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Vagally-Mediated Heart Rate Variability and Indices of Wellbeing: Results of a Nationally Representative Study

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Abstract

Objective—High frequency (HF) heart rate variability (HRV) has long been accepted as an index of cardiac vagal control. Recent studies report relationships between HF-HRV and indices of positive and negative affect, personality traits and wellbeing but these studies generally are based on small and selective samples.

Method—These relationships were examined using data from 967 participants in the second Midlife in the US (MIDUS II) study. Participants completed survey questionnaires on wellbeing and affect. HF-HRV was measured at rest. A hierarchical series of regression analyses examined relationships between these various indices and HF-HRV before and after adjustment for relevant demographic and biomedical factors.

Results—Significant inverse relationships were found only between indices of negative affect and HF-HRV. Relationships between indices of psychological and hedonic wellbeing and positive affect failed to reach significance.

Conclusions—These findings raise questions about relationships between cardiac parasympathetic modulation, emotion regulation, and indices of wellbeing.

Keywords

heart rate variability; cardiac parasympathetic regulation; emotion regulation; wellbeing

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Heart rate (HR) is recognized as a significant clinical index, reliably predicting cardiovascular and all cause mortality (Cooney et al., 2010) but the practice of computing it discards additional valuable clinical information that exists in the beat-to-beat time series of HRs. Heart rate variability (HRV) derived from these time series has become well established as a noninvasive index of cardiac autonomic regulation (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Efforts to extract clinically significant indices generally have relied on decomposing HRV into discrete frequency bands. The underlying physiology of these bands has been probed using pharmacological blockade, surgical denervation, and mathematical modeling. While it is generally well accepted that HF-HRV provides an index of cardiac vagal regulation, efforts to extract a pure physiological signal from lower frequency bands has been unsuccessful. Nonetheless, HRV measured in the time (Kleiger, Miller, Bigger Jr, & Moss, 1987) and frequency (Bigger et al., 1992) domains has considerable clinical significance, predicting mortality after acute myocardial infarction (MI) and in heart failure (La Rovere et al., 2003) and progression of coronary artery disease beyond that obtained by conventional risk markers (Huikuri, 1999). HRV also has been shown to predict clinically significant outcomes in healthy participants (Liao et al., 1997; Tsuji et al., 1996).

Recently, interest in HF-HRV as an index of cardiac vagal regulation has broadened to link it to indices of psychosocial functioning. For example, Oveis et al. reported that resting respiratory sinus arrhythmia (RSA), a measure of HF-HRV, was directly related to extraversion and agreeableness and inversely associated with neuroticism (Oveis et al., 2009). They also showed that resting RSA was directly associated with reports of increased positive but not negative mood, and trait optimism but not pessimism. These findings, they argued, suggested that higher resting HRV is a signal of positive tonic affect. Geisler et al. and Wang et al. also reported associations between HF-HRV and positive tonic affect (Geisler, Vennewald, Kubiak, & Weber, 2010; Wang, Lü, & Qin, 2013). Resting HRV also has been associated with regulation of negative emotional expression, although findings have been inconsistent (Butler, Wilhelm, & Gross, 2006; Demaree, Robinson, Everhart, & Schmeichel, 2004; Pu, Schmeichel, & Demaree, 2010). Very recently, Koval et al. reported that HRV was inversely associated with instability in positive affect, although no effect was seen in mean levels of positive affect (Koval et al., 2013). Koval et al. express more directly what other studies often imply: that “vagally mediated HRV may be especially important in the regulation of positive affective states” (p. e81536), i.e., that HRV influences these states.

The idea that HRV is associated with indices of emotion regulation, let alone that it is mechanistically involved in the regulation of these processes, goes well beyond the conventional uses of HRV as an index of cardiac autonomic function. Much of the evidence for this association comes from studies often relying on samples small in size and unrepresentative of the general population. For example, Oveis et al. and Butler et al. studied only small samples of undergraduate students. Demaree et al. (Demaree et al., 2004) and Koval et al. (Koval et al., 2013) reported findings from approximately 100 undergraduate students. Only Kok and Fredrickson studied a more representative sample (73 adults, age 21–68 years) (Kok & Fredrickson, 2010).

Confirmation of these findings in larger and more representative samples is required. This paper examines the relationship between HF-HRV and indices of personal psychosocial functioning, wellbeing, and personality characteristics using data from MIDUS II, a large, nationally representative dataset.

