The impact of heart rate variability on subjective well-being is mediated by emotion regulation

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ABSTRACT

Resting heart rate variability (HRV) can serve as an index of self-regulatory strength. In the present study we tested the hypotheses that HRV, indexing adaptive self-regulation, is associated with subjective well-being, and that this association is mediated by the habitual use of strategies of emotion regulation that involve executive functions. In addition to measuring heart rate at rest, subjective well-being – as indicated by positive habitual mood and satisfaction with life – and habitual emotion regulation were assessed via self-reports. The findings were largely consistent with our predictions. HRV was positively associated with cheerfulness and calmness, and these effects were mediated by executive emotion regulation. Mediated by these strategies, HRV was also associated with satisfaction with life. Together, the results support the use of HRV as an index of self-regulatory strength.

1. Introduction

Self-regulatory strength, defined as the ability to exert self-control and to override or alter one’s dominant response tendencies (Baumeister & Heatherton, 1996), is a major prerequisite for adaptive behavior, such as regulating emotions, persisting in the face of failure, or adopting positive health behavior (Schmeichel & Baumeister, 2004; Tangney, Baumeister, & Boone, 2004).

In previous research, heart rate variability (HRV) was found to serve as a physiological index of self-regulatory strength (Segerstrom & Solberg Nes, 2007). As the ability to exert self-control predicts a broad range of positive outcomes, such as academic and interpersonal success (Tangney, Baumeister, & Boone, 2004), it seems reasonable to expect HRV to be associated with subjective well-being (SWB). SWB refers to well-being from the people’s own perspective. It includes both cognitive judgements of satisfaction with life and affective evaluations of pleasant and unpleasant affect. Theories of SWB emphasize the interaction of life circumstances with physical health and psychological factors, such as personality traits, goal attainment and coping, in producing SWB (e.g., Diener, Suh, Lucas, & Smith, 1999). The assumption that HRV is associated with SWB was indirectly supported by a study showing an inverse relationship between perceived emotional stress and HRV (Dishman et al., 2000). However, empirical evidence for the relationship between HRV and subjective well-being has been surprisingly rare. Addressing this gap, the present study examined whether trait HRV is associated with subjective well-being, as indicated by positive habitual mood and satisfaction with life. Moreover, we tested the hypothesis that the association between HRV and subjective well-being is mediated by strategies of emotion regulation that reflect self-regulatory strength. More specifically, based on the assumption that adaptive self-regulation relies on the capacity to exert control over cognitions, emotions, behavior, and physiology (Solberg Nes, Roach, & Segerstrom, 2009; Thayer, Hansen, Saus-Rose, & Johnsen, 2009), we expected HRV to be related to cognitive strategies of emotion regulation that involve executive functions, such as reasoning, generating, and following through with goals and plans (Suchy, 2009).

1.1. Heart rate variability (HRV)

The Neurovisceral Integration Model (Thayer et al., 2009) provides a theoretical rationale for explaining the role of HRV as an index of self-regulatory strength. Within this model, which outlines the associations among different self-regulatory processes, the central autonomic network (CAN) is assumed to adjust physiological arousal to changing situational demands and thus to support goal-directed behavior and adaptation. The primary output of the CAN is mediated through sympathetic and parasympathetic (vagus nerve) neurons that innervate the heart. The interplay of these inputs with the cardiac sinoatrial node produces variability in the heart rate (HR) time series. Thus, the output of the CAN is directly linked to HRV, the beat-to-beat variation in heart rate. Especially high-frequency, vagal mediated tonic HRV is thought to...
be a peripheral proxy for regulatory strength (Thayer & Friedman, 2002). In addition, sensory information from peripheral end organs such as the heart and the immune system are fed back to the CAN. As such, HRV is an indicator of central nervous and autonomic nervous system integration. Thayer et al. (2009) propose that the CAN and other functional units within the central nervous system represent a common central functional network that is associated with processes of response organization and selection and serves to control psychophysiological resources in attention and emotion. The ability to meet changing environmental demands depends on the functioning of this central functional network.

