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Brief report

Autonomic and prefrontal events during moral elevation

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ABSTRACT

Moral elevation, or elevation, is a specific emotional state triggered by witnessing displays of profound virtue and moral beauty. This study set out to characterize the physiology underlying elevation with measurements of heart rate (HR), respiratory sinus arrhythmia (RSA), and medial prefrontal cortex (mPFC) activity. During elevation, HR and RSA increased. These findings illustrate that elevation involves an uncommon combination of both sympathetic and parasympathetic activation, which is present in circumstances where arousal and social engagement are both required. In addition, we show evidence of content-dependent alterations of mPFC activity during elevation peaks. Altogether, this study shows that the induction of moral elevation recruits an uncommon autonomic and neural pattern that is consistent with previous understanding of socioemotional-induced allostasis.

1. Introduction

Perceiving moral beauty in the altruistic, compassionate, or grateful acts of others often brings forth the emotional state of moral elevation, or elevation (Haidt, 2003). Elevation is a unique emotional process that has different cognitive and behavioral profiles from admiration or gratitude (Algoe & Haidt, 2009). The self-reported experience of elevation includes prosocial feelings, altruistic motivation, and physical sensations such as chills on the skin, tears in the eyes, and warmth in the chest (Algoe & Haidt, 2009). Experimental inductions of elevation increase altruistic behavior (Schnall, Roper, & Fessler, 2010), overcome beneficiary race as an obstacle to charitable giving (Freeman, Aquino, & McFerran, 2009), and trigger maternal nurturing behavior (Silvers & Haidt, 2008). Elevation synchronizes brain activity in a way that is distinct from neutral control and consistent between individuals (Englander, Haidt, & Morris, 2012).

The autonomic nervous system (ANS), consisting of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), prepares the body to deal with internal and environmental stimuli (McEwen, 2012; Porges, 2003). The ventral vagus nerve of the PNS serves to facilitate mammalian social engagement by controlling laryngeal and cardiac responses to social stimuli (Porges, 2003). Ventral vagus activity can be indexed by respiratory sinus arrhythmia (RSA), a pattern of high-frequency heart rate variability (HRV) (Porges, 2007). Resting RSA levels correlate positively with socially adaptive emotion-regulation strategies and trait social connectedness (Geisler, Kubiak, Siewert, & Weber, 2013). Similarly, RSA increases during social engagement states (Berntson, Cacioppo, & Grossman, 2007; Porges, 2007).

The SNS activates during fear or anger (LeDoux, 2012; McEwen, 2012; Rodrigues, LeDoux, & Sapolsky, 2009), but also during positive emotions (Shiota, Neufeld, Yeung, Moser, & Perea, 2011). Increased heart rate (HR) is either indicative of SNS activation or rapid PNS deactivation (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000).

Simultaneous activation of the SNS and PNS is possible under unique circumstances that involve both profound social engagement motivation and arousal, such as infant caretaking (Kenkel et al., 2013), sexual activity (Carter, 1992), and emotional crying (Trimble, 2012). Elevation may involve dual autonomic activation, as evidenced by studies on nursing mothers finding increased lactation and affiliative behavior, suggesting PNS activity, and sensations of goose bumps and tears, suggesting SNS activity (Silvers & Haidt, 2008). However, no studies have directly examined SNS and PNS activity in elevation.

PNS and SNS reactions are peripheral results of the brain's processing of environmental and internal events. The medial prefrontal cortex (mPFC) has been implicated in autonomic regulation during emotional states in part through connections to the amygdala, hypothalamus, and brain stem (Thayer, 2006). The current study examined the relationships of autonomic and mPFC activity to the experimental induction of elevation. We hypothesized that

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elevation would be characterized by PNS activation, indicated by increased RSA. We also predicted changes in HR and mPFC activity.

2. Method

Oregon State University students ($N = 104$; 65% female; 18–38 yrs ($M = 20.61$; mixed ethnicity)) participated in the research in exchange for extra credit in psychology courses. All procedures were approved by Oregon State University's Institutional Review Board.

2.1. Computer tasks

Video stimuli and self-report items were administered with E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). The programmed script included an emotionally-neutral baseline video (five-minute episode of *How It's Made*), an emotional video (elevation or amusement), and manipulation check items to retrospectively assess subjective experience during the emotional videos.

Participants in the elevation group watched a video stimulus used in previous studies to induce elevation (Schnall et al., 2010; Silvers & Haidt, 2008), which features teachers and their students displaying great compassion and gratitude. This was followed by another elevation-inducing stimulus which contained a story of a softball player being helped to complete a play by members of the other team after she sustained an injury. Participants in the amusement group watched excerpts from a comedy skit from CollegeHumor, which contains a comedic classroom setting with a teacher and students. Amusement has been used as a control condition in other key elevation studies in order to separate effects of elevation from those of general positive valence (Algoe & Haidt, 2009; Schnall et al., 2010; Silvers & Haidt, 2008).

To determine which portions of the elevation video were the most emotionally arousing, individuals ($N = 6$; 67% female, 22–39 years, mixed ethnicity) who did not previously participate in the physiological experiment took part in a behavioral task of rating levels of elevation on a ten-point scale every 30 s throughout the video stimulus. There was unanimous agreement on when these peaks of elevation occurred and we analyzed autonomic and neural data at these pinnacles of this emotional state (Fig. 1A).

