Personality and Individual Differences 64 (2014) 152–156

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

Openness to experience and aesthetic chills: Links to heart rate sympathetic activity

Iva Čukić *, Timothy C. Bates *

Department of Psychology, The University of Edinburgh, 7 George Square, EH8 9JZ, UK

ARTICLE INFO

Article history:
Received 8 October 2013
Received in revised form 30 January 2014
Accepted 8 February 2014

Keywords:
Openness to experience
Personality
Heart rate variability
HRV
Heart rate power

ABSTRACT

Openness to experience has important links to cognitive processes such as creativity, and to values, such as political attitudes. The biological origins of variation in openness to experience are, however, obscure. The centrality of "aesthetic chills" to high openness suggests that sympathetic nervous system activation may play a role. Here, we tested this using the low-frequency heart rate variability power measure (LF) as biomarker of sympathetic activation, tested under baseline and stress conditions in a sample of 952 subjects, and controlling for measured confounders of age, sex, height, weight and BMI. A significant association was found between LF and openness to experience ($\beta = 0.10$, 95% CI [0.02, 0.17], $p < .01$). These results suggest links between openness to experience and sympathetic nervous system activity explaining, at least in part, relationships of openness to such traits as aesthetic chills.

1. Introduction

Openness to experience is one of a small number of basic domains of human personality (McCrae & Sutin, 2009). Understanding the mechanisms of variation in openness to experience is of value in understanding its diverse correlates, which range from creativity (McCrae, 1987) to political ideology and values (Lewis & Bates, 2011). Openness to experience should also be associated with specific neural activity to account for that part of individual differences in trait levels which reflects biological function. Here we test the hypothesis that higher levels of openness to experience are reflected in increased autonomic activity, a potential biomarker for further research on the mechanisms of openness to experience. We begin by briefly reviewing the idea that differences in reward/motivation underlie openness.

In their review of the empirical literature on openness to experience, McCrae and Costa (1997) argue that while it is correlated with higher education and with IQ (e.g. Silvia & Sanders, 2010), openness to experience cannot be understood as a cognitive ability or as an acculturated value-set but is, rather, a distinct multi-faceted motivational system affecting the "*breadth, depth, and permeability of consciousness, and in the recurrent need to enlarge and examine experience*" (McCrae & Costa, 1997, p. 826). Such descriptors, they acknowledge, while they capture the experience of openness, require greater specification and mechanistic explication to form a theory. In particular, McCrae and Costa (1997) suggest that the neural correlates of openness to experience could be differences in brain regions underpinning reward/motivational structures.

One clue to the nature of potential biological links underlying openness to experience was highlighted by McCrae (2007), who reported that the single best marker of openness to experience, irrespective of culture examined was the experience of "*aesthetic chills*" defined as "*a transient emotional response to music or other experiences of beauty*" formed. Self-reported aesthetic chills, may, then, provide a behavioral marker of the biological functions underlying openness. Such biological functions that might in turn be objectively measured.

One possible systematic difference in motivation that could support openness to experience is alterations to sympathetic autonomic "fight or flight" functions: High openness to experience could plausibly be linked to alterations in autonomic responding promoting prolonged absorption in stimuli. In line with this, Blood and Zatorre (2001) reported a monotonic relationship of cerebral blood flow changes correlated with the intensity of aesthetic chills, regionalized the ventral striatum, midbrain, amygdala, orbito-frontal cortex, and ventral medial prefrontal cortex. Each of these areas is associated with reward/motivation, emotion, and arousal. These brain functional changes were accompanied by similar dose-dependent changes in heart rate, electromyogram, and respiration. Thus, the results of Blood and Zatorre (2001) indicate that openness to experience is associated with alterations in heart rate,

* Corresponding authors. Tel.: +44 131 650 3391.
E-mail addresses: icukic@staffmail.ed.ac.uk (I. Čukić), tim.bates@ed.ac.uk (T.C. Bates).

http://dx.doi.org/10.1016/j.paid.2014.02.012
0191-8869/

mediated by specific regional reward/motivation brain activation. Based on these results, in the present paper, we tentatively explored the hypothesis that heart rate activity indices linked to sympathetic autonomic activation that is reflected in cardiovascular function might provide an easily measured biomarker of openness to experience.

