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Does Baseline Heart Rate Variability Reflect Stable Positive Emotionality?

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Abstract

Several recent studies have found significant correlations, medium in effect size, between baseline heart rate variability (HRV) and measures of positive functioning, such as extraversion, agreeableness, and trait positive affectivity. Other research, however, has suggested an optimal level of HRV and found nonlinear effects. In the present study, a diverse sample of 239 young adults completed a wide range of measures that reflect positive psychological functioning, including personality traits, an array of positive emotions (measured with the Dispositional Positive Emotions Scale), and depression, anxiety, and stress symptoms (measured with the DASS and CESD). HRV was measured with a 6-minute baseline period and quantified using many common HRV metrics (e.g., respiratory sinus arrhythmia, root mean square of successive differences, and others), and potentially confounding behavioral and lifestyle variables (e.g., BMI, caffeine and nicotine use, sleep quality) were assessed. Neither linear nor non-linear effects were found, and the effect sizes were small and near zero. The findings suggest that the cross-sectional relationship between HRV and positive experience deserves more attention and meta-analytic synthesis.

Keywords

Heart rate variability; respiratory sinus arrhythmia; well-being; positive emotions; personality

1. Introduction

As people breathe in, their heart rate speeds up; as they breathe out, their heart rate slows (Drew & Sinoway, 2012). Known as respiratory sinus arrhythmia (RSA) or high-frequency heart rate variability (HRV), this variability in heart rate due to breathing reflects activity of the parasympathetic branch of the autonomic nervous system on the heart. It has attracted

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The data have been archived at Open Science Framework: https://osf.io/gxfmn/. We encourage researchers to reanalyze and use the data for their own purposes.

enormous interest in psychophysiology (Berntson, Cacioppo, & Quigley, 1993), largely because it appears to relate to self-regulation and emotional control (Graziano & Derefinko, 2013; Segerstrom, Hardy, Evans, & Winters, 2012), among many other things.

One recent application of HRV has been to individual differences in chronic positive emotionality. Several studies have reported significant cross-sectional relationships between baseline measures of HRV and self-reported measures of chronic positive experiences and traits. Oveis et al. (2009), for example, measured HRV during a 90 second baseline period in a sample of 80 young adults. This resting HRV value correlated with several self-report measures of positive functioning obtained a month later. People with higher baseline HRV had higher self-reported extraversion (r = .37), agreeableness (r = .22), optimism (r = .27), state positive affect (r = .36), and lower neuroticism (r = −.21). Similarly, Wang, Lü, and Qin (2013) measured HRV during a 5 minute baseline in a sample of 98 young adults. Resting HRV correlated with baseline positive affectivity (r = .31) but not negative affectivity (r = −.03), measured using the trait form of the PANAS (Watson, Clark, & Tellegen, 1988).

Recently, some research has suggested that the relationship might be nonlinear (Kogan, Gruber, Shallcross, Ford, & Mauss, 2013). In their study, 231 middle-aged adults' HRV was measured while they watched a 2 minute neutral film. One week before, the participants had completed measures of subjective well-being (Pavot & Diener, 1993), a 23-item version of the Global Assessment of Functioning Scale, and the Beck Depression Inventory. Significant quadratic effects of HRV were found for all three outcomes, reflecting an increase in positive experience as HRV increased and then a decline, which suggests an optimal level of HRV in the moderate-to-high range.

In the present research, we sought to replicate and extend the nascent literature on HRV and positive emotion. We combined two data sets in which people completed a baseline physiological assessment period along with many self-report measures relevant to positive functioning. Combining the data afforded a large sample and a robust test of relationships between HRV and positive emotionality. We extended past research in several respects. First, we assessed HRV more comprehensively than some past studies. Our baseline period was 6 minutes, which is notably longer than the 90-sec and 120-sec baselines used in some past studies, and we evaluated a range of HRV metrics. Most research to date has reported just one of many possible HRV metrics, so evaluating the robustness of the effect across metrics is important. Second, we assessed a wide range of outcomes relevant to positive affectivity, such as personality traits, dispositional positive emotions, and depressive and anxious symptoms. The set of outcomes includes measures used in past work as well as several new ones. Both positive indicators (e.g., dispositional positive affect) and negative indicators (e.g., depressive symptoms) of positive functioning were included, as in past work, to capture a broad range of outcomes. Third, we measured and sought to control for the influence of many behavioral and lifestyle factors that are correlated with both personality and autonomic activity, such as poor sleep, exercise, body mass index, and caffeine and nicotine use. And finally, we did this with a large sample that was racially and ethnically diverse.