Empirical evidence strongly supports these assumptions, indicating that HRV covaries with processes that are involved in self-regulation, such as emotion regulation (Appelhans & Luecken, 2006), constructive coping (Fabes & Eisenberg, 1997), and the pursuit of goals (Geisler & Kubiaik, 2009). More specifically, previous research has indicated that HRV is associated with behaviors that require executive functioning. For example, positive associations were found between resting levels of vagally mediated HRV and performance on working memory tests and a continuous performance test (Hansen, Johnsen, & Thayer, 2003), whereas negative associations were found between waking HRV and frequency and duration of worrying (Brosschot, Van Dijk, & Thayer, 2007). Further support for the use of HRV as a proxy for regulatory strength comes from neurobiological research indicating a link between HRV regulation and prefrontal cortical activity, which is a key structure for executive functioning (Lane et al., 2009). High short-term retest reliability (Kautzner, 1995) and moderate stability over time (Rotenberg, Wilhelm, Gross, Bluckians, & Gotlib, 2001; Salomon, 2005) as well as correlations with temperament (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996) and evidence for the heritability of a substantial proportion of variance in HRV (Singh et al., 1999) suggest that HRV can be conceptualized as a trait-like factor.

1.2. Executive function and emotion regulation

Strategies for emotion regulation can be distinguished along different dimensions, such as the time point targeted by a strategy within the process of emotion regulation (Gross & Thompson, 2007). Another possible way to characterize strategies of emotion regulation is by whether they involve mechanisms that reflect executive functioning (Zelazo & Cunningham, 2007). According to Zelazo and Cunningham, executive function includes higher cognitive processes that are involved in goal-directed problem-solving, such as problem representation, planning, execution, and evaluation. In their view, at an algorithmic level executive function can be characterized by the ability to formulate a rule system, maintain it in working memory, and then act on the basis of the rule systems. Executive function encompasses mental set shifting, information updating and monitoring, and inhibition of prepotent responses (Miyake, Friedman, Emerson, Witzki, & Howertor, 2000).

Strategies of emotion regulation that reflect executive function are, for example, reappraisal or refocusing that imply mental shifting, and planning that involves information updating and monitoring. By contrast, other strategies of emotion regulation appear to be associated with deficits in executive functioning. For example, depressive rumination, a response to dysphoric mood that is characterized by recurrent thoughts focusing on the causes, symptoms, and implications of one’s depressive mood (Nolen-Hoeksema, 1991), was found to be related to attentional inflexibility (Davis & Nolen-Hoeksema, 2000) and inhibitory deficits (Whitmer & Banich, 2007).

In previous research, cognitive strategies of emotion regulation that involve executive mechanisms, such as positive reappraisal, were found to be associated with higher subjective well-being (Shiota, 2006), whereas rumination that reflects deficits in executive functioning, was found to exacerbate depressive mood (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Given that HRV can be expected to be associated with the habitual use of emotion regulation strategies that involve executive processes, we tested the hypothesis that these strategies mediate the association between HRV and subjective well-being.

2. Method

2.1. Participants

Participants (N = 172, 76% women, age M = 23 years, SD = 4) were psychology and non-psychology students. They either (a) received course credit for participation, (b) took part in a lottery for a book coupon, or (c) were paid five Euros. Participants filled out questionnaires that assessed subjective well-being (mood and satisfaction with life), and habitually employed emotion regulation strategies. In addition, their heart rate was measured.

2.2. HRV

We measured heart rate at rest for 7 min via the heart rate monitoring system Polar RS800CX (Polar Electro Oy, Kempele, Finland). During measurement, participants sat still by themselves without any task since parasympathetic influences predominate at rest. Using the Polar Precision Performance Software, we preprocessed sequential interbeat intervals for artefacts. A visual screening for artefacts followed. We then used the HRV Analysis program (Niskanen, Tarvainen, Ranta-aho, & Karjalainen, 2004) to perform a frequency-based technique of power spectral analysis (autoregressive modeling technique) to extract high-frequency components, 0.15–0.4 Hz, which primarily reflect cardiac parasympathetic influence from sequential interbeat intervals. The absolute value of power was chosen as unit (ms²). With this procedure, we followed the recommendations of the American Heart Association (Task Force, 1996). In a previous study, in which heart rate was measured the same way, we obtained a considerably high retest-reliability coefficient over about 1 h (r = .70, Geisler & Kubiaik, 2009).