METHODS

Participants and Study Protocol

The data were collected from 967 participants in the Midlife Development in the U.S. (MIDUS) (Brim, Ryff, & Kessler, 2004), a study of the behavioral, psychological, and social factors accounting for age-related variation in health and wellbeing in a national sample of middle-age and older Americans. Data for the current study are from MIDUS II, a 9-year follow-up of the MIDUS I cohort, conducted between 2004 and 2006. MIDUS II consisted of five projects, including a self-administered survey of a wide array of behavioral, social and psychological factors and a Biomarker Project, with data collection conducted during a 1.5-day visit to a clinical research center (CRC) at the University of Wisconsin, UCLA, or Georgetown University. Survey data were collected from January 2004 to September 2006. Biomarker data were collected from January 2005 to December 2008. The mean interval between collection of the survey data and the biomarker data was 846.4 ± 427 days. Indices of wellbeing were collected both in the self-administered survey and again in the Biomarker Project.

Procedures

HRV Assessment—After an overnight stay at the CRC, participants were provided with a light breakfast, but no caffeine consumption was permitted. Following breakfast, they began the HRV psychophysiology protocol.

ECG electrodes were placed on the left and right shoulders, as well as in the left lower quadrant. ECG was recorded in Lead II. Respiration bands were placed around the chest and abdomen and the finger cuff of a Finometer beat-to-beat blood pressure monitor was placed around the middle finger of the non-dominant hand. Respiration was calibrated using an 800 cc spirobag (Ambulatory Monitoring Systems, Ardsley NY). While participants were in the seated position, data were recorded during an 11 min baseline as part of a more extensive psychophysiology protocol with exposure to challenging stimuli and recovery periods. Here we report HRV data from this resting baseline.

Analog ECG signals were digitized at 500 Hz by a 16-bit A/D conversion board (National instruments, Austin, Texas) and passed to a microcomputer. The ECG waveform was submitted to an R-wave detection routine implemented by custom-written software, resulting in an RR interval series. Errors in marking R waves were corrected by visual inspection. Ectopic beats were corrected by interpolation.

High frequency (0.15– 0.40 Hz) HRV was computed based on 300-second epochs, using an interval method for computing Fourier transforms similar to that described by DeBoer, Karemaker, and Strackee (DeBoer, Karemaker, & Strackee, 1984). The mean value of HF-

HRV from the two baseline 300-second epochs was computed, with the last 60 seconds excluded from analysis.

Respiration—Respiratory rate was measured using an Inductotrace respiration monitor (Ambulatory Monitoring Systems, Ardsley NY). Signals from thoracic and abdominal stretch bands were collected by the A/D board at 20 Hz and submitted to a custom written program that computed respiratory rate on a min by min basis. The mean respiratory rate for the baseline period was computed.

Biological Measurements—Other biological markers measured in the MIDUS II study that might affect HF-HRV were measured. These data included BMI, sex, age, smoking habits, and disease conditions and medications.

Assessment of Psychological Characteristics: MIDUS II Survey Data—Measures of psychological assessment were collected through a self-administered questionnaire. Data collection methods of MIDUS II were largely identical to MIDUS I but added questions in selected areas of psychological wellbeing and functioning. Details of the questionnaires already have been published (Brim et al., 2004).

Assessment of Psychological Wellbeing: The MIDUS II survey measured six variables that reflect psychological well-being. These include: autonomy, environmental mastery, self-acceptance, personal growth, purpose in life, and positive relations with others (Love, Seeman, Weinstein, & Ryff, 2010).

Assessment of Hedonic Wellbeing: Measures of hedonic wellbeing from the self-administered questionnaire included both positive affect and negative affect. The following scales were used to construct an index of hedonic wellbeing: cheerful, in good spirits, extremely happy, calm and peaceful, satisfied, and full of life. Variables used to construct an index of negative affect included sad, nervous, restless/fidgety, hopeless, feeling that everything is an effort and feeling worthless. Data from the positive and negative affect scales (PANAS) also were collected (Watson, Clark, & Tellegen, 1988).

Assessment of Personality Traits: The MIDUS II study measured six personality traits: agreeableness, openness to experience, conscientiousness, neuroticism, extraversion and agency.

