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Upward spirals of the heart: Autonomic flexibility, as indexed by vagal tone, reciprocally and prospectively predicts positive emotions and social connectedness

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ABSTRACT

Vagal tone (*VT*), an index of autonomic flexibility, is linked to social and psychological well-being. We posit that the association between *VT* and well-being reflects an "upward spiral" in which autonomic flexibility, represented by *VT*, facilitates capitalizing on social and emotional opportunities and the resulting opportunistic gains, in turn, lead to higher *VT*. Community-dwelling adults were asked to monitor and report their positive emotions and the degree to which they felt socially connected each day for 9 weeks. *VT* was measured at the beginning and end of the 9-week period. Adults who possessed higher initial levels of *VT* increased in connectedness and positive emotions more rapidly than others. Furthermore, increases in connectedness and positive emotions predicted increases in *VT*, independent of initial *VT* level. This evidence is consistent with an "upward spiral" relationship of reciprocal causality, in which *VT* and psychosocial well-being reciprocally and prospectively predict one another.

Research has linked vagal tone (*VT*) to numerous indices of psychological well-being, including trait positive emotionality (Oveis et al., 2009), prosocial behavior (Eisenberg et al., 1995), sympathy (Fabes et al., 1993) and decreased maladaptive coping (El-Sheikh et al., 2001). Individuals higher in *VT* appear to be cheerful and kind and deal well with stress, and these tendencies manifest themselves from childhood[1] onward (Porges et al., 1994). What is it that makes individuals high in *VT* better off than their low-*VT* counterparts?

Inspired by Fredrickson's (1998, 2001) broaden-and-build theory of positive emotions, we posit that the association between *VT* and well-being reflects a reciprocal causality, an "upward spiral" in which *VT* facilitates capitalizing on social and emotional opportunities and the resulting opportunistic gains, in turn, lead to higher *VT*. In such a spiral, the consequences of small, subtle, even fleeting behaviors and emotions accumulate and compound over time, eventually building durable personal resources that significantly improve a person's well-being. In other words, we conceptualize *VT* as a durable personal resource that moderates the degree to which people experience positive emotions in daily life, and that, over time, experienced positivity bolsters and builds a variety of enduring personal resources, including (but not limited to) *VT*. Similar upward spiral patterns have been observed for positive emotions and mental health (Fredrickson et al., 2008), positive emotions and coping (Fredrickson and Joiner, 2002; Burns et al., 2008) and positive emotions and trust (Burns et al., 2008), but to date research on upward spirals has not involved physiological factors.

Vagal tone is a promising upward spiral component because it is linked to autonomic flexibility, the capacity of the parasympathetic nervous system (PNS) to adapt to changes in circumstance by modifying arousal, respiration, heart rate and attention (Porges, 1995; Friedman and Thayer, 1998). Individuals high in *VT* adapt well across a number of different domains. They demonstrate superior performance on numerous indices of cognitive flexibility, including working memory (Hansen et al., 2003), directed attention (Suess et al., 1994) and inhibition of a dominant response (Johnsen et al., 2003; Mezzacappa et al., 1999). They show fewer negative responses to environmental stressors (El-Sheikh et al., 2001), show greater self-regulatory capacity (Segerstrom and Nes, 2007) and are better able to regulate negative facial expressions (Demaree et al., 2004, 2006; Kettunen et al., 2000).

Swift adaptability can influence behavior in subtle yet significant ways. For example, ego-resilience is an index of trait-level moment-by-moment adaptability and openness to current circumstances (Block and Kremen, 1996). In two articles, Waugh et al.

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[1] High vagal tone typically manifests in infants as greater behavioral reactivity to their environments, which can be interpreted as "difficultness." Greater reactivity, however, is believed to prepare the infant for greater social success, as reactive or "difficult" infants are apt to receive more social attention from caregivers than their less reactive peers (Porges et al., 1994).

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show that such resilience predicts speed of affective recovery after an anticipated threat fails to emerge. While anticipating threat, all participants experienced increases in negative affect. However, when the threat did not appear, individuals high in resilience were faster to return to baseline in both self-reported emotion (Waugh et al., 2008a) and anterior insula activity, an area associated with anticipatory anxiety (Waugh et al., 2008b). Through their exquisite attunement to the nuances of their current circumstances, resilient individuals are open to opportunities even in the midst of negativity.

Openness to opportunities can lead to greater positivity and social connectedness. In a study of social goals and well-being, approach social goals and motives in college students positively predicted life satisfaction and positive attitudes toward social relationships 8 weeks later, as well as decreased loneliness relative to start of study (Gable, 2006). These effects were mediated by increases in the number of positive life events experienced, suggesting that approach social goals influenced behavior in ways that resulted in positive life outcomes. Similarly, changes in resilience over the course of a month predicted change in life satisfaction (Cohn et al., 2009). Resilient individuals also experience more positive emotions after negative events, though they do not differ in the amount of negative emotions experienced (Fredrickson et al., 2003; Tugade et al., 2004). In all of the studies cited above, initial levels of life satisfaction or positive emotions were controlled for, suggesting that openness helps individuals to get more out of day-to-day opportunities independent of how well or how poorly they were doing at the start of the study.

