Positive affect and parasympathetic activity: Evidence for a quadratic relationship between feeling safe and content and heart rate variability

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Abstract

There has been an increased interest in the study of underlying autonomic correlates of emotions. This study tests the hypothesis that high levels of high-frequency heart rate variability (HF HRV) are associated with positive emotions. In addition, we hypothesize that this association will differ according to the type of positive emotion. Also, based on recent findings, we tested the hypothesis that this relationship would be nonlinear.

Resting-state HRV was collected and self-report measures of different positive emotions were administered to a sample of 124 volunteers.

Results: Results suggested that there was a quadratic relationship between high-frequency heart rate variability and positive emotions associated with safeness and contentment, but not with positive emotions associated with excitement or lack of arousal.

Our data suggests that different positive emotions may be characterized by qualitatively distinct profiles of autonomic activation. Also, given the role of positive emotions in social affiliation, and particularly positive emotions associated with a quiescence motivational state, results are interpreted in light of theoretical accounts that highlight the importance of vagal regulation for social behavior.

Keywords: parasympathetic activity; tonic HRV; positive affect; non-linear

1. Introduction

The autonomic nervous system activity (ANS) is seen as a major component of the emotional response in many theories of emotion (Kreibig, 2010). The ANS is subdivided into an excitatory sympathetic nervous system (SNS) and an inhibitory parasympathetic nervous system (PSNS) that often interact antagonistically to produce varying degrees of physiological arousal. Unlike the SNS, which is associated with high-arousal negative states, the PSNS is thought to be responsible for activities during states of rest.

Heart Rate Variability (HRV) is a measure of the continuous interplay between sympathetic and parasympathetic influences in the heart rate. The parasympathetic influence on heart rate is mediated via release of acetylcholine by the vagus nerve. Under resting conditions, vagal tone prevails and variations in heart period are largely dependent on vagal modulation. Thus, increases in HRV reflect increased parasympathetic or vagal (inhibitory) control over sympathetic nervous system activity, which indicate greater autonomic flexibility (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). HRV can thus be used as a non-invasive measure of the autonomic processes involved in the chronometric regulation of cardiac function.

Most of the studies exploring the role of HRV in emotion have mainly focused on negative emotionality. Negative states and moods such as anxiety and depression have been found to be associated with lower parasympathetic activity (e.g., Carney and Freedland, 2009; Friedman and Thayer, 1998; Kemp et al., 2012; Rechlin, Weis, & Kaschka 1994; Watkins et al., 1998). Emotional states such as fear or anger have also been associated with decrease HRV (e.g., Rainville et al., 2006). Decreased HRV has also been associated with less psychological flexibility and capacity for emotional regulation (e.g., Appelhans and Luecken, 2006; Butler, Wilhelm, & Gross, 2006; Thayer and Lane, 2009).

A growing number of studies, however, have been examining the relationship between positive emotions and measures of HRV, and overall results point that high resting vagal activity is associated with positive emotionality. For example, Kok and Fredrickson (2010) measured vagal tone at the beginning and end of a 9-week period in which participants reported their daily positive emotions (amusement, awe, gratitude, hope, inspiration, interest, joy, love, pride and serenity) and found that individuals who possessed higher initial levels of vagal tone increased in positive emotions more rapidly than others. Oveis et al. (2009) examined the association between resting RSA and positive emotionality (extraversion, agreeableness, positive mood, and optimism) and found that resting RSA was associated with trait positive affect (positive mood).

Still, the extent to which specific positive emotional states are characterized by increased parasympathetic activation is still in debate, since most of the studies used general measures of positive emotionality or composites of discrete positive emotions. Studies exploring the association between vagal activity and distinct positive affective states seem to suggest that different positive emotions are characterized by distinct profiles of autonomic activation. For example, in a study using slides showing emotional images to evoke specific emotions (anticipatory enthusiasm, attachment love, nurturant love, amusement, and awe), Shiota et al. (2011) found that different positive emotions were characterized by distinct profiles of autonomic activation. Also, using a self-report measure of dispositional positive emotions, Kogan et al. (2014; study 2) found an association between vagal activity (measured during a neutral film clip) and prosocial emotions (compassion and gratitude) but there was no relationship between vagal activity and other non-prosocial positive emotions (contentment, joy, desire, amusement, and interest).

