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Resting Respiratory Sinus Arrhythmia Is Associated With Tonic Positive Emotionality

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Resting respiratory sinus arrhythmia (RSA_{REST}) indexes important aspects of individual differences in emotionality. In the present investigation, the authors address whether RSA_{REST} is associated with tonic positive or negative emotionality, and whether RSA_{REST} relates to phasic emotional responding to discrete positive emotion-eliciting stimuli. Across an 8-month, multiassessment study of first-year university students ($n = 80$), individual differences in RSA_{REST} were associated with positive but not negative tonic emotionality, assessed at the level of personality traits, long-term moods, the disposition toward optimism, and baseline reports of current emotional states. RSA_{REST} was not related to increased positive emotion, or stimulus-specific emotion, in response to compassion-, awe-, or pride-inducing stimuli. These findings suggest that resting RSA indexes aspects of a person's tonic positive emotionality.

Keywords: vagal tone, positive temperament, heart rate variability, biological marker

Respiratory sinus arrhythmia (RSA) is a measure of the neural regulation of the heart's pacemaker via the myelinated fibers of the "smart" vagus (Porges, 2001), and is assessed by examining the degree of respiration-linked variability in the heart rate. Emerging evidence suggests that resting RSA (RSA_{REST}) may be linked to individual differences in emotionality in healthy adults, although this literature is decidedly mixed. With respect to phasic negative emotional reactivity, RSA_{REST} has been associated with decreased negative emotion in response to moderate-to-intense daily life stressors (Fabes & Eisenberg, 1997) and a disgusting film clip (Demaree, Pu, Robinson, Schmeichel, & Everhart, 2006; Demaree, Robinson, Everhart, & Schmeichel, 2004), but increased negative emotion during the Rorschach test (Kettunen, Ravaja, Naatanen, & Keltikangas-Jarvinen, 2000) and during a conversation about a negative film (Butler, Wilhelm, & Gross, 2006). One study found no relationship between RSA_{REST} and negative emotion in response to anxiety-inducing film clips (Frazier, Strauss, & Steinhauer, 2004). With respect to phasic positive emotional reactivity, one study found that RSA_{REST} is associated with increased positive emotion during the Rorschach test (Kettunen et al., 2000), whereas three studies yielded no relationship between RSA_{REST} and positive emotional experience or expression in response to amusement- and enthusiasm-inducing film clips (Demaree et al., 2004, 2006; Frazier et al., 2004). No study to date has examined the relationship between RSA_{REST} and tonic, trait-like, emotionality in healthy adults.

The present research was designed to investigate the relationship between RSA_{REST} and individual differences in positive and negative emotion. Our central aim was to ascertain whether RSA_{REST} is associated with tonic positive or negative emotionality across an 8-month, multiassessment study. To do so, we assessed positive and negative emotion at three levels of analysis (Rosenberg, 1998): (a) as emotional traits, captured in superordinate personality traits laden with aspects of positive (Extraversion, Agreeableness) and negative (Neuroticism) emotionality; (b) as enduring moods and expectations (optimism and pessimism); and (c) as baseline reports of current emotional states.

Our second aim was to examine the relationship between RSA_{REST} and phasic, state-like reactivity to discrete positive emotion-eliciting stimuli (Davidson, 1998; Gross, Sutton, & Ketelaar, 1998). Whereas previous studies have examined whether RSA_{REST} relates to positive emotional responses to amusement and

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enthusiasm-inducing stimuli, the present study extended this work by examining emotional responses to compassion-, pride-, and awe-inducing stimuli. Here, we examined two types of phasic responding to discrete positive emotion-eliciting stimuli: first, we examined whether RSA_{REST} relates to overall positive emotional response. Second, we explored whether RSA_{REST} relates to stimulus-specific emotional responses (e.g., feelings of pride in response to pride-inducing stimuli).