Just as openness and flexibility predict positivity and social connection, tonic positive emotions and social connectedness predict *VT*. Over the course of an 8-month study of college freshmen, baseline positive emotionality at start as well as positive mood measured 1 month and 6–8 months later were positively associated with *VT* (Oveis et al., 2009). Individuals with supportive friends show higher *VT* levels than individuals with ambivalent friends (Holt-Lunstad et al., 2007). In a male-only sample, both trait secure attachment and secure attachment within one's current relationships predicted high *VT* (Diamond and Hicks, 2005). Porges' polyvagal theory suggests that these behaviors are linked to vagal tone via the social engagement system, a feedback loop between visceromotor vagal efferent pathways regulating the heart and somamotor visceral efferent pathways to brain structures regulating musculature in the face and ears associated with emotional expressivity and other-focus (Porges, 1995, 2007).

Both social connectedness and positive emotions, then, are associated with higher *VT*. In addition, *VT* is a marker of autonomic flexibility and adaptability, characteristics that lead to increases in social connectedness and positive emotions. Assuming that flexibility helps people capitalize on socioemotional opportunities as they arise, we hypothesize that the flexibility indexed by *VT* over time leads to increased social connectedness and positive emotions. Social connectedness and positive emotions, in turn, bring about incremental increases in *VT*, laying the groundwork for upward spirals toward greater flexibility and well-being.

To test this upward spiral hypothesis, community-dwelling adults were asked to monitor and report their positive emotions and the degree to which they felt socially connected each day for 9 weeks as part of a larger experimental study.[2] Measures of *VT* were taken at the beginning and end of the study. We divided our overarching hypothesis into two testable components: though all participants would gain by capitalizing on the opportunity to reflect (Burton and King, 2007), (1) individuals with higher initial *VT* are hypothesized to show greater positive change in positive emotions and social connectedness over the course of the study, and (2) increases in positive emotions and social connectedness are hypothesized to predict increases in end-of-study *VT*. In combination, these elements would provide evidence to support our hypothesized psychophysiological upward spiral toward improved well-being.

1. Method

Seventy-three adult participants (90.4% white, 40% male, mean age = 37.3, range 21–68) were recruited from the university community through fliers and email invitation. After giving consent, participants provided a 2-min[3] free-respiration vagal tone baseline while alone in a small, quiet room. *VT* was measured via respiratory sinus arrthymia (RSA), a non-invasive measure of cardiac vagal control characterized by increases in heart rate with inspiration and decreases in heart rate with expiration (Berntson et al., 1997). Continuous recordings were made of heart rate and respiration measures at a sampling rate of 1000 Hz. From these recordings, second-by-second averages were computed. Disposable snap electrodes were placed in a bipolar configuration on lateral sides of the chest on the lowermost ribs to measure the participant's echocardiogram (ECG). Respiration was collected with pneumatic bellows, placed around the participant's chest. All data were inspected offline and corrected for artifacts. RSA was calculated off-line based on changes in heart rate associated with respiration using a modified Grossman peak-to-valley method (Grossman, 1983) with interbeat intervals prorated to an equal sampling interval of 125 ms. Data were excluded if neither a peak or a valley could be identified during a sampling interval. Respiration was statistically controlled for in analyses by using the residual of RSA values when predicted by respiration.[4]

Each day for the next 63 days, participants listed the three social interactions in which they spent the most time that day. They then rated these three interactions in aggregate using 2 items adapted from Russell's UCLA Loneliness scale (1996): "During the social interactions, I felt "in tune" with the person/s around me" and "During the social interactions, I felt close to the person/s," using a 7-point scale (1 = *not at all true*, 7 = *very true*). The items were averaged to create a mean social connectedness score (mean daily α = .94, *SD* = .03). Participants also gave daily emotion reports using the modified Differential Emotions Scale (mDES; Fredrickson et al., 2003). Participants rated their strongest experiences of 20 emotions in the past day on a 5-point scale (0 = *not at all* to 4 = *extremely*). Participants' mean positive emotion score was composed of amusement, awe, gratitude, hope, inspiration, interest, joy, love, pride and serenity (mean daily α = .94, *SD* = .01). Participants' mean negative emotion score was composed of anger, boredom, contempt, disgust, embarrassment, fear, guilt, hate, sadness and shame (mean daily α = .85, *SD* = .07). After 9 weeks, participants provided another two-minute RSA baseline under the same laboratory conditions.

2. Results

Preliminary analyses. The data were first analyzed by computing the per-week mean, standard deviation and number of reports for social connectedness, positive emotions and negative emotions. As shown in Table 1, participants began the study slightly above the scale midpoint on self-rated social connectedness and slightly below the scale midpoint on positive and negative emotions, indicating a minimal likelihood of ceiling effects in the subsequent analyses. We also examined change in the variability in participants' responses over time. Decreasing variability in reported emotions or connectedness over time might suggest that participants had modified their reports in response to perceived demand

[2] The data are drawn from a field experiment that investigated the psychological effects of learning to meditate, akin to the experiment reported by Fredrickson et al. (2008). Participants were randomly assigned to attend a 7-week meditation workshop or to serve in a monitoring, waitlist control. All completed a number of measures beyond those reported here. Experimental condition was controlled for in all models.

[3] Before beginning psychophysiological data collection, participants spent several minutes in the cubicle at rest with psychophysiological sensors attached in order to habituate them to their environment and establish a similar physiological state of relaxation for all participants. To confirm stability of measurement over the two minute period, RSA values for the first and second minute were correlated. During the first lab session, r = .85, p < .0001. During the second lab session, r = .91, p < .0001.

[4] Fourteen participants were missing RSA data at either time 1 or time 2, five participants' RSA scores were discarded due to high ECG impedances and RSA data from one participant was excluded due to an anomalous RSA reading over 5 standard deviations from the mean.