In fact, there are reasons to believe that different positive emotions may be differently associated with ANS functioning and with HRV. Discrete emotions are thought to help address adaptive problems (or opportunities) by coordinating cognitive, physiological and behavioral mechanisms likely to facilitate fitness-enhancing responses to the situations (Tooby and Cosmides, 2008; Kenrick and Shiota 2008). Thus, it is not unexpected that different positive emotions that may have evolved for different purposes (e.g., reward approach, exploration, social connectedness) show different motivational and neurophysiological correlates. In this regard, and according to recent findings from neurobiology (see Burgdorf and Panksepp, 2006 for a review) and social neuroscience (McCall and Singer, 2012), there appears to be at least two distinct classes of positive affective states that can be distinguished by distinct neuroanatomical substrates, autonomic responses, and motivation. One is associated with an approach-motivated appetitive state, that increases the capacity for action and reward-seeking; the other is associated with a quiescent state, associated with goal achievement (reward acquisition and consumption) and inaction. At the level of subjectivity, approach and quiescence motivational states differ in terms of their affective qualities; while quiescence should be associated with positive feelings of warmth, safeness, and contentment, approach should be associated with excitement (when positively valenced). Quiescence and approach motivations should be particularly distinguishable by their autonomic responses, with the quiescence state being associated with parasympathetic activity, and the appetitive state being associated with increased sympathetic activity. In this line, a recent study offers some evidence for the association between soothing positive affect (peacefulness, contentment, safeness), and parasympathetic activity indexed by increased HRV. Petrocchi et al. (2017) found that direct stimulation of the left temporal lobe (left insula) using transcranial direct current stimulation increased both HF-HRV and soothing positive affectivity, but had no effect on activating positive affect. In addition, there was a significant association between increases in soothing positive affect and concomitant increases in vagally-mediated HRV. Findings form this study also support the idea that the quiescence state is particularly related to homeostasis and social affiliation (Depue and Morrone-Strupinsky, 2005; McCall and Singer, 2012), as the left insular cortex has been linked to social emotions (Lamm and Singer, 2010). In fact, is has been suggested that the subjective experience of warmth and soothing reflect the capacity to experience reward elicited by affiliative stimuli, which would motivate close interpersonal behavior (Depue and Morrone-Strupinsky, 2005).

There are some contradictory findings in the literature that may suggest that autonomic functioning and positive emotionality may be non-linearly associated. For instance, extremely high levels of vagal activity are associated with high risk for mania (Gruber et al., 2008), and increased positive emotion reactivity in individuals with bipolar disorder (Gruber, Harvey, & Purcell, 2011). Rainville et al. (2006) observed a reduction in HRV during happiness, also reported in another study (Lane et al., 2001). In a recent study, Kogan et al. (2014) reported through a series of studies a nonlinear relationship between vagal activity and prosociality (prosocial traits, prosocial emotions, and outside ratings of prosociality by complete strangers). Data from these studies suggest that very high levels of HRV may not always be adaptive. One possible explanation is that such high levels may compromise the cardiac vagal brake - the flexible withdrawal of vagal regulation of the heart in response to environmental challenges which is critical to successful adaption (Kogan et al., 2014; Thayer and Brosschot, 2005). Thus, these studies highlight the complexity of the relationship between vagal activity and positive emotions, and suggest that a linear account of this relation may not adequately fit these phenomena.

The aim of this study is to explore linear and nonlinear relationships between resting parasympathetic activity and different types of self-reported positive emotions. We hypothesize that positive emotions associated with activation and excitement will not be associated with parasympathetic activation and that positive emotions related to low arousal and activation and with feelings of safeness and contentment will be associated with increased parasympathetic activity, linearly and/or nonlinearly. The relationship between HRV and a widely used measure of general positive emotions (PANAS) was also tested.