Assessment of Psychosocial Characteristics: MIDUS II Biomarker Data—During the visit to the clinical research centers, when HRV was measured, participants also completed another series of questionnaires (Carol D. Ryff, Seeman, & Weinstein, 2013) including the Spielberger Anger/Control, Anger/In, Anger/Out, and Trait Anger indices. From the Mood And Symptom Questionnaire (MASQ), symptoms of General Distress-Anxiety, General Distress-Depression, and the Positive Affect Scale were measured. Social anxiety was measured using the Liebowitz Social Anxiety Scale. Depressive symptoms were measured using the Center For Epidemiological Studies Depression Inventory (CES-D). Finally, three indices of subjective wellbeing were collected: happiness, gratitude, and satisfaction with life (C. D. Ryff, Seeman, & Weinstein).

Statistical Analysis

Because HF-HRV data were skewed, they were natural log transformed. Four linear regression models were used to test the association of HF-HRV with measures of wellbeing and personality characteristics collected during the MIDUS II Survey and during the MIDUS II Biomarker visit.

In Model 1, each measure was regressed solely on ln HF separately. Model 2 added the covariates sex, age, BMI, site of assessment, menstrual status, exercise, and smoking status. Menstrual Status was categorized as pre- and postmenopausal. Exercise was entered as a dichotomous variable indicating whether or not the subject engaged in at least 20 minutes of exercise at least 3 times a week. Smoking status was categorized into three components: current smoker, former smoker and never a smoker. Model 3 added to the above data on medications that either enhanced or inhibited parasympathetic activity, any diagnosis of heart disease, a diagnosis of stroke, Parkinson´s Disease, and any diagnosis of other neurological condition (Mori et al., 2014). With Model 4, each measure was regressed on the Model 3 variables, except that ln HF-HRV was residualized for Respiration Rate.

We conducted an additional analysis to assess the impact of the time lag between collection of the MIDUS II survey data and HRV, examining this interval as a moderator of the relationship between HF-HRV and the survey measures. For this analysis, we added the time lag and the time lag*HF-HRV interaction terms to Model 4, and tested the interaction term for significance.

Individuals with data missing for a particular variable were removed from analyses involving that variable. The maximum level of missing data for any analysis performed was less than 13%. All analyses were carried out in SAS 9.3.

RESULTS

Sample and Measures

4041 participants had the measures of psychological and hedonic wellbeing and personality characteristics. Among 1255 MIDUS II Biomarker Study participants, a total of 1153 individuals had technically acceptable HF-HRV data. 967 participants had both sets of data. Table 1 provides descriptive statistics for the demographic, lifestyle, and biomedical characteristics for these 967 participants. Participants in the Biomarker Study were “not significantly different from either Project 1 sample on age, sex, race, marital status, or income, although respondents in the biological protocol were significantly more likely to have a college degree and significantly less likely to have only high school or some college compared with the national sample” (p. 1068, (Love et al., 2010)).

HF-HRV and Psychological Wellbeing

Table 2 presents the mean values for indices of psychological and hedonic wellbeing and personality traits. Table 3 presents results from the regression analyses. At the univariate level and in models 2, 3, and 4 after adjustment for covariates, HF-HRV was not associated

with measures of autonomy, environmental mastery, personal growth, positive relations, self-acceptance, or purpose in life.

HF-HRV and Hedonic Wellbeing

At the univariate level, HF-HRV was not significantly related to any index of positive or negative affect. However, in models 2, 3, and 4, after adjustment for covariates, both the composite index of negative affect and the negative affect index from the PANAS were inversely and significantly related to HF-HRV. Neither the composite nor the PANAS index of positive affect was related to HF-HRV in any of the models.

HF-HRV and Personality Traits

Model 1, unadjusted for any covariates, revealed no significant relationships between HF-HRV and agency, agreeableness, contentiousness, extraversion, neuroticism, or openness. Adjustment for covariates in models 2, 3, and 4 did not change these findings, except for neuroticism, which was found to be significantly and inversely related to HF-HRV in model 2, but not for either model 3 or 4.

HF-HRV and Anger, Anxiety, Depression, Subjective Wellbeing

Table 4 presents the descriptive statistics for these measures collected concurrently with the measures of HF-HRV. Results of the regression analyses are presented in Table 5. They also reveal no significant associations between HF-HRV and psychosocial functioning.

Does the Time Lag Moderate the Relationship between MIDUS Survey Wellbeing Data and HF-HRV?