Method

Participants

Eighty undergraduates (60 female; age $M = 20.0$ years; 51 Asian, Asian American, or Southeast-Asian, 14 White, 5 Latino/a, 2 African American, 8 other) beginning their first semester of college participated in exchange for $90.

Procedure

Shortly after beginning their first semester of college, participants were recruited for a yearlong study of emotion. Here we report on data from (a) an initial laboratory session consisting of an assessment of RSA_{REST} as well as a positive emotion-induction task, during which participants viewed neutral, compassion-, pride-, and awe-inducing slides; (b) an online questionnaire completed approximately one month later during which participants reported on positive and negative emotional dispositions and moods; and (c) a second online questionnaire completed 6–8 months after the initial lab visit during which measures from the previous online questionnaire were reassessed.

Time 1 Assessment of Resting RSA

After obtaining informed consent, participants were connected to the physiological apparatus in a well-lit, sound-attenuated room measuring approximately 2 × 3 m. Participants were then given 15 min to acclimate to the laboratory while seated in a comfortable chair. Next, participants were asked to relax and remain seated while RSA_{REST} was assessed for 90 s, in accordance with standards of measurement for high-frequency heart rate variability (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Electrocardiogram recordings were sampled at 1 kHz using an Ambulatory Monitoring System (VU-AMS, The Netherlands), with leads placed on the torso in a Lead II configuration. All data were inspected offline and corrected for artifacts. CMET cardiac metric software (available from http://apsychoserver.psych.arizona.edu) was used to calculate RSA from the R-wave to R-wave interbeat interval series in the frequency range of spontaneous breathing (.12 Hz–.40 Hz).

Time 1 Assessment of Responses to Positive Emotion-Inducing Slides

Following the assessment of RSA_{REST}, participants viewed sets of slides pretested to elicit: no emotion (neutral), compassion, awe, and pride[1] (Oveis, Horberg, & Keltner, 2008). The neutral slides were always viewed first, followed by the compassion, awe, and pride sets presented in randomized order. All slides were presented on a 17" flat-screen LCD monitor, with each slide having display dimensions of approximately 11" × 14". Each slide set presentation ran 2 min and 15 s, beginning with a 15-s display of a blank screen, followed by the continuous presentation of 15 thematically consistent slides for 8 s each. The compassion slides depicted scenes of vulnerability and harm, the awe slides depicted scenes of vastness in nature, the pride slides depicted national and university symbols, and the neutral slides depicted numbers and shapes. After viewing each set of slides, participants rated how strongly they felt the positive emotions compassion, awe, enthusiasm, and pride, and the negative emotions fear, anger, and sadness on a scale from 0 (*not at all*) to 8 (*strongest possible*). Composites were computed by averaging the four positive emotions, and by averaging the four negative emotions (see Table 2 for alphas). Phasic response scores were calculated by subtracting baseline (neutral) emotional reports from each emotional slide set's corresponding emotional reports. Phasic response composites were computed by averaging the four positive emotion change scores, and by averaging the four negative emotion change scores, for each of the three emotional slide sets.

Online Questionnaires 1 Month and 6–8 Months After Initial Laboratory Session

Approximately 1 month after the initial lab visit ($M = 37.7$ days, $SD = 14.3$; $n = 73$), and again 6–8 months after the initial lab visit ($M = 218.9$ days, $SD = 13.0$; $n = 56$), participants completed an online questionnaire assessing personality traits related to positive and negative emotionality (Extraversion, Agreeableness, Neuroticism), enduring positive and negative moods, and optimism and pessimism.

Extraversion, Agreeableness, and Neuroticism. Participants completed the Extraversion (eight items, $\alpha = .91$), Agreeableness (nine items, $\alpha = .79$), and Neuroticism (eight items, $\alpha = .85$) scales of the Big Five Inventory (John & Srivastava, 1999) on a response scale from 1 (*disagree strongly*) to 5 (*agree strongly*).