2. Method

2.1. Participants

One hundred and twenty-four undergraduate students from the University of Coimbra were initially recruited to participate in exchange for psychology course credits. Of these, six were excluded due to the presence of a cardiovascular condition, one was excluded due to current use of antidepressants, one was excluded due to a faulty recording of HRV, and twenty were excluded due to missing data in questionnaires. Given the low number of male participants in the sample ($n = 5$), these were excluded from the sample to avoid confounding effects. The final sample consisted of ninety-one female participants (mean age = 20.45 years, $SD = 1.68$).

2.2. Procedure

Participants were instructed to refrain from certain activities and behaviors known to affect HRV measurement before coming to the laboratory. Specifically, participants were asked to refrain from eating in the previous 2 hours, drinking caffeine or alcohol on the day of the testing, and vigorous physical activity in the previous 24 hours. Participants were excluded if they had any cardiovascular disease and current use of medication that could interfere with the HRV measurement (e.g., antidepressants). Participants arrived at the laboratory and were asked to fill in the self-report measures. Because several studies found and association between Body Mass Index (BMI) and HRV (e.g., Molfino et al., 2009), height and weight were also measured to calculate BMI. Participants were then asked to sit in a comfortable position while their heart rate was monitored. It took 30 minutes on average to complete the self-report questionnaires and HRV measurement. All procedures were in accordance with the Helsinki Declaration of 1975. All participants provided their written informed consent.

2.3. Measures

2.3.1. Self-report measures

2.3.1.1 Types of Positive Affect Scale (TPAS; Gilbert et al., 2008). The scale is composed by three factors measuring different types of positive affect: Activating Positive Affect (e.g., excited, dynamic, active); Relaxed Positive Affect (e.g., relaxed, calm, peaceful) and Safe/content Positive Affect (e.g., safe, secure, warm). While relaxed positive affect seems to capture absence of activity or arousal, the safeness/contentment factor seems to tap positive affect in the presence of safeness as conferred by self or others, and thus is thought to be associated with the quiescence motivational state (Gilbert et al., 2008). A general Low Arousal Positive Affect variable was also computed by summing the scores of the Relaxed and Safeness/contentment subscales (Petrocchi et al., 2017). Participants were asked to rate how they felt during the last two months using a 5-point scale (0 = 'not characteristic of me' to 4 = 'very characteristic of me'). The scale showed good psychometric properties with Cronbach alphas of .88 for Activating Positive Affect, .93 for Relaxed Positive Affect, and .83 for Safe/contentment Positive Affect in this study.

2.3.1.2. The Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) consists of two 10-item mood scales and was developed to provide brief measures of positive affect and negative affect. Respondents were asked to rate the extent to which they have experienced each particular emotion in the last two months using a 5-point scale (1 = 'very slightly or not at all', to 5 = 'very much') Only the positive scale was used in this study, and showed good psychometric properties with a Cronbach alpha of .89.

2.3.2. Heart rate variability

Interbeat intervals (IBI) were measured for 5 min via the eMotion HRV (Mega Electronics), an ambulatory heart rate variability (HRV) measurement system at 1000 Hz, which receives heart rate data from two disposable Ag-AgCl electrodes placed in participants (right clavicle and precordial site V6). Participants' IBIs were recorded while they were relaxed in a seated position in a well-lit room without distracting stimuli. Participants were breathing spontaneously during the recording period. This procedure allowed to obtain a measure of resting-state heart rate variability, or trait level, which is thought to be a marker for the dynamic regulation of autonomic activity (Thayer et al., 2012). All participants were tested in the afternoon (1500h-1800h) to control for daily oscillations in HRV.