2. Method

2.1. Participants

The sample consisted of 239 young adults (173 women, 66 men) enrolled at UNCG. People participated as part of a voluntary research option for a psychology class or took part and received $10 USD in cash. The average age of the sample was 19.0 years (*SD* = 1.59, range from 18 to 30). The sample was diverse regarding self-reported race and ethnicity: 60% European American, 31% African American, 11% Hispanic or Latino, 4% Asian or Pacific Islander, and 3% Native American (people could pick more than one option or decline to pick any). The average BMI of the participants was 24.34 (*SD* = 4.60, range from 15.91 to 44.63), indicating wide variability with an average at the cusp of "normal weight" and "overweight." The sample of 239 people does not include 19 participants whose data were excluded because of technical problems or an inability to get clean readings, most of which stemmed from hardware or software problems, or 4 people who were excluded because of prescription medications that affect cardiorespiratory activity.

2.2. Procedure

People took part individually. The research was approved and monitored by the UNCG IRB. After completing the consent form, people were connected to the physiological monitoring equipment. After the signals were screened and allowed to stabilize for approximately 4 minutes, baseline data were collected while the participants spent 10–12 minutes sitting upright and completing innocuous computer-based questionnaires with a mouse. Unlike "active relaxation" or "no activity" baselines, this "normal activity" baseline does not attempt to induce a state of relaxation (which would confound baseline HRV with individual differences in the ability to relax), and it provides a good estimate of what people's baseline HRV is during a common activity for the sample (i.e., sitting at a computer). The middle 6 minutes were screened and scored for the baseline assessment. The middle six minutes were selected to ensure that the signals had thoroughly stabilized.

The total sample represented a pooling of two samples. The first sample (*n* = 131) took part in a study of the psychophysiology of effort (Silvia, Nusbaum, Eddington, Beaty, & Kwapil, in press); the second sample (*n* = 108) took part in an unpublished study of physiological aspects of aesthetic experience. Both studies had the same baseline period but varied in the post-baseline tasks and questionnaires, so the two datasets could be pooled for the purpose of analyzing individual differences in baseline HRV.

2.3. Self-Report Measures

2.3.1. Personality traits—Participants in both samples completed the NEO Five Factor Inventory (McCrae & Costa, 2007, 2008), a 60-item scale that measures the five major factors of personality: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. People responded to each item on a 5 point scale (1 = *strongly disagree*, 5 = *strongly agree)*. Oveis et al. (2009) used measures of extraversion, agreeableness, and neuroticism as markers of stable positive emotionality, and a large literature has demonstrated links between extraversion and neuroticism in particular on positive and negative emotions (Watson, 2000).

2.3.2. Dispositional positive emotions—Participants in the second sample completed the Dispositional Positive Emotions Scale (DPES; Shiota, Keltner, & John, 2006), which measures an array of positive emotions. The scale has 38 items that people complete using a 7-point response scale (1 = *strongly disagree*, *7 = strongly agree)*. The scale has subscales for the typical experience of amusement ("I am very easily amused"), awe ("I feel wonder almost every day"), compassion ("I often notice people who need help"), contentment ("I am at peace with my life"), joy ("I often feel bursts of joy"), love ("I love many people"), and pride ("I am proud of myself and my accomplishments").

2.3.3. Depressive symptoms—Both samples completed the 21-item version of the Depression Anxiety Stress Scales (DASS; Lovibond & Lovibond, 1995), which measures anhedonic depressive symptoms, anxious arousal symptoms, and general stress symptoms. The DASS was designed to cover the full range of core symptoms of anxiety and depression while discriminating between them, and it works well in both clinical and unselected samples (Lovibond, 1998). People describe how much each item applied to them during the past week using a 4-point scale (0 = *Did not apply to me at all*, 3 = *Applied to me very much)*.

The first sample also completed the Center for Epidemiological Studies—Depression Scale (CESD; Radloff, 1977). The CESD has 20 items that measure a broader range of depressive symptoms than the DASS. People report how often they "felt or behaved" the way described by an item (e.g., "I felt lonely" and "I had crying spells") during the past week, using a 4-point scale.