Positive and negative moods. Enduring positive and negative moods were assessed using the state version of the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark & Tellegen, 1988), wherein participants reported on emotional moods experienced "during the past month" on a scale from 1 (*slightly or not at all*) to 5 (*very much*). This approach, compared to the general version of the PANAS, enables participants to report on actual moods, rather than attitudes about moods (see Robinson & Clore, 2002). Internal reliability was good for the 10-item positive mood scale ($\alpha = .91$) and the 10-item negative mood scale ($\alpha = .88$).

Optimism and pessimism. Participants completed the Life Orientation Test (Scheier & Carver, 1985), a 12-item scale that measures dispositional optimism and pessimism with 8 core items (4 concerning optimism, 4 concerning pessimism) along with 4 distracters. Each item was assessed on a scale from 1 (*disagree strongly*) to 5 (*agree strongly*). We conducted a principal components analysis with principle axis factoring to determine how to treat the eight core items, as one factor or two. A scree plot indicated two factors, with eigenvalues of 4.07 (50.8% of variance) and 1.38 (17.3% of variance). All other eigenvalues were well below 1.00. The rotated factor matrix showed

[1] All slides and a complete report of emotion ratings are available from the corresponding author.

that the four optimism items formed a coherent factor, with loadings from .61 to .92 and a highest cross-loading of .31. Similarly, the four pessimism items formed a coherent factor, with loadings from .58 to .73 and a highest cross-loading of .25. Internal reliability was good for the four optimism items ($\alpha = .86$) and the four pessimism items ($\alpha = .82$).

Results

Tests of the Association Between Resting RSA and Emotional Dispositions and Enduring Moods

To test the relationship between RSA_{REST} and positive and negative emotion at the tonic level, we first examined three stable superordinate personality traits that are characterized by positive (Extraversion, Agreeableness) and negative (Neuroticism) emotionality. Extraversion, characterized by an energetic approach to the social world, is defined by positive emotionality (John & Srivastava, 1999). Agreeableness, characterized by a prosocial and communal orientation, is characterized by interpersonal warmth (Graziano & Tobin, 2002; John & Srivastava, 1999). In contrast, Neuroticism is characterized by negative emotionality and a lack of emotional stability (John & Srivastava, 1999). Consistent with the claim that RSA_{REST} is associated with tonic positive emotionality, RSA_{REST} ($M = 6.09$ ln ms^2, $SD = 1.01$) was significantly and positively associated with Extraversion at 1 month, $r(73) = .37$, $p < .01$, and 6–8 months, $r(56) = .38$, $p < .01$ (see Table 1). RSA_{REST} was associated positively with Agreeableness marginally at 1 month, $r(73) = .22$, $p = .06$, and significantly at 6–8 months, $r(56) = .35$, $p < .01$. RSA_{REST} was marginally and negatively associated with Neuroticism at 1 month, $r(73) = -.21$, $p = .07$, and was not significantly associated with Neuroticism at 6–8 months, $r(56) = -.20$, $p = .14$.

Table 1
Correlation of Time 1 RSA_{REST} With Personality Traits, Moods, and Optimism Assessed 1 and 6–8 Months Later

Variable	Time 1 resting RSA	
	1 month	6–8 months
Personality traits		
Extraversion		
r	.37**	.38**
df	73	56
Agreeableness		
r	.22[a]	.35**
df	73	56
Neuroticism		
r	−.21[b]	−.20
df	73	56
Moods and optimism		
Positive mood		
r	.36**	.34*
df	71	56
Negative mood		
r	.03	−.11
df	71	56
Optimism		
r	.27*	.33*
df	66	50
Pessimism		
r	−.17	−.17
df	66	50

Note. RSA_{REST} = resting respiratory sinus arrhythmia. One month and 6–8 months indicate temporal distance from Time 1 assessment of RSA_{REST}.
[a] $p = .06$. [b] $p = .07$.
* $p < .05$. ** $p < .01$.