Although both sets of analyses above were consistent in showing no relationship between HF-HRV and indices of wellbeing, it is possible that the absence of a relationship between the survey data and HF-HRV is due to the long interval – 846 days on average – between their measurements. To test for this, we examined whether the time lag moderated the relationship between HF-HRV and the 16 personality and wellbeing measures from the survey, testing the hypothesis that a longer lag would be associated with a weaker relationship to HF-HRV. This moderation effect achieved significance for only a single wellbeing index (positive relations, $\beta = -0.035$, $p = 0.03$), an effect that did not survive adjustment for multiple comparisons. Results of this analysis suggest that there was no moderating effect of the time lag on the relationship between MIDUS survey indices and HF-HRV.

DISCUSSION

Originally only an index of cardiac vagal regulation, HF-HRV has become identified as an index of several other functions, including emotion regulation. Just as high levels of HRV are associated cardiac health, so, recent evidence suggests, high levels of HRV are associated with personality characteristics such as extraversion, agreeableness, optimism, and positive mood (Oveis et al., 2009), positive hedonic tone, cheerfulness and calmness (Geisler, Kubiak, Siewert, & Weber, 2013), stability of positive affect (Koval et al., 2013), and connectedness and positive emotions (Kok & Fredrickson, 2010). Moreover, low levels of

HRV are associated with characteristics such as neuroticism (Oveis et al., 2009) and psychological inflexibility (Kashdan & Rottenberg, 2010). Thus, HRV has been suggested to relate to both physical as well as psychological wellbeing.

Sometimes, HRV is described as a marker of the integrity of circuits connecting brain regions associated not only with affect but also with cognitive function and physiological regulation. HRV is an index of "the degree to which a mPFC-guided 'core integration' system is integrated with the brainstem nuclei that directly regulate the heart" (p. 748, (Julian F. Thayer, Öhs, Fredrickson, Sollers III, & Wager, 2012)) and of "activity in a flexible network of neural structures that is dynamically organized in response to environmental challenges" (p. 86, (Julian F. Thayer & Lane, 2009)). Pu et al. report "cardiac vagal control reflects an internal marker of self-regulatory tendencies" (p. 531, (Pu et al., 2010)). Others use more causal language. Hopp et al. write how cardiac vagal control influences depressive symptoms and speculate that "Interventions that increase RSA could possibly enhance social behavior" (p. 148, (Hopp et al., 2013)). Most dramatically, Kok and Fredrickson suggest that HRV exerts a causal effect on emotional state: "it moderates the degree to which people experience positive emotions and social connection in daily life…" ((Kok & Fredrickson, 2010), p. 435).

Much of this literature appeals to the increased capacity for flexible response that high levels of HF HRV permit. The intact vagus exerts inhibitory control on heart rate and vagal withdrawal allows HR to increase to meet the environmental demands in a rapid and efficient manner. This capacity is central to the theories of Porges and Thayer and Lane (Lane et al., 2009; Porges, 2001). Both theories are based in part on the anatomy of the vagus, which is influenced by cortical and subcortical brain regions subserving emotion and which terminates not only on the sinoatrial node but also on organs involved in emotion and communication, e.g., the larynx, bronchi, and facial muscles. Correspondingly, many studies report that individuals who demonstrate a greater ability to regulate emotions tend to have higher levels of resting HRV, allowing greater capacity to respond to physically and environmentally demanding situations (Daly, Baumeister, Delaney, & MacLachlan, 2014; Gyurak & Ayduk, 2008; Kemp & Quintana, 2013; Lane et al., 2009).

Our data suggest that anatomy is not destiny. With the single exception of negative affect, we found no associations between HF-HRV and indices of psychological or hedonic wellbeing or affect. These findings are inconsistent with those from studies employing smaller and less representative samples. Oveis et al. studied 80 college women (Oveis et al., 2009). Geisler et al. recruited samples that were larger but still male and female undergraduates (Geisler et al., 2013). Koval et al. studied 83 undergraduates (Koval et al., 2013). Kok and Fredrickson studied 73 adult participants. Studies linking HF-HRV more broadly to emotion regulation also overwhelmingly rely on students, mostly undergraduates (Daly et al., 2014; Demaree & Everhart, 2004; Geisler et al., 2013; Gyurak & Ayduk, 2008; Kemp et al., 2012).

Others differences between these studies and ours exist. Our analyses controlled for a variety of biological confounders including BMI, age, cardioactive medications and conditions, smoking, menopausal status, exercise activity, and respiratory rate. Covariates such as menopausal status and cardioactive medications are likely to be irrelevant in undergraduates

but others, e.g., smoking status (Alyan et al., 2008; Cagirci et al., 2009; Dinas, Koutedakis, & Flouris, 2013) and exercise activity (Billman et al., 2015), are not.