2.3.4. Lifestyle and behavioral control items—Participants in both samples completed items designed to measure behavioral and lifestyle factors that could influence autonomic activity during the period of the experiment. People reported the number of caffeinated drinks that had that day and whether they had consumed nicotine (0 = *No, 1 = Yes)* or exercised (0 = *No, 1 = Yes)* in the 3 hours before the study. The past night's sleep was measured with two items: one for duration ("Around how many hours did you sleep last night?" reported in hours), and one for quality ("Apart from how long you slept, how would you rate the *quality* of your sleep last night?" 1 = *Very Poor*, 5 = *Very Good)*. Body mass index (BMI) was calculated using people's self-reported height and weight. Finally, people listed all the medications they were currently taking. People who reported medications that strongly affected cardiac or respiratory autonomic functioning (e.g., beta blockers and anticholinergics) were excluded and do not appear in this sample. The remaining participants were classified as listing no (scored 0) or any prescription medications (scored 1).

2.4. Physiological Assessment

Impedance cardiography methods were used to measure the physiological parameters necessary to estimate HRV. Cardiac interbeat intervals were measured via an electrocardiogram (ECG), for which electrodes were placed in a modified Lead-II configuration (left and right lowest ribs and the right clavicle). Respiration was measured using the thoracic impedance (Z_0) signal (Ernst, Litvack, Lozano, Cacioppo, & Berntson,

1999). Spectral methods can reliably estimate variation in Z_0 due to breathing (Houtveen, Groot, & de Geus, 2006). All signals were sampled at 1000 Hz and filtered offline with a 60 Hz notch filter and bandpass filters for the ECG (.5 to 45 Hz) and Z_0 (10 to 45 Hz) signals. The ECG data were visually inspected and manually corrected for ectopic beats, artifacts, and misidentified R-peaks as needed. A very small percentage required correction (< .1% of beats).

Because a wide range of HRV metrics are available (Allen, Chambers, & Towers, 2007) and past work has used different outcomes, we calculated and evaluated many metrics. Respiratory sinus arrhythmia (RSA), the most common frequency domain measure, was calculated as high-frequency heart rate variability (HRV) in the frequency range associated with respiration (0.12–0.40 Hz). Root mean square of successive differences (RMSSD), the most common time-domain measure, calculates variability in the interbeat interval (IBI) series. Two additional time-domain measures were evaluated: the standard deviation of the IBI values (SDNN) and the percentage (pNN50) of IBI values that were at least 50 ms different from the preceding value. In all cases, higher numbers reflect greater variability.

The six-minute baseline period was carved into six 60-second epochs. The physiological outcomes—heart rate (HR), interbeat intervals (IBI), respiration rate, and the HRV metrics—were calculated for each epoch and then averaged for an overall score. Some data for some epochs were missing for some participants, usually because of excessive noise or movement.

3. Results

3.1. Descriptive Statistics

Table 1 reports the descriptive statistics and correlations for the HRV metrics; Table 2 reports their correlations with the outcome variables. The sample sizes vary somewhat due to missing data. The data have been archived at Open Science Framework: https://osf.io/gxfmn/. We invite readers to download the data and use them for their own purposes.

3.2. Linear Effects of HRV on Outcome Variables

Did HRV correlate with markers of positive affectivity? Table 2 displays the correlations between the self-report outcomes and the metrics of HRV. None of the correlations between any metric of HRV and the self-reported outcomes were significant. When viewed in light of effect sizes (Cumming, 2014), these correlations reveal effects that range from essentially zero to small, using the .10/.30/.50 guidelines for small/medium/large effect sizes (Cohen, 1988). The only statistically significant correlation in Table 2 is between openness to experience and respiration rate. In short, it's apparent that the linear effects found in past research, such as the moderate (r = .30) correlations between HRV and trait positive affectivity, were not replicated here (Oveis et al., 2009; Wang et al., 2013).

3.3. Are the Effects Non-Linear?

Our next analyses evaluated whether the effects were nonlinear, in light of Kogan et al.'s (2013) evidence for quadratic effects. For each outcome, we ran a regression model with

linear and quadratic terms for each HRV metric. For simplicity, we evaluated only RSA and RMSSD, which are the two most prominent HRV metrics. The HRV scores were first standardized to center them at zero, and quadratic terms were created by squaring the standardized variables. Table 3 reports the R^2 values for these models. In terms of effect sizes, it's apparent the amount of variance explained was quite small, less than 2% in nearly all cases. In terms of statistical significance, only one model contained significant predictors. For the CESD, RMSSD had significant linear (b = 2.72, SE = 1.81, p = .042) and quadratic (b = −.69, SE = .33, p = .039) effects. The pattern, however, is not in the direction one would expect: CESD scores increased and then declined as RMSSD increased. Viewed broadly, the non-linear effects found in past work (Kogan et al., 2013) did not replicate in this sample.