Due to intercorrelations among the three traits at both assessments (e.g., at the 1-month assessment, Extraversion with Neuroticism, $r(74) = -.31$, $p = .01$; Agreeableness with Neuroticism, $r(74) = -.32$, $p = .01$), we simultaneously regressed RSA_{REST} onto 1-month Extraversion ($\beta = .33$, $p < .01$), Agreeableness ($\beta = .15$, $p = .19$), and Neuroticism ($\beta = -.05$, $p = .66$), and separately onto 6- to 8-month Extraversion ($\beta = .28$, $p = .05$), Agreeableness ($\beta = .23$, $p = .10$), and Neuroticism ($\beta = -.02$, $p = .90$). Here, the relationship between RSA_{REST} and Extraversion remained significant; 6- to 8-month Agreeableness still accounted for marginally significant variance in RSA_{REST}; any relationship between Neuroticism and RSA_{REST} was reduced to minimal and nonsignificant levels.

Again consistent with the view that RSA_{REST} is associated with tonic positive emotionality, RSA_{REST} was positively associated with participants' reports of increased positive enduring moods at 1 month, $r(71) = .36$, $p < .01$, and 6–8 months, $r(56) = .34$, $p < .05$, but not with negative enduring moods at 1 month, $r(71) = .03$, $p = .83$, or 6–8 months, $r(56) = -.11$, $p = .44$. Positive and negative moods were not significantly correlated at 1 month, $r(72) = .10$, $p = .42$, or 6–8 months, $r(56) = .08$, $p = .58$. When simultaneously regressing RSA_{REST} onto 1-month positive ($\beta = .37$, $p < .01$) and negative moods ($\beta = -.01$, $p = .94$), or onto 6–8 month positive ($\beta = .35$, $p < .01$) and negative moods ($\beta = -.13$, $p = .31$), the relationship between RSA_{REST} and positive mood remains significant.

Similarly, RSA_{REST} was positively associated with trait optimism at 1 month, $r(66) = .27$, $p < .05$, and 6–8 months, $r(50) = .33$, $p < .05$, but not trait pessimism at 1 month, $r(66) = -.17$, $p = .17$, or 6–8 months, $r(50) = -.17$, $p = .23$. Optimism and pessimism were significantly negatively correlated at 1 month, $r(67) = -.51$, $p < .001$, and 6–8 months, $r(50) = -.38$, $p < .01$. When simultaneously regressing RSA_{REST} onto 1-month optimism ($\beta = .24$, $p = .09$) and pessimism ($\beta = -.05$, $p = .71$), or onto 6- to 8-month month optimism ($\beta = .31$, $p < .05$) and pessimism ($\beta = -.06$, $p = .70$), the relationship between RSA_{REST} and optimism remains significant or marginally significant.

Tests of the Association Between Resting RSA and Brief Positive Emotional Responses

Manipulation checks confirmed that each slide set elicited elevated reports of the target emotions, and significantly greater amounts of the target emotions than any other emotion (all ps $< .01$). The awe slides produced reports of awe, ($M = 5.75$, $SD = 2.28$), the compassion slides produced reports of compassion ($M = 6.36$, $SD = 1.80$) and sadness ($M = 6.22$, $SD = 1.45$), and the pride slides produced reports of pride ($M = 5.55$, $SD = 2.36$).

