Seymour, & Dolan, 2006; O'Doherty, Dayan, Friston, Critchley, & Dolan, 2003; Sepeta et al., 2012; Steinhauer & Hakerem, 1992), decreased pupil dilation while viewing positive emotional stimuli might be associated with low HRV. Additional evidence supportive of a relationship between low HRV and decreased pupil dilation and attentional bias towards positive emotional stimuli comes from work on emotion regulation and positive emotional information processing. Two separate studies found that more efficient shifts in processing away from neutral and towards positive-valenced stimulus features predicted decreased rumination in daily life and greater ability to downregulate negative affect in response to a negative mood induction (Genet, Malooly, & Siemer, 2013; Malooly, Genet, & Siemer, 2013), suggesting that greater attentional processing of positive emotional information is important for adaptive emotion regulation. Given low HRV's status as a putative marker of emotion dysregulation (Beauchaine & Thayer, 2015) and its relationship with depression (Jandackova, Britton, Malik, & Steptoe, 2016; Kemp et al., 2010; Vazquez et al., 2016), low HRV may be linked with decreased overt attentional processing of positive emotional information (i.e., indexed by PAB) as well as reduced covert attentional allocation and/or emotional arousal (i.e., indexed by pupil dilation) while viewing positive emotional stimuli.

It is also plausible that the relations between HRV and attention bias/pupil dilation are more pronounced under acute stress. The modulation of emotional processing by mood context is a well-replicated finding (e.g., Bradley, Mogg, & Lee, 1997; Mansell, Clark, Ehlers, & Chen, 1999; Hallion & Ruscio, 2011). A meta-analysis by Hallion and Ruscio (2011) found that modification of attention biases in anxiety were stronger and more robustly linked with symptoms following a stressor. Similarly, Mansell, Clark, Ehlers, and Chen (1999) found attention biases among socially anx-