Perseverative cognition : the impact of worry on health

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Chapter 6

Effects of explicit and implicit perseverative cognition on cardiac recovery after cognitive stress

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Abstract

Slow cardiovascular (CV) recovery after stress is a predictor of adverse CV outcomes. Perseverative cognition (PC) about stress has been hypothesized to co-determine slow recovery. In the present study, it was investigated whether two types of trait PC, i.e. trait worry and trait rumination, predicted delayed cardiac recovery after a cognitive stressor. Furthermore, it was examined whether explicit state PC (i.e. negative intrusive thoughts) or implicit state PC (i.e. automatic vigilance) additionally predicted delayed cardiac recovery.

Fifty nine participants performed a stressful task, which consisted of an unsolvable synonym task. After a 6-minute recovery period, participants reported on their level of negative intrusive thoughts (i.e. explicit state PC), and performed a lexical decision task (LDT) to measure automatic vigilance for task-related information (i.e. implicit state PC). Cardiac activity was continuously measured using heart rate (HR) and heart rate variability (HRV). Trait worry and rumination were measured by the Penn State Worry Questionnaire (PSWQ) and the Ruminative Response Scale (RRS), respectively.

The results showed that high trait worriers had a slower HR recovery from the cognitive stressor compared to low trait worriers. They also showed delayed HRV recovery, but only when the tendency to dwell upon ones negative mood (the ‘brooding’ subscale of the RRS) was low. Slow HR recovery was associated with high levels of negative intrusive thoughts and with automatic vigilance, but in the unexpected direction for the latter. These results provide evidence that delayed cardiac recovery is associated with trait as well as state PC, and suggest that brooding attenuates the HRV suppressing effect of high trait worry.

Introduction

A large body of research has made clear that stressful events can have profound effects on the pathogenesis of cardiovascular diseases (e.g., Rozanski, Blumenthal, & Kaplan, 1999; Black & Garbutt, 2002; Krantz & McCeney, 2002; Rosengren et al., 2004). The investigation of how stressful events can affect cardiovascular health has for a long period focused on adverse cardiovascular activity *during* these stressful events, while in more recent years the insight has grown that stress-related cardiovascular activity that is *prolonged* beyond the presence of these stressors might be much more detrimental (McEwen, 1998; Pieper and Brosschot, 2005; Schwartz et al., 2003). Delayed heart rate recovery has indeed been found to be predictive of coronary events (Pitsavos, 2004), heightened levels of carotid atherosclerosis (Heponiemi, 2007; Jae et al., 2008) and even all-cause mortality (Cole, 2000; Nishime, Cole, Blackstone, Pashkow, & Lauer, 2000). In addition, delayed blood pressure recovery predicted hypertension 3 and 5 years later (Stewart & France, 2001; Borghi, Costa, Boschi, Mussi, & Ambrosioni, 1986, respectively). Clearly, it is important to elucidate the psychological, that is, cognitive-emotional, factors that contribute to this delayed cardiovascular recovery.

It has been suggested that stressful events are associated with delayed cardiovascular recovery particularly because these events evoke negative, worrisome thoughts (Brosschot, Gerin & Thayer, 2006). According to the perseverative cognition (PC) hypothesis (Brosschot et al., 2006), worry and rumination extend the mental representation of a stressful event beyond its actual presence and this is suggested to delay cardiovascular recovery after this event. Perseverative cognition (PC) is defined as “the repeated or chronic activation of the cognitive representation of one or more psychological stressors” (cited from: Brosschot et al., 2006, p 114). This definition of PC is quite broad and as such, previous studies have focused on different operationalizations of PC when testing the PC hypothesis. First, PC can be measured as a trait or personality characteristic – some people are more prone to worry or ruminate than others – or as a state, that is, measuring the actual experience of negative repetitive thoughts during an experiment or in daily life. Trait and state worry appear only marginally related (Verkuil, Brosschot & Thayer, 2007). The second aspect is the content of the stressor that is represented. Whereas ‘worry’ refers to PC about future stressors, ‘depressive rumination’ refers to PC about ones current sad mood, while ‘angry rumination’ refers to PC about anger provocations. Third, all previous studies have focused on explicit forms of PC whereas it likely that implicit forms of PC exist. Below we will discuss to what extent these different operationalizations of PC have yielded supportive evidence for the PC hypothesis.