2.3. Self-report scales

2.3.1. Mood

Habitual mood was measured by the UWIST Mood Adjective Check List (Matthews, Jones, & Chamberlain, 1990; German adaptation Hermanns, Kubiaik, Kulzer, & Haak, 2003). The UWIST Mood Adjective Check List contains six subscales measuring positive and negative hedonic tone (cheerful vs. dissatisfied), tense arousal (calm vs. anxious), and energetic arousal (vigor vs. tired). Participants rated on a 9-point scale ranging from 1 “not at all true” to 9 “totally true” how they felt in general. Each subscale consists of four items; scale scores were computed by summing the respective item scores. Cronbach’s α ranged from .78 to .93.

2.3.2. Satisfaction with life

We employed the Temporal Satisfaction with Life Scale to assess past, present, and expected future life satisfaction (Favot, Diener, & Suh, 1998; German adaptation Trautwein, 2004). Item scores ranged from 1 “not at all true” to 4 “totally true”. Each subscale consists of four items; scale scores were computed by summing the respective item scores. Higher scores indicate greater satisfaction with life. Cronbach’s α ranged from .80 to .89.

2.3.3. Emotion regulation strategies

Cognitive emotion regulation strategies were assessed with two self-report instruments. (1) The Cognitive Emotion Regulation
Questionnaire (CERQ-short; Garnefski & Kraaij, 2006) was chosen, because it focuses on a broad range of cognitive components of emotion regulation, referring to an individual's thoughts in response to the experience of threatening or stressful events, rather than behavioral aspects of coping (Garnefski, Kraaij, & Spinhoven, 2002). The CERQ-short includes nine subscales measuring nine conceptually distinct cognitive emotion regulatory strategies (Self-blame, other-blame, rumination, catastrophizing, positive refocusing, planning, positive reappraisal, putting into perspective, and acceptance). Cronbach's $\alpha$ ranged from .51 to .83. (2) The Response Style Questionnaire (RSQ; German adaptation Bürger & Kühner, 2007; Nolen-Hoeksema, 1991) was added as a second instrument, because it is a common measure of rumination and distraction, which proved to be particularly important strategies in regulating dysphoric mood (Nolen-Hoeksema, 1991). The RSQ contains three subscales: distraction, self-focused rumination, and symptom-focused rumination. Cronbach's $\alpha$ ranged from .66 to .77.

On a theoretical basis, we distinguished between two classes of strategies: those that imply executive functioning, and those that reflect deficits in executive function (see Table 1 for the two classes and the intercorrelations among the scales). The CERQ-scales Other-blame and Acceptance were omitted, as it is not clear from their definition whether they reflect executive functioning or deficits in executive function. For example, acceptance could be the result of actively processing and coming to terms with a negative event, which would imply effortful executive control. However, it also could reflect passivity and resignation. Thus, high scores in acceptance cannot be clearly related to high or low executive functioning (Garnefski et al., 2002). Other-blame may indicate the tendency to ‘deflect from one’s faults, but it may also reflect a sensible appraisal of negative events caused by other persons, as may be the case for anger-eliciting situations (Smith & Lazarus, 1993). The theoretically based classification was confirmed by a factor analysis of the scale scores. We used a principal axis factoring method of factor extraction and a Varimax rotation method. The first three eigenvalues were 2.07, 2.04, and 1.43. The Scree test suggested a two-factor solution. The two-factor solution explained 41.12% of the variance. Factor loadings are depicted in Table 1.

After $z$-standardizing the subscale scores, we computed a sum score for a new scale containing the executive emotion regulation strategies (executive emotion regulation), and a scale encompassing the non-executive emotion regulation strategies (non-executive emotion regulation). Higher scores indicate greater use of the respective type of emotion regulation. Cronbach's $\alpha$ for the Executive Emotion Regulation scale and the Non-Executive Emotion Regulation scale were .60 and .58, respectively. Considering that these scales each cover a broad range of strategies, the internal consistencies appeared to be acceptable.