The most specific measure of sympathetic activity accessible from heart rate measures is the low-frequency (LF) component of the heart rate variability measure of variance in beat-to-beat interval (Camm et al., 1996; Stajzel, 2004). Heart rate or R-wave to R-wave (the largest depolarization peak in an EKG recording of a heart beat, corresponding to contraction of the left and right ventricles) interval information can be translated into the frequency domain via Fast-Fourier transform, and subjected to spectral analysis (Fig. 1). A number of studies have identified a principal influence of sympathetic autonomic nervous system activity on low-frequency power (0.04–0.15 Hz), whereas parasympathetic activity and respiration are linked to higher power in the high-frequency band (0.15–0.50 Hz) (Malik, 2008). Heart rate variability measures demonstrate stable individual response patterns across situations (e.g. stress-tasks), and these individual differences are also stable across time (Berntson & Cacioppo, 2004). In this, they show trait-like characteristics similar to personality traits, and thus could potentially act as their biomarkers (Koelsch, Enge, & Jentschke, 2012).

Factors linking openness to experience and sympathetic HRV are, of course, not conclusive; Indeed, to the best of our knowledge this association has not been tested. Suggestive evidence includes research showing that HRV is linked to differences in attention (Hansen, Johnsen, & Thayer, 2003) and with sympathetic cardiovascular influences inducing more adaptive attentional state (Duschek, Muckenthaler, Werner, & del Paso, 2009). In addition, music is a common elicitor of aesthetic chills, and cardiovascular measures including heart rate and blood pressure vary greatly in response to music, and even music conducting (Harrer & Harrer, 1977) In a further study, HRV was found to be responsive to music: listening to sedative and excitative music increased LF power component and LF/HF ratio, while both measures decreased in the no-music condition, suggesting sympathetic nervous system activation as a response to music stimuli (Iwanaga, Kobayashi, & Kawasaki, 2005).

Based on these earlier research findings, we tested the prediction that higher openness to experience would be associated with increased low-frequency power in the heart rate signal at baseline, reflecting sympathetic activation. Conversely, we predicted that this relationship would not hold for high-frequency power, which reflects activity in the parasympathetic activity. More speculatively, because HR was recorded under both stress and baseline conditions, we also explored whether these relationship would differ depending on whether LF heart rate power was elicited under a non-task baseline condition or a cognitive stressor. Based on research indicating both that creative responding occurs primarily under non-task directed situations (Hennessey & Amabile, 2010), and evidence that under stress, the heart-rate response is primarily driven by emotional responding, we predicted that the link between O and LF heart rate power would be stronger under baseline than under a stress (Pagani et al., 1991). We tested these hypotheses using data from Wave II of the MacArthur Foundation Survey for Midlife Development in the U.S. (MIDUS II: Ryff & Almeida, 2009). All analyses controlled for covariates linked to heart function: age, sex, weight, height, and body mass index (BMI), as is standard in analysis of cardiovascular fitness measures (Aberg et al., 2012).

2. Method

2.1. Participants

Participants were all eligible persons in Project 4 of Wave II of the MacArthur Foundation Survey for Midlife Development in the U.S. (MIDUS II: Ryff & Almeida, 2009). The Project 4 sub-sample participants were assessed for major biomarkers, including HRV (Love, Seeman, Weinstein, & Ryff, 2010). All 952 subjects for whom biomarker and openness scores were available were included in the analyses (mean age 54.6 years, SD = 11.6). In total, there were 429 males (mean age 55.3 years, SD = 11.9) and 523 females (mean age 54.03 years, SD = 11.3).

2.2. Measures

2.2.1. Heart rate variability measures

The electrocardiogram (ECG) was recorded continuously during the protocol. Analog signals were digitalized at 500 Hz and 16-bit resolution with an analog-to-digital board (National Instruments, Austin, TX), and then processed by proprietary event detection software implementing an algorithm for identifying consecutive ventricular depolarizations (or RR intervals) based on the recordings of maximum voltage. These maxima were detected automatically, with post-detection visual inspection of marked-up waveforms to correct any software errors (Berntson, Quigley, Jang, & Boysen, 1990; Dykes et al., 1986). Heart rate variability was computed from this beat-to-beat information. The resulting data were used to calculate cardiovascular reactivity in frequency domain with separate assessments of sympathetic and vagal activity based on power in the low (LF: 0.04–0.15 Hz) and high (HF: 0.15–0.50 Hz) frequency bands, respectively (Bootsma et al., 1994; Camm et al., 1996). These measures have been shown to be reproducible in normal as well as clinical samples (Camm et al., 1996).