While we were unable to detect relationships between HF-HRV and indices of positive affect, our findings revealed the often-reported inverse relationship between negative affect and HF-HRV (Carney, Freedland, & Stein, 2000; Demaree et al., 2004; Friedman & Thayer, 1998; Rechlin, 1994). This finding is consistent with the results of a meta-analysis of eight neuroimaging studies representing data from 191 participants demonstrating that brain regions including the amygdala and the medial PFC that are involved in perceptions of threat and safety, characteristics more closely associated with negative rather than positive affect, are also associated with HRV (Julian F. Thayer et al., 2012).

Much of the literature invoking the polyvagal or neurovisceral integration theories relies on the conflation of physiological and psychological flexibility and inhibition. It is true that the vagus exerts an inhibitory effect on HR. Inhibition of emotion, however, is a far more complex process involving assessment of a situation, evaluation of a context, the experience of an impulse, assessing the capacity to regulate it, and marshaling the resources to do so (DeSteno, Gross, & Kubzansky, 2013; Gross & John, 2003). Reporting that imaging studies reveal that regions associated with the experience of emotion also are associated with the regulation of the heart, and therefore, that HRV functions to index the integrity of these pathways, conceals these important differences. Suggestions that HRV actually regulates emotion (Kok & Fredrickson, 2010) further confuse matters.

This confusion is reflected in the routine citation of reports connecting HF-HRV and indices of wellbeing, personality, and affect, including some of ours, as supportive of a regulatory role for HRV. Indeed, we have reported that hostility is inversely associated with HF-HRV (Richard P. Sloan et al., 2001; R. P. Sloan et al., 1994). A great many other studies also have documented inverse associations between HF-HRV and indices of dysphoric affect (Kemp & Quintana, 2013). First, these studies show relationships between HF-HRV and indices of negative but not positive affect, findings consistent with the only significant effect we found.

Second, these studies were conducted to test whether the well-documented role played by autonomic nervous system dysfunction in coronary artery disease (Bigger et al., 1992; La Rovere et al., 2003; Liao et al., 1997) (La Rovere et al., 2003) also might account the risk of CAD conveyed by negative affect. Rather than demonstrating that vagal regulation indexes the integrity of an axis of neurovisceral integration, these studies support the view that the elevated risk of CAD associated with depressive symptomatology or high levels of hostility may be at least in part the product of reduced levels of cardiac vagal modulation.

Of course, HF-HRV could be both an index of the integrity of the neurovisceral axis and a mechanism by which negative affect elevates the risk of CAD. Thayer and Lane suggest precisely this (J. F. Thayer & Lane, 2007). However, for HF-HRV to function in both capacities, it must be associated with indices of psychological wellbeing. Our findings show no such associations. While it is possible that HF-HRV reflex the integrity of the neurovisceral axis only for negative affect and that positive affect is associated with other circuits, such specificity has not been proposed.

Limitations

While we found no relationships between HF-HRV and measures of psychosocial wellbeing, indices from the MIDUS II Survey project were measured before the biomarker data collection and therefore, it is possible that the lack of any relationship between these indices and HRV is due to the effect of this time lag. We think that this is unlikely for several reasons. First, psychosocial data collected concurrently with the biomarker data also were unrelated to HF-HRV. Second, in a supplementary analysis, we found no moderating effect of the time lag on the HF-HRV-wellbeing relationships. Third, the MIDUS survey wellbeing measures are remarkably stable psychological characteristics. Turiano et al. have demonstrated that over a 10-year period, nearly 5 times greater than the lag in our paper, the correlations for the MIDUS trait indices (openness, agreeability, neuroticism, conscientiousness, and extraversion) ranged from .62 to .70 (Turiano et al., 2012). Finally, the study was designed to have enough power to detect even small effect sizes (n>1000) and all the CIs, except those for negative affect, span zero (see Tables 3 and 5) indicating a high likelihood of the real effect sizes being zero or at least very small (Colegrave & Ruxton, 2003; O'Keefe, 2007).

Another limitation is that, although based on a nationally representative sample, participants in the MIDUS II Biomarkers Project had to travel to one of three clinical research centers around the country. This requirement functioned to select only those willing and healthy enough to travel. Finally, our analyses were limited to examining the relationship between resting levels of HF-HRV and indices of wellbeing. Other studies have examined the relationship between HF-HRV responses to challenging stimuli and wellbeing (Demaree et al., 2004; Wang et al., 2013).