3. Results

3.1. HRV, mood, and life satisfaction

The descriptive statistics and intercorrelations for mood and satisfaction with life are depicted in Tables 2 and 3. The HR measures of 11 participants were omitted from further analyses due to poor measurement quality, $M_{\text{mean, HRV}} = 782$ ms, $SD = 129$; $M_{\text{HRV}} = 341.35$ ms$^2$, $SD = 397.05$. As hypothesized, HRV was significantly positively correlated with positive mood, specifically with positive hedonic tone (i.e., cheerfulness) and positive tense arousal (i.e., calm; see Table 2). No significant associations were found between HRV and energetic arousal. Unexpectedly, HRV was not correlated with satisfaction with life.

3.2. Mediation analyses

3.2.1. Mood

To test the hypothesis that executive emotion regulation strategies mediate the influence of HRV on mood, we followed the causal step approach by Baron and Kenny (1986), revealing the following results: Step 1: As mentioned above, HRV (the independent variable, IV) was related to positive hedonic tone, $F(1, 154) = 3.91, p < .05, \text{adj. } R^2 = .02$, and positive tense arousal, $F(1, 154) = 4.41, p < .05, \text{adj. } R^2 = .03$ (the dependent variables, DV). Step 2: HRV (IV) significantly predicted the use of executive emotion regulation (mediator, M), $F(1, 154) = 8.13, p < .01, \text{adj. } R^2 = .04$, but not the use of non-executive emotion regulation, $F(1, 154) = .37, p = .54, \text{adj. } R^2 = .00$. Step 3: HRV (IV) and executive emotion regulation (M) together predicted positive hedonic tone (DV), $F(2, 148) = 8.32, p < .001, \text{adj. } R^2 = .09$, and positive tense arousal (DV), $F(2, 154) = 7.47, p < .01, \text{adj. } R^2 = .08$. Beta-weights for all steps are depicted in Table 4. The data were consistent with complete mediation, indicating that executive emotion regulation significantly mediated the influence of HRV on positive hedonic tone, Sobel $z = 2.32, p < .05$, and tense arousal, Sobel $z = 1.65, p < .05$.

3.2.2. Satisfaction with life

Even though HRV was not directly correlated with satisfaction with life, we tested the hypothesis that executive emotion regula-

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**Table 1**

Scale intercorrelations and factor loadings.

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<tbody>
<tr>
<td>1. Refocusing $^a$</td>
<td>.15</td>
<td>.16</td>
<td>.34 $^*$</td>
<td>.46 $^*$</td>
<td>-.10</td>
<td>-.12</td>
<td>-.12</td>
<td>-.12</td>
<td>-.14</td>
<td>.58</td>
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<tr>
<td>2. Planning $^a$</td>
<td>.26 $^*$</td>
<td>.30 $^*$</td>
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<td>.09</td>
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<td>-.08</td>
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<tr>
<td>3. Reappraisal $^a$</td>
<td>.26</td>
<td>.32 $^*$</td>
<td>-.04</td>
<td>.09</td>
<td>-.38</td>
<td>-.29 $^*$</td>
<td>-.13</td>
<td>.64</td>
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<tr>
<td>4. Putting into perspective $^a$</td>
<td>.32 $^*$</td>
<td>-.19</td>
<td>-.11</td>
<td>-.39 $^*$</td>
<td>-.14</td>
<td>-.08</td>
<td>.68</td>
<td>-.17</td>
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<tr>
<td>5. Distraction $^a$</td>
<td>.70</td>
<td>.17</td>
<td>.02</td>
<td>.62</td>
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$^a$ CERQ-short.

$^b$ RSQ.

$p < .05$.

$p < .01$.