Heart rate was assessed in a seated position under two conditions: rest and cognitive stress. Stress was induced twice: once with a math task (Turner, Sims, Carroll, Morgan, & Hewitt, 1987; Turner et al., 1986), and once with an attentional-control stressor (Stroop). In the arithmetic task, subjects perform addition and subtraction tasks that adaptively increased or decreased in difficulty to

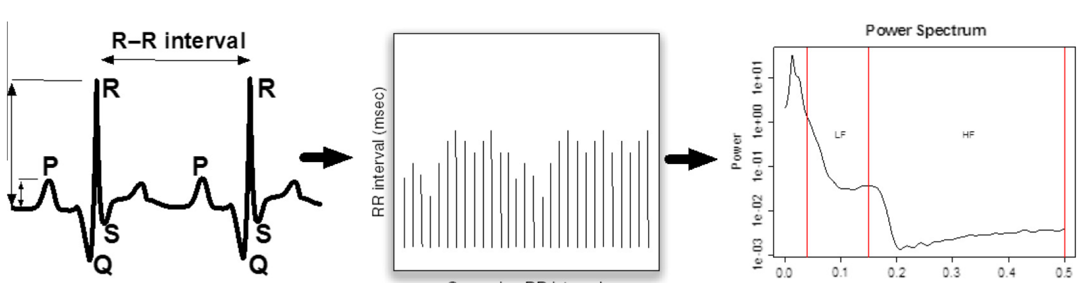

Fig. 1. Processing from EKG signal interval RR-intervals and power spectrum. (LF: 0.04–0.15 Hz) and high (HF: 0.15–0.50 Hz).

create a cognitive stress. The second condition, the Stroop Color-Word Task involved adaptive presentation of Stroop stimuli as a function of task performance in similar way to that used in the arithmetic task. Both are standard stressors in heart rate research, and full details about the presentation and a full list of measures obtained during the protocol are provided elsewhere (Love et al., 2010).

2.2.2. Covariates

The choice of covariates followed the work of Koelsch et al. (2012). Weight and height were self-reported according to a detailed protocol, including tape measure provided to subjects. To remove the extreme values, heights greater than 84 inches were set to 84 inches. Then, respondent's weight in kilograms was divided by their height in meters squared to form the BMI measure. We treated height, weight, BMI, age and age^2 as continuous variables. The age and sex interaction term is entered as a covariate following Stein, Kleiger & Rottman (1997).

2.2.3. Personality

Openness to experience was assessed using the Big Five adjective rating scale developed for the MIDUS study, based on existing trait lists and inventories (Lachman & Weaver, 1998). Participants rated themselves on a set of adjectives using a Likert scale ranging from 1: "Not at all" to 4: "A lot". The adjectives for openness were: "Creative", "Imaginative", "Intelligent", "Curious", "Broad-minded", "Sophisticated", and "Adventurous". The scale showed satisfactory reliability ($\alpha = .77$).

2.3. Procedure

Heart rate measures were taken as part of a two-day collection protocol conducted in a hospital clinic setting on the morning of the second day of participants' hospital stay. Testing consisted of a 6-min baseline measure, a stress challenge, a 6-min recovery period/s baseline, followed by a second, 6-min, stressor task. The two cognitive stressors were presented in randomized order. Total test time was approximately half an hour.

3. Results

All analyses were conducted using linear regression modeling in the R environment (R Core Team., 2012). Descriptive statistics for the personality and cardiovascular reactivity measures are shown in Table 1. The two measures of heart function under stress correlated highly (r values ranged from .81 to .91, all p-values were less than .001 and HRV measures from the two challenge conditions were therefore combined in all subsequent analyses. For those subjects who had valid data for only one task ($n = 63$) the single available measure was used in place of the average.

Our first hypothesis was that higher levels of openness would be associated with increased autonomic activation in the form of greater low-frequency power at rest. This was examined using multiple regression with openness as the dependent variable (following Koelsch et al., 2012) and LF power at baseline as the independent variable, and, entering age, sex, BMI, height, and weight as covariates. This model showed a significant overall effect. Importantly, LF had a significant effect in the predicted direction ($p = .01$: see Model 1, Table 2). We next tested our second hypothesis, that HF power, the marker of parasympathetic (rather than sympathetic) activation, would be unrelated to openness to experience. The model tested was identical to that presented above, including the same covariates, but had baseline-condition HF power as the independent variable. In line with the hypothesized effect, HF power at baseline was not a significant contributor to model fit ($t(1) = 1.45$, $p = .229$, see Model 2, Table 2 for the estimates).