We first examined whether RSA_{REST} was associated with tonic emotionality at the level of current emotional states by examining emotional reports associated with the neutral slides. Here we find that RSA_{REST} was positively related to positive emotion in response to the neutral slides, but not to negative emotion in response to the neutral slides (see Table 2). When simultaneously

Table 2
Correlation of RSA_{REST} With Concurrent Emotional Reports

Value	Correlation of RSA_{REST} with emotional reports			
	Neutral slides	Compassion slides	Pride slides	Awe slides
Composite positive emotion				
r	.29**	−.15	.02	−.13
p	.01	.21	.86	.26
df	74	74	74	74
α	.82	.60	.68	.49
Composite negative emotion				
r	.07	.07	−.05	.07
p	.56	.58	.65	.55
df	74	74	74	74
α	.60	.56	.76	.68

Note. For the compassion, pride, and awe slides, emotional reports are calculated as change scores from baseline. RSA_{REST} = resting respiratory sinus arrhythmia.
** $p < .01$

regressing RSA_{REST} onto positive ($\beta = .33$, $p = .01$) and negative emotion ($\beta = -.08$, $p = .54$), the relationship between RSA_{REST} and tonic positive emotion remains significant.

We next examined whether RSA_{REST} was related to phasic positive and negative emotional reports following the three positive emotion-eliciting slide sets. No significant relationship was obtained between RSA_{REST} and change in positive or negative emotion from baseline to any of the three positive emotion-eliciting slide sets.

Finally, we examined correlations between RSA_{REST} and video-matched emotional responding to determine if RSA_{REST} related to emotion-specific reactivity, finding no systematic relationship. RSA_{REST} was not significantly associated with change in compassion, $r(74) = .05$, $p = .67$, or sadness, $r(74) = -.07$, $p = .58$, to the compassion film, nor with change in pride to the pride film, $r(74) = -.14$, $p = .23$, or change in awe to the awe film, $r(74) = -.12$, $p = .32$.

Discussion

The central aim of the present study was to ascertain whether resting RSA is associated with tonic positive or negative emotionality. Consistently, we found that RSA_{REST} was associated with tonic positive emotionality but not with tonic negative emotionality. RSA_{REST} was associated with tonic positive emotionality at three levels of measurement: in terms of emotionally laden personality traits, Extraversion and Agreeableness; in terms of positive moods that endure over time and dispositional optimism; and in terms of current reports of positive emotion following the display of neutral stimuli. The associations between RSA_{REST} and Extraversion, Agreeableness, positive mood and optimism were observed even when separated by 6–8 months. This pattern of results makes less likely the possibility that the observed associations were obtained due to transient state variance.

Simultaneous regressions confirmed that RSA_{REST} continued to be associated with positive mood when controlling for negative mood, with optimism when controlling for pessimism (although marginally so at 1 month), and with positive emotions following neutral slides when controlling for negative emotions following neutral slides. Similarly, RSA_{REST} and Extraversion, a trait defined by positive emotionality, continued to be associated when controlling for Agreeableness and Neuroticism; Agreeableness, defined by interpersonal warmth, continued to account for considerable (and, at 6–8 months, marginally significant) variance in RSA_{REST} when controlling for Extraversion and Neuroticism. Taken together, these results provide strong evidence linking resting RSA to tonic positive emotionality.

In pursuing our second aim, the results argue against the possibility that RSA_{REST} indexes positive (or negative) emotional reactivity to three types of positive emotion-inducing stimuli—compassion, pride, or awe. Whereas RSA_{REST} was associated with positive emotion at baseline, RSA_{REST} was not associated with phasic positive or negative emotion in response to the stimuli, conceptualized in terms of change from baseline. Nor was RSA_{REST} associated with slide-congruent emotional reactivity to compassion-, pride-, and awe-inducing slides, such as increased reports of pride to the pride slides. These results are consistent with previous studies finding no relationship between RSA_{REST} and positive emotion in response to amusement- or enthusiasm-inducing film clips (e.g., Demaree et al., 2004, 2006; Frazier et al., 2004), and extend previous work by examining more social elicitors of positive emotion (people, in the case of both compassion and pride), as well as more social emotions (compassion, pride, and awe). However, it is important to bear in mind the caveat that the slide-congruent reactivity analyses were conducted using single-item emotion responses, which are typically less reliable than composite measures such as our positive and negative emotion composites. Thus, a more extensive investigation of phasic emotional reactivity across a greater array of emotional stimuli is warranted.