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tion mediates the influence of HRV on satisfaction with life. In doing so, we followed the recommendation of Shrout and Bolger (2002), who argued that for distal processes (in our case, the influence of HRV on satisfaction with life), the mediation analysis may proceed on the basis of the strength of the theoretical arguments rather than on the basis of the statistical test of the DV on the IV. Following again the causal step approach by Baron and Kenny (1986), the mediation analyses revealed the following results: Step 1: As mentioned above, HRV (IV) was not significantly related to past, present, and expected future satisfaction with life, $F(1, 158) < 1.31, p > .25$, adj. $R^2 = -.01$. Step 2: (for results, see the mediation analyses for mood). Step 3: HRV (IV) and executive emotion regulation (M) together predicted present satisfaction with life (DV), $F(2, 154) = 6.30, p < .01$, adj. $R^2 = .06$, and expected future satisfaction with life (DV), $F(2, 154) = 9.02, p < .001$, adj. $R^2 = .09$. The data were consistent with complete mediation, indicating that executive emotion regulation significantly mediated the influence of HRV on present and expected future satisfaction with life, Sobel $z = 4.88, p < .001$, and Sobel $z = 6.91, p < .001$, respectively. Other

than present and expected future life satisfaction, HRV (IV) and executive emotion regulation (M) together did not predict past life satisfaction, $F(2, 154) = .61, p = .55$, adj. $R^2 = -.01$. Beta-weights for all steps are presented in Table 5.

### 4. Discussion

The major aim of the present study was to explore the relationship between trait HRV, which is thought to be an index of self-regulatory strength (Segerstrom & Solberg Nes, 2007; Thayer et al., 2009), and subjective well-being. We hypothesized that higher HRV would be related to better subjective well-being, as indicated by better mood and higher satisfaction with life. Moreover, we predicted that the relationship between HRV and well-being would be mediated by emotion regulation strategies that implicate cognitive processes of executive functioning, such as inhibition, planning, and mental shifting.

The results largely confirmed our predictions. HRV was positively associated with positive hedonic tone (cheerfulness) and positive tense arousal (calmness), and these effects were completely
mediated by the habitual use of executive emotion regulation strategies. Furthermore, although HRV was not correlated with present and expected future satisfaction with life, it was related with life satisfaction, mediated by the habitual use of executive emotion regulation. Taken together, these results support the use of HRV as an index of self-regulatory strength, in particular, executive emotion regulation.

One notable implication of the present findings is that while executive emotion regulation may reflect self-regulatory strength, and may contribute to subjective well-being, these strategies may also have their costs in that the effort expended in exerting control may weaken self-regulatory strength. In previous research, executive emotion regulation strategies such as refocusing or reappraisal were thought to carry lower costs than, for instance, suppressing emotions (Gross & Levenson, 1997; Richards & Gross, 2000). Yet, future research is needed to examine whether the effort needed to exert control via executive emotion regulation may lead to fatigue and (momentarily) to failures in self-regulation (Segerstrom & Solberg Nes, 2007).

5. Limitations

Two major limitations of the present study should be mentioned. The first limitation is that the study is cross-sectional. With a cross-sectional design it remains unclear whether HRV indexes the ability to exert executive functions, or whether the habitual use of executive emotion regulation (thus exerting executive functions) is just reflected in higher levels of HRV. Similarly, it is also possible that HRV does not increase positive affect, but that positive affect increases HRV. Supporting the latter view, it has been argued that positive mood may improve executive functions such as inhibition (Phillips, Bull, Adams, & Fraser, 2002).

The second limitation of the present study concerns the classification of executive and non-executive strategies of emotion regulation that was based on two instruments that cover a broad range of cognitive strategies. The small to moderate intercorrelations among the respective strategies and the moderate internal consistency of the two scales that were theoretically derived from these two instruments suggest that although the strategies within the two classes appear to have something in common (presumably executive functions vs. deficits in executive functions), the two classes are still quite heterogeneous. For future studies on the association between HRV, emotion regulation, and subjective well-being, it would be useful to generate categories of emotion regulation strategies that include more specific executive processes, such as planning, mental shifting, updating information, and inhibition (Zelazo & Cunningham, 2007).

References


Diener, E., Suh, E. M., Lucas, R. E., & Smith, H. L. (1999). Subjective well-being: Three classes are still quite heterogeneous. For future studies on the association between HRV, emotion regulation, and subjective well-being, it would be useful to generate categories of emotion regulation strategies that include more specific executive processes, such as planning, mental shifting, updating information, and inhibition (Zelazo & Cunningham, 2007).