Limitations notwithstanding, these findings are inconsistent with those from studies showing that vagally mediated HRV is associated with indices of psychological and hedonic wellbeing. In a large and nationally representative dataset, there was no such relationship. These findings raise questions about both the polyvagal and neurovisceral integration theories. More broadly, they raise concerns about the conflation of inhibition and flexibility at the physiological and psychological level.

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Table 1

Demographic and Biomedical Data

	Analyzed Subjects (967)			
Variable	**N**	**Mean**	**SD**	**Range**
Age (years)	967	54.60	11.55	34.0–83.0
Body Mass Index (kg/m^2)	938	27.88	5.49	14.2–58.0
ln HF-HRV (msec^2) *	967	4.76	1.26	0.7–9.6
Variable	**N**	**Level**	**Frequency**	**Percent**
Sex	967	Female	531	54.91
Site *	967	1 (Wisconsin)	402	41.57
		2 (UCLA)	309	31.95
		3 (Georgetown)	256	26.47
Menopausal Status (% Of Women Only)	458	Post-Menopausal	192	41.92
Regular Exercise *	967	Yes	763	78.90
Smoking Status *	966	Current Smoker	109	11.28
		Former Smoker	321	33.23
		Never A Smoker	536	55.49
Medication Causing Decreased Parasympathetic Response	967	Yes	212	21.92
Medication Causing Increased Parasympathetic Response	966	Yes	138	14.27
Heart Trouble *	967	Yes	135	13.98
History of Stroke *	967	Yes	23	2.38
History of Parkinson's *	967	Yes	1	0.10
History of Other Neurological Disorder	959	Yes	50	5.21

* Significant Difference between Analyzed and Unanalyzed Subjects

Table 2

Descriptive Statistics for Measures of Wellbeing and Personality

Psychological Measure Category	Variable	Mean	SD	Range
Psychological Wellbeing				
	Environmental Mastery	38.74	7.48	11.0–49.0
	Personal Growth	39.71	6.58	14.0–49.0
	Positive Relations w/ others	41.06	6.81	14.0–49.0
	Purpose in Life	39.59	6.51	10.0–49.0
	Self-Acceptance	38.72	8.12	7.0–49.0
Hedonic Wellbeing				
	Negative affect	1.49	0.55	1.0–4.8
	Negative affect from PANAS	1.53	0.52	1.0–4.6
	Positive affect	3.44	0.70	1.0–5.0
	Positive affect from PANAS	3.62	0.74	1.0–5.0
Personality Traits				
	Agency	2.62	0.66	1.0–4.0
	Agreeableness	3.44	0.50	1.2–4.0
	Autonomy	37.38	6.68	14.0–49.0
	Conscientiousness	3.40	0.45	1.8–4.0
	Extraversion	3.13	0.57	1.2–4.0
	Neuroticism	2.03	0.63	1.0–4.0

Table 3

Results of Regression Analyses of HF-HRV and Measures of Wellbeing and Personality

