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Heart rate variability is enhanced in controls but not maladaptive perfectionists during brief mindfulness meditation following stress-induction: A stratified-randomized trial

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ABSTRACT

Heart rate variability (HRV) is a vagal nerve-mediated biomarker of cardiac function used to investigate chronic illness, psychopathology, stress and, more recently, attention-regulation processes such as meditation. This study investigated HRV in relation to maladaptive perfectionism, a stress-related personality factor, and mindfulness meditation, a stress coping practice expected to elevate HRV, and thereby promote relaxation. Maladaptive perfectionists ($n = 21$) and Controls ($n = 39$) were exposed to a lab-based assessment in which HRV was measured during (1) a 5-minute baseline resting phase, (2) a 5-minute cognitive stress-induction phase, and (3) a post-stress phase. In the post-stress phase, participants were randomly assigned to a 10-minute audio-instructed mindfulness meditation condition or a 10-minute rest condition with audio-description of mindfulness meditation. Analyses revealed a significant elevation in HRV during meditation for Controls but not for Perfectionists. These results suggest that mindfulness meditation promotes relaxation following cognitive stress and that the perfectionist personality hinders relaxation possibly because of decreased cardiac vagal tone. The results are discussed in the context of developing psychophysiological models to advance therapeutic interventions for distressed populations.

1. Introduction

Heart rate variability (HRV) is the beat-to-beat variation in heart rate (HR) or the inter-beat interval (i.e. heart period) and is a widely used biomarker for the coordinated activity of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS; Cacioppo et al., 2007; Karim et al., 2011) Psychological stress (i.e. problem solving, decision-making, worrying) leads to cardiovascular activation via the autonomic nervous system (ANS; Fabes and Eisenberg, 1997; Taelman et al., 2009). A typical cardiac stress response involves SNS activation wherein sympathetic nerve fibers release the excitatory neurotransmitters epinephrine and norepinephrine onto the heart's sinoatrial (SA) node to accelerate HR (Cacioppo et al., 2007; Karim et al., 2011; Thayer et al., 2012). In the aftermath, return to cardiac resting state requires parasympathetic influence to be instated through vagal nerve activation and its associated release of acetylcholine—a neurotransmitter that inhibits the SA node and decelerates HR. In contrast to stressful states, more restful and self-regulated states are typically marked by increased HRV, largely attributed to respiration-based (parasympathetic) HR control, particularly as slower respiration stimulates vagus nerve activity (Grossman and Taylor, 2007; Porges and Byrne, 1992). Thus, as an indicator of autonomic cardiac activity, the variation in HRV is used as an index of continuous and real-time changes in parasympathetic function at rest and under specific conditions (Allen et al., 2007; Force, 1996).

Insufficient parasympathetic function (corresponding with reduced HRV) can result in difficulties in reaching restful and relaxed states post-stress, while extended autonomic activity can accumulate as cardiovascular disease risks (Haensel et al., 2008; Kemp et al., 2012) and as stable or chronic anxiety-depressive conditions (Brosschot et al., 2006). Conversely, a growing literature associates increased HRV with enhanced attention-regulation (Chida and Steptoe, 2010; Segerstrom and Nes, 2007; Thayer et al., 2009) and with the practice of various forms of meditation (Burg and Wolf, 2012; Krygier et al., 2013; Phongsuphap et al., 2008). Collectively, the evidence suggests that variations in relaxation capabilities after stressful conditions can be explained by the effective practice of attention regulation techniques.

A relevant yet unexplored stress-related factor that can potentially hinder the relaxation process is maladaptive perfectionism. Maladaptive perfectionism is a personality construct characterized by a persistent striving for unrealistic personal standards, an excessive concern over mistakes, and an attentional bias for failure (Hewitt and Flett, 1991; Lo and Abbott, 2013). Excessive perfectionistic thinking is consistently associated with chronic stress (Ashby et al., 2012; Flett et al., 1998; Pirbaglou et al., 2013), greater worry and rumination levels

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(Harris et al., 2008), and psychiatric diagnoses (Antony et al., 1998; Chang and Sanna, 2001; Saboonchi and Lundh, 1997).

Perseverative cognitions—characterized as worry and rumination—have been suggested to produce health detriments including frequently prolonged elevations in HR and decreases in HRV (Brosschot et al., 2006; Brosschot, 2010). These suggestions are supported by both short term and long term studies on the cardiac response to stress and worry (Brosschot et al., 2007; Brosschot and Thayer, 2003; Glynn, 2002; Pieper et al., 2007, 2010; Verkuil et al., 2009). For example, in a study of normal populations assessed by ambulatory monitoring, HRV decreased during periods when participants reported that they had been worrying (Brosschot et al., 2007). Further, Papousek et al. (2011) studied HR responses to a task that provided performance feedback manipulated to be inconsistent with participants' self-concept. They found evidence of delayed psychophysiological recovery which supported the 'perseverative cognition' model of detriments from negative cognitive representations of stressful conditions (Papousek et al., 2011). Taken together, these findings support the hypothesis that Perfectionists, who are known to engage in a higher frequency of perseverative cognitions, will demonstrate decreased HRV during and after a stress-induction that activates cognitive schemas pertaining to perceived failure and unrealistic performance standards.