We next tested our third hypothesis: whether the association of openness to experience to either of LF or HF power would hold under the cognitive stress condition. Two models were constructed with openness to experience as a dependent variable, and LF power under stress (the marker of sympathetic activity under stress) as the independent variable in the first model, and HF power (the marker of parasympathetic activity) under stress as the independent variable in the second model. Both models included the standard covariates, as above. Neither power measure significantly contributed to model fit ($t(1) = 2.68$, $p = .10$ and $t(1) = 0.55$, $p = .50$ for LF and HF models, respectively). Furthermore, dropping LF power from the first of the two stress models did not significantly decrease the fit ($F(1, 900) = 2.68$, $p = .10$). The same was true for the HF model in the stress condition – excluding the HF power measure did not significantly change the fit ($F(1, 900) = 0.55$, $p = .46$).

Table 1
Descriptive statistics for all variables examined.

		Female		Male		Total	
	N	M	SD	M	SD	M	SD
Openness	952	2.94	0.54	2.98	0.50	2.96	0.52
Height (feet)	934	4.99	0.16	5.28	0.45	5.12	0.36
Weight (pounds)	943	161.8	34.7	199.3	35.9	178.7	39.9
BMI	923	27.49	5.95	28.42	4.79	27.91	5.48
Baseline SDRR	952	3.46	0.44	3.53	0.45	3.49	0.44
Baseline LF power	952	5.35	1.10	5.60	1.13	5.46	1.12
Baseline HF power	952	4.80	1.21	4.71	1.23	4.76	1.22
Stress LF power	937	4.71	1.04	4.90	1.14	4.80	1.09
Stress HF power	937	4.45	1.19	4.40	1.23	4.43	1.21

Note. Openness scores are given in raw units. All HRV measures are given in m sec^2 and are log-transformed. M = Mean; SD = Standard Deviation; BMI = Body Mass Index; SDRR = Standard Deviation of R-wave to R-wave interval; LF = Low-frequency; HF = High Frequency.

4. Discussion

Openness to experience was related to increased low-frequency heart beat power, an indicator of increased sympathetic autonomic activity. This association was specific to low-frequency power recorded under the baseline non-task condition. Furthermore, it was not present in the high-frequency power realm under either condition. Results were robust to the inclusion of covariates of age, sex, height, weight, and BMI. These results, then, support the idea that openness is, in part, reflected in sympathetic autonomic activity in the resting, non-task, condition and may account for the association of openness to experience with aesthetic chills.

McCrae and Costa (1997) have argued that openness to experience must be viewed as a primarily non-cognitive system of motivational structures and, moreover, that an autonomic effect – aesthetic chills – forms the best single marker of openness to experience (McCrae, 2007). The results here linking autonomic function to openness suggest a mechanism important pathway to a mechanistic understanding of openness. The finding that that dispositional autonomic activation may be a useful biological marker for openness is important in its own right. The finding was strengthened by the fact that controlling for covariates potentially linked to one or both of openness and heart function did not diminish the relationship between openness and LF power. The finding that the increased low-frequency cardiac power pattern was associated

Table 2
Relationship of openness to experience with power measures of HRV at baseline condition.

	Model 1: low-frequency power					Model 2: high frequency power				
	Est.	S.E.	*t*	*p*-Value	*β*	Est.	S.E.	*t*	*p*-Value	*β*
Intercept	3.927	1.586	2.475	.014	0.01	4.040	1.590	2.540	.011	0.04
Age	0.014	0.013	1.034	.301	0.02	0.014	0.013	1.072	.284	−0.01
Sex (*F*)	−0.370	0.171	−2.164	.031	0.03	−0.403	0.171	−2.360	.019	−0.01
Age^2	−0.000	0.000	−1.020	.308	−0.04	−0.000	0.000	−1.164	.245	−0.04
Age × sex	0.007	0.003	2.357	.019	0.16	0.007	0.003	2.452	.014	0.17
BMI	−0.037	0.025	−1.445	.149	−0.39	−0.036	0.026	−1.401	.162	−0.38
Weight	0.005	0.004	1.250	.212	0.39	0.005	0.004	1.168	.243	0.37
Height	−0.022	0.023	−0.954	.340	−0.17	−0.021	0.023	−0.887	.376	−0.15
HRV power	0.044	0.017	2.617	**.009**	**0.10**	0.018	0.015	1.203	.230	0.04