After emotion induction, participants reported aspects of their subjective experience on Likert-type scale items (Supplementary Table 1). These served as a manipulation check for elevation and amusement induction, similarly to previous studies (e.g. Schnall et al., 2010).

2.2. Physiological measures

All analyses of physiological measures focused on two-minute periods, corresponding to reported peak moments of elevation (5.5–7.5 min and 10.5–12.5 min), or analogous 2 min of the amusement video (4.5–6.5 min), which also contained humans, as experimental values. Electrocardiogram (ECG) data were collected at 1000 Hz with the MP150 Data Acquisition System and Acqknowledge 4.2 software (Biopac Systems Inc., Santa Barbara, CA). The interbeat interval was evaluated for RSA and HR using CardioEdit/CardioBatch software (Brain-Body Center, University of Illinois-Chicago, Chicago, IL). Because of well-known association of social engagement with RSA increases (Porges, 2007), one-tailed paired and independent-sample *t*-tests were used to evaluate RSA-related effects.

Concentration of oxygenated (OxyHb) and deoxyogenated hemoglobin (DeoxyHb) in the mPFC was measured using functional near-infrared spectroscopy (fNIR; fNIR Devices LLC., Potomac, MD) with a sampling rate of 2 Hz. The positioning of the sensor pad, based on anatomical landmarks, was based on previous work (Ayaz et al., 2012) which integrates probabilistic mapping of optode locations and visualized data on brain surface image (Ayaz et al., 2006, 2011). Specialized data analysis software (fnirSoft; Ayaz, 2010) was used to refine fNIR signal. Signal quality was assured with the sliding-window motion artifact rejection algorithm (Ayaz, Izzetoglu, Shewokis, & Onaral, 2010; Ruocco et al., 2014) and the use of a low-pass finite impulse response filter for removing pulsation noise (Ayaz et al., 2012). Correlation-based signal improvement (Cui, Bray, & Reiss, 2009) was used to isolate the negatively correlated OxyHb versus DeoxyHb signal that is known to reflect cerebral neural activation. Temporal means of OxyHb and DeoxyHb were calculated for each channel. For this study, OxyHb and DeoxyHb concentrations from the center four channels were averaged to serve as a measure of mPFC activity, the region of interest.

2.3. Procedure

Upon arrival, an informed consent process explained physiological measures. Participants were led to a private room containing the physiological monitoring equipment and seated in front of the stimulus presentation computer. The experimenter then left and operated a control computer in the adjacent room. Once the participant had 15 min to acclimate to the physiological recording, video stimuli were presented, including the baseline video followed by videos intended to induce either elevation or amusement, depending on the between-subjects condition. Self-report items were then administered to retrospectively determine subjective experience during the emotional video. After participants completed these tasks, they were disconnected from the physiological monitoring equipment, debriefed and dismissed.

3. Results

Indices of HR, RSA, and mPFC reactivity were computed from neutral baseline followed at reported peaks of elevation (Fig. 1). The first peak of elevation revealed significant increases in RSA, $t(50) = -2.01$, $p = 0.02$ and HR, $t(50) = -3.23$, $p = 0.002$. However, mPFC activity changes were not significantly different from baseline or the amusement condition (elevation: OxyHb: $M = -0.003$ μM, SE = 0.29; DeoxyHb: $M = -0.02$ μM, SE = 0.11; $p > 0.05$). RSA and HR changes, compared to baseline, increased more in elevation participants ($M = 0.18$ ms^2, standard error [SE] = 0.09; $M = 1.79$ beats per minute (bpm), SE = 0.55) than in the amusement control group ($M = -0.07$ ms^2, SE = 0.08; $M = 1.21$ bpm; SE = 0.66). This difference was not significant for RSA change, but was for HR change, $t(96) = 3.04$, $p = 0.003$, Cohen's $d = 0.62$.

For the second peak of elevation, RSA and HR were also significantly boosted in elevation participants, RSA: $t(50) = -3.05$, $p = 0.002$ and HR, $t(50) = -2.65$, $p = 0.01$, but not in the amusement control group. Difference between RSA and HR changes in elevation from baseline to second peak and changes in amusement group were significant, RSA: $t(86.1) = 2.00$, $p = 0.02$, Cohen's $d = 0.40$, HR: $t(96) = 2.68$, $p = 0.009$, Cohen's $d = 0.55$. A trend towards mPFC activation appeared to occur in this elevation peak (OxyHb: $M = 0.46$ μM, SE = 0.23; DeoxyHb: $M = -0.34$ μM, SE = 0.18) when compared to baseline, OxyHb: $t(39) = 2.00$, $p = 0.05$, DeoxyHb: $t(39) = 1.90$, $p = 0.07$ and amusement, OxyHb: ($M = 0.10$ μM, SE = 0.13), $t(58.9) = 1.90$, $p = 0.06$, Cohen's $d = 0.43$; DeoxyHb: ($M = 0.10$ μM, SE = 0.10), $t(59.5) = -2.15$, $p = 0.04$, Cohen's $d = 0.49$.

Most manipulation check items were significantly different between groups and were consistent with successful emotion induction (Supplementary Table 1).