3.4. Additional Analyses

Additional exploratory analyses were conducted to consider the possible influence of outlying values or confounding factors. The results were not appreciably affected when (1) people who reported any medication use were excluded, and (2) people with RSA or RMSSD values of more or less than 2.5 *SD* from the sample mean were excluded. Likewise, controlling for lifestyle and behavioral factors did not notably alter the results. Finally, we conducted power analyses, using Monte Carlo simulations (Muthén & Muthén, 2002), to estimate power to detect significant effects for a bivariate correlation across a range of effect sizes (see Table 4). These power values show that our power to find the moderate linear effects found in past work (Oveis et al., 2009; Wang et al., 2013) was high.

4. Discussion

Does baseline HRV predict individual differences in positive emotionality? The present findings did not replicate several other studies: HRV did not significantly predict any of the measures of positive functioning, and the effect sizes for both linear and non-linear models were very small. Our study differed from past work in several respects: (1) it assessed a wide range of HRV metrics along with a wide range of measures of positive functioning, including some that have not been explored in past research (e.g., the DPES); (2) for many outcomes, it had a sample size that was over twice as large as many past studies on this topic; and (3) it had a lengthy baseline period (6 minutes) that was much longer than some baselines in past work (e.g., 90 or 120 seconds).

Psychology is in a period of renewed interest in replications, false positives, and publication bias (e.g., Makel, 2014; Murayama, Pekrun, & Fiedler, 2014; Simmons, Nelson, & Simonsohn, 2011). We should point out that failing to replicate past work does not necessarily mean that something went awry in past work: there are false negatives as well as false positives, of course, and our methods and sample varied from past work in many respects. Our sample was racially and ethnically diverse, with a high proportion of African Americans, and it had a high proportion of women. BMI was also quite variable, with an average that is somewhat high given the population (young college students). Age, gender, BMI, and race and ethnicity are known to influence baseline levels of HRV (e.g., Bhattacharyya, Whitehead, Rakhit, & Steptoe, 2008; De Meersman & Stein, 2007), and it

would be important for future work to report these sample features in more detail than past research has done.

More generally, we agree with Cumming's (2014) notion of "meta-analytic thinking," a research mindset that emphasizes effect sizes, recognizes the large influence of sampling variability on research findings, and focuses on pooling individual studies for eventual synthesis. Some research has found linear effects of HRV on positive emotionality (Oveis et al., 2009), some studies have found non-linear effects (Kogan et al., 2013), and others, such as the present study, have found neither. This problem is nicely suited to meta-analysis. Many studies have measured baseline HRV and outcomes that reflect positive psychological functioning as part of testing other hypotheses, so there are many effect sizes that could be pooled.

We should point out that the present research focused on cross-sectional correlations between baseline HRV and individual differences related to positive emotionality. It wasn't intended to speak to other contributions of HRV to emotion, such as how people control their emotions (e.g., Graziano & Derefinko, 2013), respond to emotional images (e.g., Oveis et al., 2009), or behave in everyday life (e.g., Kok & Fredrickson, 2010). In addition, our focus, as in past work, was on normally functioning populations rather than groups with cardiovascular disease (e.g., Bhattacharyya et al., 2008) or with diagnosed psychological disorders. It's notable, however, that two meta-analyses of research with clinically-depressed samples have found only small effect sizes of depression on HRV (Kemp et al., 2010; Rottenberg, 2007). The very small effects observed in the present sample seem consistent with the small effects observed in studies that compared "extreme groups" that differed in psychological well-being.

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Research Highlights

- Heart rate variability (HRV) predicts positive emotionality in past studies.
- Several HRV metrics were derived from a 6-min. baseline period.
- Measures of positive and negative emotion and experience were assessed.
- Small, null effects appeared for all HRV metrics and all outcomes.
- The linear and non-linear effects from past work were not replicated.