Note. Model 1: $R^2 = 0.03$, $F(8, 914) = 3.09$, $p < .01$; Model 2: $R^2 = 0.02$, $F(8, 914) = 2.40$, $p < .05$.

with high-openness to experience only under baseline conditions is of interest. It is possible that the reaction of the heart under stress is driven by emotional factors, or perhaps openness is suppressed under conditions of stress or fear (Walker & Jackson, 2014). Alternatively, directedness of behavior is also known to suppress creative responding (Hennessey & Amabile, 2010) and may suppress LF power-openness to experience links. Significant associations with autonomic activity may, then, reflect a basic association of autonomic orienting to openness to experience.

4.1. Limitations

Within the present research design, we could not adjudicate between alternative causal directions in the observed relationship between LF and openness to experience. Both directions of influence are plausible: It may be that higher autonomic nervous system activity in part underlies the enhanced orienting to novel stimuli characteristic of high openness. Alternatively, cortical mechanisms increasing the processing of novelty as rewarding and resource consuming may trigger increased autonomic activity medial pre-frontal cortical areas associated with anxiety, and which directly project to brain stem autonomic centers perhaps, causing decreased heart rate variability as a consequence of negative affective cognitions (Berntson & Cacioppo, 2004). Future research should assess HRV under creativity – and aesthetic stimulation conditions to examine whether this modulates the apparent effect.

In summary, an association of low-frequency power with openness to experience was found which, while modest in magnitude, was significant, and restricted to sympathetic (low-frequency) and not parasympathetic (high frequency) power as predicted. The association was restricted to non-task/low stress conditions, and may reflect a biological mechanism underlying the drive to expand and consider experience characteristic of openness to experience.

Acknowledgments

The MIDUS I study (Midlife in the U.S.) was supported by the John D. and Catherine T. MacArthur Foundation Research Network on Successful Midlife Development. The MIDUS II research was supported by a grant from the National Institute on Aging (P01-AG020166) to conduct a longitudinal follow-up of the MIDUS I investigation.

The research was further supported by the following grants M01-RR023942 (Georgetown), M01-RR00865 (UCLA) from the General Clinical Research Centers Program and 1UL1RR025011 (UW) from the Clinical and Translational Science Award (CTSA) program of the National Center for Research Resources, National Institutes of Health.

References

Aberg, M. A., Waern, M., Nyberg, J., Pedersen, N. L., Bergh, Y., Aberg, N. D., et al. (2012). Cardiovascular fitness in males at age 18 and risk of serious depression in adulthood: Swedish prospective population-based study. *The British Journal of Psychiatry, 201*(5), 352–359.

Berntson, G. G., & Cacioppo, J. T. (2004). Heart rate variability: Stress and psychiatric conditions. In M. Malik & A. J. Camm (Eds.), *Dynamic electrocardiography* (pp. 57–64). New York: Futura.

Berntson, G. G., Quigley, K. S., Jang, J. F., & Boysen, S. T. (1990). An approach to artifact identification: application to heart period data. *Psychophysiology, 27*(5), 586–598.

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences of the United States of America, 98*(20), 11818–11823.

Bootsma, M., Swenne, C. A., Van Bolhuis, H. H., Chang, P. C., Cats, V. M., & Bruschke, A. V. (1994). Heart rate and heart rate variability as indexes of sympathovagal balance. *AJP – Heart and Circulatory Physiology, 266*(4), H1565–H1571.

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., et al. (1996). Heart rate variability: Standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation, 93*(5), 1043–1065.

Duschek, S., Muckenthaler, M., Werner, N., & del Paso, G. A. (2009). Relationships between features of autonomic cardiovascular control and cognitive performance. *Biological Psychology, 81*(2), 110–117.

Dykes, F. D., Ahmann, P. A., Baldzer, K., Carrigan, T. A., Kitney, R., & Giddens, D. P. (1986). Breath amplitude modulation of heart rate variability in normal full term neonates. *Pediatric Research, 20*, 301–308.