All samples were inspected for artefacts. Frequency-domain analyses and time-domain analyses were computed, compliant with the established guidelines (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Artiifact (version 2; Kaufmann et al., 2011), a tool for heart rate artifact processing and heart rate variability analysis, was used to calculate High Frequency (HF) band (0.15–0.4 Hz; normalized units) using the Fast Fourier transformation. The HF band of frequency domain is influenced almost exclusively by parasympathetic activity and has been argued to be an index of vagal tone (Akselrod et al., 1981; Lane et al., 2009; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). The square root of the mean squared differences of successive heart periods (RMSSD) was also calculated. RMSSD is a time domain HRV measure that is strongly associated with HF-HRV ($r = 0.93$) (Goedhart et al., 2003).

2.4. Data Analyses

First, associations between age, BMI, HF-HRV, and RMSSD were tested using Pearson's correlation coefficient to explore potential confounding effects of such variables in the models. To test the hypotheses regarding the associations between different types of positive affect and HRV, several hierarchical linear regressions were conducted. In these models HF-HRV / RMSSD were entered as a first step, and a quadratic HF-HRV / RMSSD term in the second step (HF-HRV*HF-HRV or RMSSD*RMSSD). This procedure allows us to test both the linear and quadratic relationship between HRV and emotions, and also whether introducing a quadratic term increases the variance explained in the model. The different types of positive affect, as measured by the TPAS and PANAS were the dependent variable in the models. IBM SPSS version 23 was used for all analyses.

3. Results

First, we tested associations between age, BMI and HRV (HF-HRV and RMSSD). No significant associations were found. There was a positive and significant association between HF-HRV and RMSSD ($r = 0.42$, $p < 0.001$). Then, we conducted hierarchical linear regressions with HF-HRV or RMSSD entered in the first step, and a quadratic HF-HRV or RMSSD term in the second step, respectively. Results for the first step of the analysis showed that there were no statistically significant linear relationships between HF-HRV or RMSSD and different types of positive emotions. However, when a quadratic term of the HF-HRV was introduced in the second step of the analysis, we found a statistically significant quadratic effect for the safeness/contentment positive affect. Also, when the quadric term was introduced in the model there was a significant *R*change (0.06, $p = 0.02$) (Table 1). These results suggest that as HF-HRV increased, the relationship between HF-HRV and safe positive affect progressively became more and more negative. Graphical inspection of the curves (see Figure 1) demonstrates an inverted U-shape curve. In contrast, the quadratic term of RMSSD was not significantly associated with positive affect.

[insert Table 1]

[insert Figure 1]

4. Discussion

In the present study, guided by theorizing and previous findings about neurophysiological differences in positive affect, relationships between autonomic function and different types of positive affective states were tested. Given contradicting findings in the literature regarding the association between vagal function and positive emotions (e.g., Kogan et al., 2014), linear and non-linear relations were explored. Contrary to previous findings, we found no evidence for a linear relationship between vagal activity and positive emotions in all measures. However, we found a significant quadratic relationship between vagal activity and safeness/contentment affect, but not with relaxed and activating positive affect, a composite measure of low arousal positive affect, nor with a general measure of positive emotions (PANAS).

The existence of a quadratic relationship between vagal activity (as measured by HF-HRV) and positive emotions suggests that there may be an optimal level of vagal activity, and that very low or very high levels may be maladaptive. On one hand, these results indicate that participants experiencing low safeness and contentment affect also present low levels of HF-HRV. Thus is line with empirical evidence relating low HRV with low positive emotions (e.g., Oveis et al., 2009), and can be interpreted in light of the the neurovisceral integration model (Thayer and Lane, 2000, 2009). According to this model, low HRV may indicate a predisposition to chronic threat perception and amygdala hyperactivation, and an inability to recognize safety signals, via the associations between HRV and neural structures that are involved in the appraisal of threat and safety, such as the prefrontal cortex and the amygdala (Thayer et al., 2012). Thus, this model helps explain the link between low HRV and low levels of positive affect, and particular an inability to feel safeness. On the other hand, these results suggest that very high levels of HRV may be maladaptive as they are associated with less positive emotions, which is also in line with previous studies (e.g., Gruber et al., 2008, 2011; Kogan et al., 2014; Rainville et al., 2006).