It is important to note that respiration rate and depth, which can affect RSA_{REST} independent of vagal tone (Grossman & Taylor, 2007), were not measured in the present study. This introduces a potential confound as well as additional error variance in using RSA_{REST} as an index of vagal tone. However, measures of RSA_{REST} that include respiratory parameters are well-correlated with those that do not, and debate exists about the necessity of including respiratory measures when assessing RSA_{REST} (Houtveen, Rietveld, & De Geus, 2002). Of the six studies we cite concerning the relationship between RSA_{REST} and emotional responding in healthy adults, only one (Butler et al., 2006) employed measures of respiration. Further, resting assessments of RSA are less susceptible to respiratory confounds than those conducted under mental, emotional, or physical demands (Grossman & Taylor, 2007; Houtveen et al., 2002). Thus, we do not think it is likely that systematic patterns of respiration rate or depth account for the observed associations between RSA_{REST} and tonic positive emotionality. Nevertheless, further work is necessary to rule out this possibility.

It will also be important for future research to consider a possible role of emotion regulatory processes in the observed relationship between RSA_{REST} and tonic positive emotionality (e.g., Butler et al., 2006; Fabes & Eisenberg, 1997). RSA_{REST} and other measures of cardiac vagal control tend to be associated with increased regulatory abilities (e.g., Fabes & Eisenberg, 1997;

Segerstrom & Solberg Nes, 2007). In studies of emotional reactivity, it is often difficult to parse the independent influences of emotional reactivity and regulatory processes on emotional responding. By examining a broad range of emotional responses over time, our work attempted to avoid regulatory influences on emotion that occur due to regulatory strategies employed during emotional states. However, recent research suggests that individuals possess trait-based emotion regulatory tendencies that chronically influence emotional responding (Gross & John, 2003). Thus, a promising avenue of research will be to examine how long-term and trait-based emotion regulation strategies may factor into the relationship between RSA_{REST} and tonic increases in positive emotion.

More generally, the results from the present investigation fit with an emerging view that RSA_{REST} is associated with the ability to adapt effectively to the social environment (Beauchaine, 2001; Porges, 2001). RSA_{REST}, our data suggest, indexes tonic positive emotionality, which may function as a relational building block, serving to promote approach, signal cooperation, and build social support resources (Fredrickson, 1998). The present findings are also consistent with perspectives from the child development literature indicating that RSA_{REST} may serve as an indicator of social competence and emotional style (e.g., Eisenberg et al., 1995; see Beauchaine, 2001 for a review).

The results of the present study also dovetail with studies of psychopathology suggesting a positive association between RSA_{REST} and positive emotion. Depression, a disorder characterized by deficits in positive emotion, is often (though not always) marked by low RSA_{REST} (Beauchaine, 2001; see Rottenberg, 2007 for a review). In contrast, samples of participants at risk for and clinically diagnosed with bipolar disorder, which involves episodes of mania characterized by abnormally elevated positive emotion, display elevated tonic cardiac vagal control (Beauchaine, 2001; Gruber, Johnson, Oveis, & Keltner, 2008).

To be speculative, our work may contribute to attempts to document physiological markers of affective style. Relevant research has documented that relatively higher left versus right frontal lobe activation predicts more intense positive emotional response (e.g., Davidson, 1992), that Extraversion has been linked to dopamine response (Depue & Morrone-Strupinsky, 2005), as well as to left amygdala activation during the detection of positive facial stimuli (Canli, Sivers, Whitfield, Gotlib, & Gabrieli, 2002), and that oxytocin promotes trust and prosocial behavior (Kosfeld, Heinrichs, Zak, Fischbacher, & Fehr, 2005). The endeavor to map relations between RSA and central nervous system processes associated with positive emotion is an area of inquiry brimming with likely discoveries, and is enabled by present data linking resting RSA to tonic positive emotionality.

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