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology, 48*(3), 263–274.

Harrer, G., & Harrer, H. (1977). Music, emotions and vegetative functions. In M. D. Critchley & R. A. Henson (Eds.), *Music and the brain. Studies in the neurology of Music*. London: William Heinemann Medical Books Ltd.

Hennessey, B. A., & Amabile, T. M. (2010). Creativity. *Annual Review of Psychology, 61*, 569–598.

Iwanaga, M., Kobayashi, A., & Kawasaki, C. (2005). Heart rate variability with repetitive exposure to music. *Biological Psychology, 70*(1), 61–66.

Koelsch, S., Enge, J., & Jentschke, S. (2012). Cardiac signatures of personality. *PLoS One, 7*(2), e31441.

Lachman, M. E., & Weaver, S. L. (1998). The sense of control as a moderator of social class differences in health and well being. *Journal of Personality and Social Psychology, 74*, 763–773.

Lewis, G. J., & Bates, T. C. (2011). From left to right: How the personality system allows basic traits to influence politics via characteristic moral adaptations. *British Journal of Psychology, 102*(3), 546–558.

Love, G. D., Seeman, T. E., Weinstein, M., & Ryff, C. D. (2010). Bioindicators in the MIDUS National Study: Protocol, measures, sample, and comparative context. *Journal of Aging and Health, 22*(8), 1059–1080.

Malik, M. (2008). Standard measurement of heart rate variability. In J. A. Camm & M. Malik (Eds.), *Dynamic electrocardiography* (pp. 13–21). New York: Wiley.

McCrae, R. R. (1987). Creativity, divergent thinking, and openness to experience. *Journal of Personality and Social Psychology, 52*(6), 1258–1265.

McCrae, R. R. (2007). Aesthetic chills as a universal marker of openness to experience. *Motivation and Emotion, 31*(1), 5–11.

McCrae, R. R., & Costa, P. T. Jr., (1997). Conceptions and correlates of openness to experience. In R. Hogan & J. A. Johnson, et al. (Eds.), *Handbook of personality psychology* (pp. 825–847). San Diego, CA, USA: Academic Press Inc.

McCrae, R. R., & Sutin, A. R. (2009). Openness to experience. In M. R. Leary & R. H. Hoyle (Eds.), *Handbook of individual differences in social behavior* (pp. 257–273). New York, NY, US: Guilford Press.

Pagani, M., Mazzuero, G., Ferrari, A., Liberati, D., Cerutti, S., Vaitl, D., et al. (1991). Sympathovagal interaction during mental stress. A study using spectral analysis of heart rate variability in healthy control subjects and patients with a prior myocardial infarction. *Circulation, 83*(4 Suppl), II43–51.

R Core Team. (2012). *R: A language and environment for statistical computing (Version 2.15.X)*. Vienna, Austria: R Foundation for Statistical Computing.

Ryff, C. D., & Almeida, D. M. (2009). *National survey of midlife in the United States (MIDUS II): Daily stress project, 2004–2009*. Inter-university Consortium for Political and Social Research (ICPSR).

Silvia, P. J., & Sanders, C. E. (2010). Why are smart people curious? Fluid intelligence, openness to experience, and interest. *Learning and Individual Differences, 20*(3), 242–245.

Stajzel, J. (2004). Heart rate variability: A noninvasive electrocardiographic method to measure the autonomic nervous system. *Swiss Medical Weekly, 134*, 514–522.

Stein, P. K., Kleiger, R. E., & Rottman, J. N. (1997). Differing effects of age on heart rate variability in men and women. *The American journal of cardiology, 80*(3), 302–305.

Turner, J. R., Hewitt, J. K., Morgan, R. K., Sims, J., Carroll, D., & Kelly, K. A. (1986). Graded mental arithmetic as an active psychological challenge. *International Journal of Psychophysiology, 3*(4), 307–309.

Turner, J. R., Sims, J., Carroll, D., Morgan, R. K., & Hewitt, J. K. (1987). A comparative evaluation of heart rate reactivity during MATH and a standard mental arithmetic task. *International Journal of Psychophysiology, 5*(4), 301–303.

Walker, B. R., & Jackson, C. J. (2014). How the Five Factor Model and revised Reinforcement Sensitivity Theory predict divergent thinking. *Personality and Individual Differences*.