Outcome Variable	Model 1		Model 2		Model 3		Model 4	
	β	η^2	β	η^2_p	β	η^2_p	β	η^2_p
Personality Traits								
Agency	−0.01 [−0.04,0.03]	0.0001	0.01 [−0.02,0.05]	0.0004	0.01 [−0.02,0.04]	0.0003	0.01 [−0.03,0.06]	0.0003
Agreeableness	−0.01 [−0.04,0.01]	0.0008	−0.00 [−0.03,0.02]	0.0001	−0.00 [−0.03,0.02]	0.0000	−0.00 [−0.04,0.03]	0.0000
Contentiousness	−0.01 [−0.03,0.02]	0.0004	−0.01 [−0.03,0.02]	0.0004	−0.01 [−0.03,0.02]	0.0003	−0.01 [−0.04,0.02]	0.0004
Extraversion	−0.01 [−0.04,0.02]	0.0009	−0.00 [−0.03,0.02]	0.0001	−0.01 [−0.04,0.02]	0.0002	−0.01 [−0.05,0.03]	0.0002
Neuroticism	−0.00 [−0.03,0.03]	0.0000	**−0.04 * [−0.07,−0.01]**	0.0055	−0.03 [−0.06,0.01]	0.0037	−0.04 [−0.08,0.01]	0.0032
Openness	−0.00 [−0.03,0.02]	0.0000	0.00 [−0.02,0.03]	0.0000	0.00 [−0.02,0.03]	0.0001	0.00 [−0.03,0.04]	0.0001
Hedonic Wellbeing								
Negative Affect	−0.01 [−0.04,0.01]	0.0010	**−0.04 ** [−0.07,−0.01]**	0.0084	**−0.03 * [−0.06,−0.01]**	0.0059	**−0.04 * [−0.07,−0.01]**	0.0056
PANAS Negative Affect	−0.02 [−0.04,0.01]	0.0018	**−0.05 *** [−0.07,−0.02]**	0.0148	**−0.04 *** [−0.07,−0.02]**	0.0120	**−0.05 ** [−0.08,−0.02]**	0.0115
Positive Affect	0.00 [−0.03,0.04]	0.0001	0.03 [−0.00,0.07]	0.0039	0.03 [−0.01,0.06]	0.0029	0.03 [−0.01,0.08]	0.0026
PANAS Positive Affect	−0.02 [−0.06,0.01]	0.0014	0.01 [−0.03,0.05]	0.0002	0.01 [−0.03,0.04]	0.0001	0.00 [−0.04,0.05]	0.0000
Psychological Wellbeing								
Autonomy	−0.30 [−0.64, 0.03]	0.0033	−0.10 [−0.44,0.24]	0.0003	−0.08 [−0.43,0.27]	0.0002	−0.12 [−0.56,0.32]	0.0003
Environmental Mastery	−0.18 [−0.56, 0.19]	0.0010	0.24 [−0.14,0.61]	0.0016	0.19 [−0.19,0.56]	0.0010	0.21 [−0.26,0.69]	0.0008
Personal Growth	0.06 [−0.27,0.39]	0.0001	0.14 [−0.20,0.47]	0.0007	0.11 [−0.23,0.45]	0.0005	0.12 [−0.31,0.55]	0.0003

Outcome Variable	Model 1		Model 2		Model 3		Model 4	
	β	η^2	β	η^2_p	β	η^2_p	β	η^2_p
Positive Relations	−0.20 [−0.54,0.14]	0.0014	0.08 [−0.26,0.42]	0.0002	0.06 [−0.29,0.40]	0.0001	0.05 [−0.39,0.49]	0.0001
Self-Acceptance	0.01 [−0.40, 0.41]	0.0000	0.35 [−0.06,0.76]	0.0029	0.29 [−0.12,0.70]	0.0020	0.24 [−0.28,0.76]	0.0018
Purpose In Life	0.09 [−0.23, 0.41]	0.0003	0.23 [−0.10,0.56]	0.0019	0.19 [−0.14,0.52]	0.0013	0.23 [−0.19,0.65]	0.0012

β: Estimate of Change in Outcome Variable for 1 unit increase in log HF HRV (95% Confidence Interval)

η^2: Eta-squared (Subscript "p" denotes partial)

Model 1: Unadjusted for Any Covariates
Model 2: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, and Smoking
Model 3: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, Smoking, Medications affecting Parasympathetic Activity positively or negatively, Any Heart Trouble, History of Stroke, Parkinson's, and Any Other Neurological Condition.
Model 4: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, Smoking, Medications affecting Parasympathetic Activity positively or negatively, Any Heart Trouble, History of Stroke, Parkinson's, and Any Other Neurological Condition, and Corrected for Respiration Rate.

* P-value<.05

** P-value<.01

*** P-value<.001

Table 4

Descriptive Statistics for Supplementary Wellbeing Measures

Variable	Mean	SD	Range
Spielberger Anger Expression: Anger/Control	10.09	2.22	4.0–14.0
Spielberger Anger Expression: Anger/In	14.60	4.09	8.0–31.0
Spielberger Anger Expression: Anger/Out	12.79	3.13	8.0–28.0
Spielberger Trait Anger	23.75	5.21	15.0–47.0
Spielberger Trait Anxiety	33.58	8.82	20.0–69.0
Social Anxiety Scale	1.83	0.54	1.0–3.8
CES-D Scale	8.02	7.72	0.0–49.0
MASQ: General Distress-Anxious Symptoms	16.59	4.55	11.0–47.0
MASQ: General Distress-Depressive Symptoms	18.38	6.50	12.0–60.0
MASQ: High Positive Affect	44.75	10.08	14.0–70.0
Subjective Wellbeing: Happiness	4.92	1.40	1.0–7.0
Subjective Wellbeing: Gratitude	6.29	0.80	2.0–7.0
Subjective Wellbeing: Satisfaction with Life	4.90	1.28	1.0–7.0