The finding that only safeness and contentment affect was related to vagal activity can also be explained in light of recent theories derived from social neuroscience. McCall and Singer (2014) suggested that positive feelings of warmth and contentment are associated with parasympathetic activity and may be activated when the individual is in a quiescence motivational state. In turn, these affective states are thought to be essential for homeostatic regulation and particularly for social affiliation (Depue and Morrone-Strupinsky, 2005). In this line, Porges' Polyvagal theory (Porges, 2001) proposes that the mammalian autonomic nervous system (ANS) developed the myelinated vagus nerve to facilitate engagement with the environment, and in particular social interactions, through its inhibitory influence on the heart's sinoatrial node. Thus, when the surrounding environment is seen as safe, the vagal regulation of cardiac output slows the heart and encourage social behavior and homeostatic functions. According to this theory, this physiological state is essential for optimal social interaction. Higher HRV reflects not only autonomic regulation but also a physiological state that is compatible with social interaction. In support of these accounts, a growing body of studies is providing evidence for an association between vagal activity and socially-related variables. For example, vagal activity is positively associated with perceived social support (Schwerdtfeger and Schlagert, 2011), positive emotions and feelings of connectedness during social interactions (Kok and Fredrickson, 2010), having more supportive friends (Holt-Lunstad et al., 2007), affiliation with a minimal group (Sahdra, Ciarrochi, & Parker, 2015) prosociality (Kogan et al., 2014), daily couple positive interaction (Diamond, Hicks, & Otter-Henderson, 2011), and emotion recognition (Quintana et al., 2012).

The finding that general positive emotions and positive emotions associated with an approach motivation system (activating positive affect) were not significantly associated with vagal activity suggests that the relationship between emotions related to the quiescence state and vagal activity is not a reflection of a general relation between vagal activity and positive emotionality.

The finding that only the frequency domain measure of HRV was associated with positive affect is line with a previous study in which HF HRV, but not SDNN (a time domain measure of HRV) was associated with soothing positive affect (Petrocchi et al., 2017).

Despite the promising findings, this study has several limitations that should be taken into account. First, the sample size was relatively small, and only female participants were included. Although this allows to control for gender differences in HRV (e.g., Diamond et al., 2011), at the same time limits the generalizability of the findings. Also, data on emotions was derived entirely through self-report measures and thus the findings are subject to the limitations associated with this type of methodology. Experiencing sampling method, for example, may be a more ecologically valid way to explore how people typically feel in their daily lives. In addition, although this was a sample from the general population, we cannot exclude the possibility that a certain percentage of participants may suffer from mental disorders, which could have impacted the results. The use of BMI is also a potential limitation of the present study, as several problems regarding BMI’s sensitivity and specificity as a measure of body fat have been identified (e.g., Rothman, 2008). Also, no conclusions can be made over causality due to study design. Thus, it remains unclear whether change in HF-HRV impacts on safeness and contentment emotions, or whether the experience of such emotions could impact on HF-HRV – which could help explain the links between positive emotions and several indicators of physical health (e.g., Cohen and Pressman, 2006).

Additionally, the association between positive emotion and vagal tone measures could be accounted for by a wide variety of third variables. In particular, it's unclear whether the observed effect reflects characteristics of positive emotion per se (as a psychological state), or some trait-level correlate of high dispositional safeness/contentment, such as agreeableness which has been found to be associated with vagal activity (Kogan et al., 2014). Future work would benefit from experimental manipulation of HF HRV to observe the consequence in terms of positive emotions. Also, we did not measure respiratory rate during the HRV assessment. There has been considerable debate on the necessity of controlling for respiration when assessing HRV (Quintana et al., 2016). Denver et al. (2007) have argued against the need to control for respiration – at least for resting state recordings, but this is still a controversial subject and other authors have argued that measuring respiration is important (e.g., Grossman and Taylor, 2007). In general, given the exploratory nature of the design, low sample size, and small effect sizes, the results of this study should be replicated in larger and more heterogeneous samples.