Given this hypothesis, it is important to explore stress-regulation practices conducive to cardiac-based relaxation evident through increases in HRV. Recent theoretical and empirical developments suggest that perfectionism and perseverative cognitions can be reduced by cognitive-behavioral therapy and mindfulness meditation (Delgado et al., 2010; Masuda and Tully, 2012; Nyklíček et al., 2013). A recent randomized controlled-trial adopting both approaches to treat maladaptive perfectionists revealed significant reductions in anxiety sensitivity and negative automatic thoughts (Radhu et al., 2012a; Guglietti et al., 2013). An additional trial has shown that post-intervention improvements may be seen in Perfectionists cortical inhibition—a neurophysiological mechanism associated with therapy-related improvements and mindfulness meditation (Radhu et al., 2012b). Given the importance of attention regulation and mindfulness to current psychotherapeutic approaches, more evidence is needed to support the hypothesis that mindfulness training can assist individuals in regulating cardiac stress responses.

Mindfulness meditation has received significant interest in health psychology, neurophysiology, and, more recently, psychophysiology. Evidence indicates that mindfulness meditation helps regulate psychological distress through physiological relaxation processes (Argus and Thompson, 2007; Short and Mazmanian, 2013). Mindfulness is conceptualized as a family of techniques that emphasize purposeful and non-judgmental awareness of present moment experiences i.e. cognitions, emotions, physical sensations, and external stimuli (Didonna, 2009). Putatively, seated mindfulness meditation generates a relaxation effect through a combination of focal attention on one's breathing sensations and open-monitoring of immediate experiences (Didonna, 2009), processes that serve to orient one to the present time-frame in contrast to past experiences or future outcomes (Grossman et al., 2004).

Studies have found mindfulness practices associated with positive changes in cognitive function (Chiesa et al., 2011), brain regions associated with attention (Lazar et al., 2006) and emotion regulation (Lutz et al., 2008), and reductions in chronic stress (Mankus et al., 2013; Ritvo et al., 2013). Furthermore, HRV has been shown to increase during brief mindfulness meditation practice (Burg and Wolf, 2012; Ditto et al., 2006; Tang et al., 2009) as well as after engagement in long-term meditation retreats (Delgado-pastor et al., 2013; Krygier et al., 2013). Given that parasympathetic HR control is primarily established by respiratory-linked variations modulated by the vagus nerve (Allen et al., 2007; Force, 1996), and that respiration (via awareness of breathing) is central to meditation, HRV is posited as a physiological correlate of mindful states, while respiration is an important confounding variable to control (Allen et al. 2007).

The present study assessed a sample of maladaptive perfectionists and a control group on stress reactivity and post-stress relaxation. A three-phase protocol involved HRV measurement (primary outcome) during a baseline rest phase, a stress-induction phase, and a post-stress phase in which participants were randomized to a brief audio-guided mindfulness meditation condition or a resting condition consisting of an audio description of mindfulness meditation. The following hypotheses were tested:

1. Stress phase HRV would be lower than baseline HRV for all participants. This effect was expected to be greater in Perfectionists compared to Controls.
2. Control participants assigned to the mindfulness meditation condition, but not Perfectionists, would exhibit increases in HRV from Phase 2 (stress phase) to Phase 3 (meditation).

2. Materials & methods

2.1. Participants

This study was conducted at a large public university and recruited undergraduate students of all years of study and majors through an online system of research participation which grants course credit.

Exclusion criteria included a history or current diagnosis of any anxiety disorder and/or major depressive disorder and cardiovascular disease (hypertension, coronary artery disease, and arrhythmias) as these conditions are known to involve ANS dysfunction (Chalmers et al., 2014; Haensel et al., 2008; Kemp et al., 2012; Marano et al., 2009; Miu et al., 2009). Participants were excluded if they had a history of practicing mindfulness meditation or even minimal exposure to the practice (>60 min).

2.2. Sample size estimation

Based on a review of the literature, changes in HRV during mindfulness meditation have been reported to range between medium (Burg and Wolf, 2012; Takahashi et al., 2005) and large effect sizes (Krygier et al., 2013). Given $\alpha = .05$ and the employment of multivariate statistical tests to study within-subject HRV changes during meditation, it was estimated that a total sample size of 40 participants would provide acceptable power (0.80) to assess a medium effect size (partial eta squared > 0.06) and excellent power (0.95) for detecting a large effect size (partial eta squared > 0.14).

2.3. Screening

The Perfectionism Cognitions Inventory (PCI) assesses the frequency of automatic thoughts with perfectionist themes that highlight the discrepancy between one's current and ideal self (Flett et al., 2007; Flett et al., 1998; Flett et al., 2011). Participants are asked to indicate how often they experienced perfectionistic thoughts (e.g. "I should never make the same mistake twice" and "I must be efficient at all times") in the previous week on a 5-point Likert scale. The PCI has demonstrated adequate validity and reliability and correlational analyses have revealed strong associations with trait perfectionism, psychological distress, and depressive-anxious symptoms (Flett et al., 2007; Flett et al., 2011; Pirbaglou et al., 2013). Furthermore, there has been no gender difference in mean PCI scores found (Flett et al., 1998).

The current study utilized the procedure used in two previous randomized-controlled trials (Arpin-Cribbie et al., 2008; Radhu et al., 2012b) to screen for maladaptive perfectionism. The Perfectionist group consisted of participants with PCI scores falling at or above 66, which represents the value lying one standard deviation above the established mean of the PCI (Arpin-Cribbie et al., 2008). The Control group consisted of all eligible participants whose scores fell below the cut-off of 66. The alpha coefficient value for the PCI in this study