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Table 5

Results of Regression Analyses of HF-HRV and Measures of Supplementary Measures of Wellbeing

Outcome Variable	Model 1		Model 2		Model 3		Model 4	
	β	η^2	β	η^2_p	β	η^2_p	β	η^2_p
Spielberger Anger Measures								
Anger Control	0.06 [−0.05,0.17]	0.0013	0.10 [−0.01,0.22]	0.0032	0.11 [−0.01,0.22]	0.0036	0.13 [−0.01,0.28]	0.0035
Anger In	0.18 [−0.02,0.38]	0.0031	−0.03 [−0.24,0.17]	0.0001	−0.01 [−0.21,0.20]	0.0000	−0.00 [−0.26,0.26]	0.0000
Anger Out	0.05 [−010,0.20]	0.0004	−0.07 [−0.22,0.09]	0.0008	−0.05 [−0.20,0.11]	0.0004	−0.06 [−0.26,0.14]	0.0004
Trait Anger	−0.06 [−0.32,0.19]	0.0002	−0.17 [−0.44,0.09]	0.0017	−0.10 [−0.36,0.17]	0.0006	−0.12 [−0.46,0.21]	0.0006
Anxiety/Depression Measures								
CES-D Scale	0.09 [−0.29,0.47]	0.0002	−0.14 [−0.53,0.25]	0.0005	−0.03 [−0.41,0.35]	0.0000	−0.02 [−0.50,0.46]	0.0000
MASQ: General Distress-Anxious Symptoms	−0.00 [−0.23,0.22]	0.0000	−0.17 [−0.40,0.06]	0.0023	−0.11 [−0.33,0.12]	0.0009	−0.13 [−0.42,0.15]	0.0009
MASQ: General Distress-Depressive Symptoms	−0.02 [−0.34,0.30]	0.0000	−0.29 [−0.61,0.03]	0.0032	−0.21 [−0.53,0.10]	0.0018	−0.25 [−0.66,0.15]	0.0016
Social Anxiety Scale	0.01 [−0.02,0.04]	0.0006	−0.00 [−0.03,0.02]	0.0001	−0.00 [−0.03,0.03]	0.0000	−0.00 [−0.04,0.03]	0.0000
Spielberger Trait Anxiety	0.08 [−0.36,0.52]	0.0001	−0.21 [−0.66,0.23]	0.0009	−0.11 [−0.56,0.33]	0.0003	−0.11 [−0.67,0.45]	0.0002
Positive Scale Measures								
Subjective Happiness Scale	−0.02 [−0.09,0.05]	0.0003	0.01 [−0.07,0.08]	0.0000	−0.01 [−0.08,0.06]	0.0001	−0.02 [−0.11,0.07]	0.0001
MASQ: High Positive Affect	−0.31 [−0.81,0.19]	0.0015	−0.06 [−0.57,0.45]	0.0001	−0.15 [−0.66,0.37]	0.0003	−0.22 [−0.87,0.43]	0.0005
Subjective Wellbeing: Gratitude	−0.01 [−0.05,0.03]	0.0001	0.01 [−0.03,0.05]	0.0002	0.01 [−0.03,0.05]	0.0002	0.01 [−0.05,0.06]	0.0000
Subjective Wellbeing: Satisfaction with Life	−0.02 [−0.09,0.04]	0.0006	0.01 [−0.06,0.07]	0.0001	−0.00 [−0.07,0.07]	0.0000	−0.01 [−0.09,0.08]	0.0000

β: Estimate of Change in Outcome Variable for 1 unit increase in log HF HRV (95% Confidence Interval)

η^2: Eta-squared (Subscript "p" denotes partial)

Model 1: Unadjusted for Any Covariates
Model 2: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, and Smoking
Model 3: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, Smoking, Medications affecting Parasympathetic Activity positively or negatively, Any Heart Trouble, History of Stroke, Parkinson's, and Any Other Neurological Condition.
Model 4: Adjusted for Sex, Age, BMI, Site, Menstrual Status, Exercise, Smoking, Medications affecting Parasympathetic Activity positively or negatively, Any Heart Trouble, History of Stroke, Parkinson's, and Any Other Neurological Condition, and Corrected for Respiration Rate.

*P-value<.05

**P-value<.01

***P-value<.001