In sum, the results of this study are in accordance with recent accounts of a quadratic relation between positive emotionality and vagal activity (Kogan et al., 2014; Gruber et al., 2015). In addition, these findings add to the growing body of literature showing that positive emotion is not a single, unidimensional phenomenon, and support recent conceptualizations that favor a functional approach to positive emotions (e.g., Shiota et al., 2014). The fact that no relationship was found between vagal activity and relaxed positive affect, for example, supports this idea given that both contentment and relaxation are at the same end of the arousal continuum (Gilbert et al., 2008). This suggests that our data may not be well explained by models of emotion that limit differentiation to high-versus low arousal states.

In addition, our findings add to the literature on the importance of positive emotions, and particularly emotions associated with a quiescence motivation state. Although causality cannot be established, it is possible that the wide benefits associated positive emotions (Fredrickson, 1998) may be vagally mediated. This can have important clinical applications. Experiencing low positive affect is associated with negative mental health outcomes, and the dysregulation of positive affect can result in psychopathology (e.g., Carl et al., 2013; Watson and Naragon-Gainey, 2010). For example, studies show that depressed participants, compared to never-depressed controls, experience less positive affect in the course of daily life (Barge-Schaapveld et al., 1999; Bylsma, Taylor-Clift, & Rottenberg, 2011; Peeters et al., 2006). Also, they generate less positive affect from pleasant stimuli during experimental tasks (Bylsma, Morris, & Rottenberg, 2008), though in daily life this phenomenon is debatable (Bylsma, et al., 2011; Peeters et al., 2003). In other words, positive affect may represent a resilience phenotype against depression. Individuals vulnerable to depression may therefore benefit from learning to experience more positive affect. Moreover, research indicate that it is the safeness and contentment types of positive affect, and not the activating positive affect, that may be particularly associated with depression (Gilbert et al., 2008). Also, some evidence suggests that pharmacological treatments may have an impact on autonomic function. Accordingly, a 2-year longitudinal study (Licht, Penninx, & de Geus, 2010) reported that all classes of antidepressants including the tricyclic (TCA) antidepressants, the selective serotonin and noradrenaline reuptake inhibitors and the selective serotonin reuptake inhibitors, were associated with adverse cardiovascular effects as indicated by reductions in heart rate variability (HRV). Thus, it may be important to develop non-pharmacological interventions to increase HRV and positive emotions, particularly for patients with already compromised parasympathetic function. Mindfulness and compassion-based interventions have been found to increase both HRV (Krygier et al., 2013; Kirby et al., 2017; Libby et al., 2012), and positive emotions (Fredrickson et al., 2008; Geschwind et al., 2011), and thus their role as alternative non-pharmacological interventions in this context should be further explored.

Funding: This work was supported by the first author's Ph.D. Grant no. SFRH/BD/81416/2001, sponsored by FCT (Foundation for Science and Technology), Portugal, and co–sponsored by ESF (European Social Fund), Belgium, through Portuguese POPH (Human Potential Operational Program).

No conflict of interested is reported by the authors.