Table 1

Descriptive Statistics for the Physiological Variables

Outcome	*M*	*SD*	*RSA*	RMSSD	SDNN	pNN50	Respiration Rate	Heart Rate	IBI
RSA	6.32	1.37	1						
RMSSD	61.40	74.99	.76	1					
SDNN	60.68	51.44	.80	.99	1				
pNN50	22.90	20.67	.69	.37	.37	1			
Respiration Rate	18.48	2.61	−.22	−.01	−.05	.00	1		
Heart Rate	79.08	11.67	−.52	−.29	−.30	−.68	.13	1	
IBI	776.40	119.68	.48	.29	.29	.68	−.12	−.97	1

Note. RSA = respiratory sinus arrhythmia; RMSSD = root mean square of successive differences (RMSSD); SDNN = standard deviation of the IBI values; pNN50 = percentage of IBI values that were at least 50 ms different from the preceding value; IBI = interbeat interval.

Table 2

Descriptive Statistics and Correlations Between Physiological Variables and Psychological Measures

Outcome	*n*	α	*M*	*SD*	RSA	RMSSD	SDNN	pNN50	Respiration Rate	Heart Rate	IBI
Neuroticism	223	.84	3.15	.66	−.04	−.09	−.10	.08	.00	−.06	.09
Extraversion	223	.79	3.54	.52	.11	.01	.02	.09	.00	−.02	−.01
Openness to Experience	223	.77	3.62	.54	.01	−.01	−.01	.07	.17	.02	.00
Agreeableness	223	.80	3.69	.56	.09	.06	.07	.07	.06	.05	−.05
Conscientiousness	223	.83	3.51	.54	.02	.01	.03	.01	.05	.02	−.02
DASS: Depression	220	.87	.58	.61	.00	.02	.02	.09	−.02	−.06	.08
DASS: Anxiety	220	.77	.58	.54	.03	−.02	−.02	.13	.03	−.08	.08
DASS: Stress	220	.79	.92	.61	−.01	−.02	−.02	.10	.00	−.04	.05
CESD	124	.91	15.00	10.54	.06	.05	.07	.13	.07	−.08	.12
Amusement	99	.74	5.04	1.16	−.14	−.16	−.15	.05	.15	.04	−.05
Awe	99	.77	4.72	1.04	−.03	−.03	−.05	.10	−.01	.06	−.06
Compassion	99	.79	5.67	1.01	−.02	−.03	−.04	−.01	.03	.16	−.17
Contentment	99	.82	4.88	1.07	.12	.11	.12	.03	−.05	.08	−.09
Joy	99	.80	4.86	1.04	.06	.02	.03	.04	−.05	.06	−.08
Love	99	.76	4.29	1.12	.03	.04	.04	.05	−.04	.04	.00
Pride	99	.67	5.24	.87	−.01	.02	.03	.00	−.03	.09	−.11

Note. *n* is the sample size for the analyses for that outcome. The only significant correlation is between openness to experience and respiration rate. RSA = respiratory sinus arrhythmia; RMSSD = root mean square of successive differences (RMSSD); SDNN = standard deviation of the IBI values; pNN50 = percentage of IBI values that were at least 50 ms different from the preceding value; IBI = interbeat interval.

Table 3

Total Variance Explained (Linear and Quadratic Effects) by RSA and RMSSD

Outcome	RSA	RMSSD	*n*
Neuroticism	1.0	1.3	223
Extraversion	1.6	1.9	223
Openness to Experience	0.2	0.0	223
Agreeableness	0.8	0.3	223
Conscientiousness	0.2	0.4	223
DASS: Depression	0.2	0.1	220
DASS: Anxiety	0.1	0.3	220
DASS: Stress	0.1	0.3	220
CESD	0.3	3.7*	124
Amusement	2.1	2.6	99
Awe	0.1	0.1	99
Compassion	0.3	1.6	99
Contentment	1.6	1.4	99
Joy	0.4	0.4	99
Love	0.8	0.4	99
Pride	0.2	0.4	99

Note. Values are percentages for a model including both linear and quadratic effects. An asterisk indicates that one or more effects were significant (see text for details).

Table 4

Monte Carlo Power Simulations for a Range of Correlation Coefficients

Coefficient	Full Sample (*n* = 223)	Subsample 1 (*n* = 124)	Subsample 2 (n = 99)
r = .10	.34	.25	.22
r = .20	.86	.67	.59
r = .30	.99	.95	.89
r = .40	1.00	.99	.99
r = .50	1.00	1.00	1.00

Note. The simulations were run in Mplus 7.2, using 1000 Monte Carlo samples.