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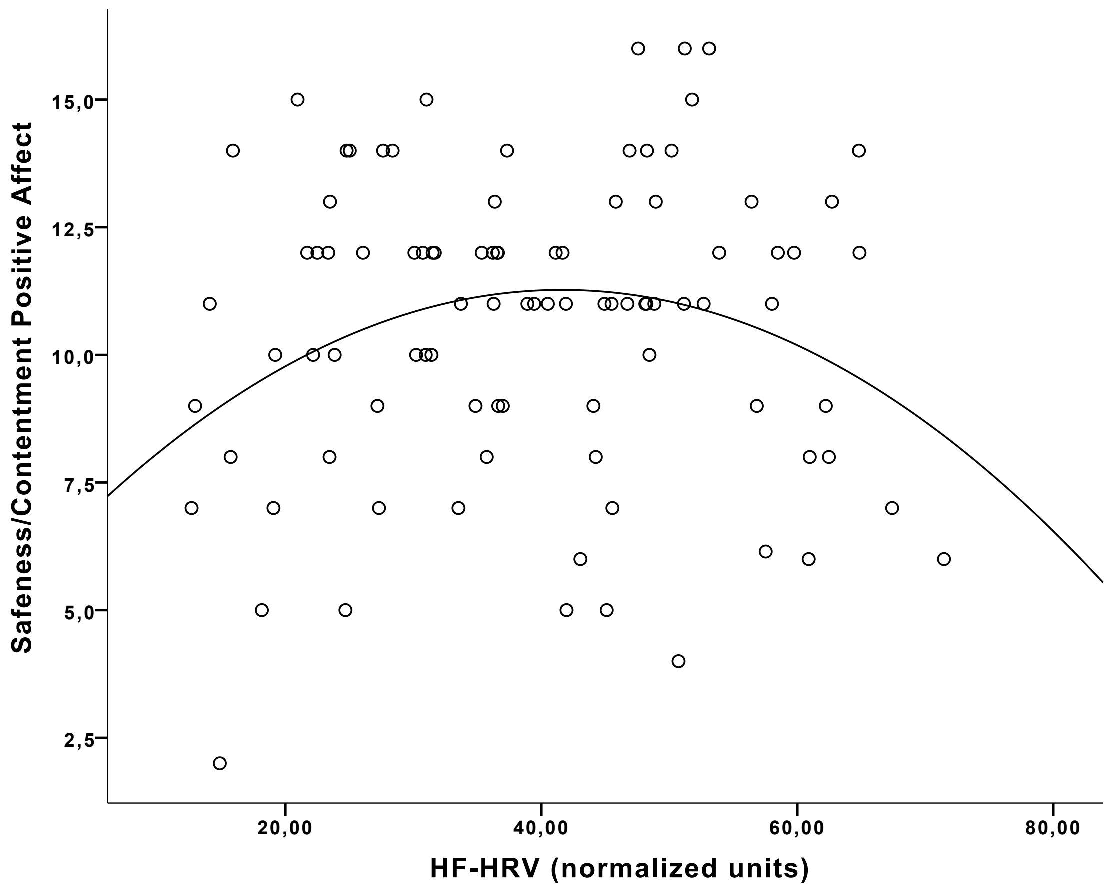
Table 1

Hierarchical Multiple Regression for Linear and Quadratic Models of the Effect of Heart Rate Variability on Positive Emotions (N = 96)

	Linear Model HF HRV					Quadratic Model HF HRV					
Outcome	*B*	95 % CI	β	*t*	*p*	*B*	95% CI	β	*t*	*p*	R^2 Change
Activating Affect	0.040	-0.032, 0.112	0.115	1.108	0.271	-0.003	-0.007, 0.002	-0.118	-1.12	0.265	0.014
Relaxed Affect	0.022	-0.046, 0.089	0.067	0.640	0.524	0.000	-0.005, 0.004	-0.013	-0.118	0.906	0.000
Safeness/contentment Affect	0.010	-0.032, 0.053	0.051	0.483	0.630	-0.003	-0.006, -0.001	-0.246	-2.38	0.019*	0.059*
Low Arousal Positive Affect	0.032	-0.063, 0.127	0.070	0.667	0.506	-0.003	-0.010, 0.003	-0.615	-1.12	0.267	0.014
Positive emotions (PANAS)	-0.009	-0.106, 0.089	-0.019	-0.182	0.856	-0.004	-0.010, 0.002	-0.129	-1.221	0.225	0.016

Note. *p < .05; HF HRV = High Frequency Heart Rate Variability; CI = Confidence Interval

Figure 1. Vagal activity (resting high frequency heart rate variability) association with safeness/contentment positive affect.


Safeness/Contentment Positive Affect
15,0
12,5
10,0
7,5
5,0
2,5
20,00
40,00
60,00
80,00
HF-HRV (normalized units)