Several studies have suggested that high trait ruminators recover more slowly from stressful events (Gerin, Davidson, Christenfeld, Goyal, & Schwartz, 2006; Roger & Jamieson, 1988; Key, Campbell, Bacon, & Gerin, 2008). However, these studies measured trait anger rumination (Gerin et al., 2006) and trait depressive rumination (Key et al., 2008; Roger and Jamieson, 1988) and not trait worry, that is, *anxious* PC. Both trait worry and trait depressive rumination are important risk factors for the onset and maintenance of mood and anxiety disorders (Nolen-Hoeksema, 1991; Borkovec, Ray & Stöber, 1998) which are in turn important risk factors for the development of cardiovascular diseases (CVD) (Kawachi, Sparrow, Vokonas, & Weiss, 1994; Wulsin, Vaillant, & Wells, 1999). For example, worry is one of the central features of Generalized Anxiety Disorder (GAD) and rumination plays an important role in Major Depressive Disorder (MDD). At least two study have shown that trait worry directly predicts cardiovascular health problems, that is myocardial infarction (Kubzansky et al., 1997) and the long term cardiovascular effects of a major stressful event (‘9/11’; Holman et al., 2008). Although depressive rumination and anxious worry are related forms of PC, they possess some characteristics that distinguish them. For example, Watkins et al. (2005) found that worrisome thoughts are rated as more upsetting and disturbing than ruminative thoughts. This would imply that worrisome thoughts, which are typically measured with the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990), might have stronger cardiac effects than ruminative thoughts. On the contrary, depressive rumination, as typically measured by the items of the Ruminative Response Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003) might have somewhat less forthright physiological effects. This idea seems to be supported by empirical evidence. On the basis of their review of the physiological effects of PC, Brosschot et al. (2006) concluded that trait worry, as measured with the PSWQ is a the better predictor of delayed physiological recovery than trait rumination, as measured with the RRS. Moreover, worrisome thoughts were reported to continue for a greater number of years than rumination (Watkins, Moulds, & Mackintosh, 2005), implying that worrying may cause longer ‘wear and tear’ on the body (cf: McEwen, 2003). In the present study, we addressed this issue and expected trait worry (measured by the PSWQ) to be the stronger predictor of delayed cardiac recovery than trait rumination (measured by the RRS).

State worry has also been suggested to be implicated in slow CV recovery after stressful events (Brosschot et al., 2006). It has been shown that during experimentally induced worry as well as during worry in daily life cardiovascular activity is increased (Lyonfields, Borkovec, & Thayer, 1995; Thayer, Friedman, & Borkovec, 1996; Verkuil, Brosschot, Borkovec, & Thayer, 2009; Pieper, Brosschot, van der Leeden, & Thayer, 2007). Worry has also been shown to mediate the effects of daily stressors on prolonged cardiac activity during waking and sleeping (Brosschot, van Dijk, & Thayer, 2007). Yet, direct evidence that delayed cardiovascular recovery after a stressful event is due to perseverative cognition is still scarce, as most experimental studies have only found an association between delayed recovery and trait PC, and not, or not consistently, between state PC measured after or during the recovery period (Glynn, Christenfeld, & Gerin, 2002; Key et al., 2008; Gerin et al., 2006). This may be due to several limitations of these latter studies. Firstly, these studies used anger provocation or emotional recall tasks as stressors, after which explicit state worry might just be less likely. For example, only 31% of the participants in a study by Glynn reported anger related thoughts after an anger recall task. The present study aimed to use a more general stressor, i.e. performance on an unsolvable cognitive task within an evaluative context. Such tasks have been previously shown to be experienced as physiologically and psychologically stressful (Brosschot et al., 1992; Weidner, Friend, Ficarrotto, & Mendell, 1989). Accordingly, in the present study we tested whether state PC concerning a previous stressor is associated with slowed cardiac recovery and adds to a model wherein slowed cardiac recovery is predicted by trait PC.

A second limitation of these previous studies pertains to the nature of state PC. Gerin and colleagues found that although delayed cardiovascular recovery after recalling an anger provoking event was predicted by trait angry rumination (Gerin et al., 2006; Glynn et al., 2002), this was not due to state rumination, as measured by thought sampling. However, in a more recent study Key et al. (2008) did find an effect of state rumination on cardiovascular recovery, but this was – unexpectedly - only true for people *low* in trait rumination (Key et al., 2008). As a possible explanation for this finding the authors suggested that perseverative cognition in frequent ruminators occurs largely implicit, without conscious awareness, and would therefore be difficult to report. Thus, delayed cardiac recovery after stressful events might not or not only be caused by explicit PC, but also by implicit or *unconscious* PC related to these events. It is not unlikely that implicit PC exists. In the last decades it has become clear that a large part of our information processing in daily life occurs relatively implicit and without reflective conscious awareness (Bargh & Chartrand, 1999; Bargh & Ferguson, 2000). Thus, there is reason to expect that stressful events not only give rise to explicit PC, but also to implicit PC. One example of implicit PC is ‘automatic vigilance’ for stressor related information. Automatic vigilance can be regarded as the increased sensitivity of the attentional system for task or stressor related information. This occurs for example after failure on a task (Rothermund, 2003; Smith, Ruiz, & Uchino, 2000). To date, no study has directly addressed the possibility that this type of PC causes prolonged stress-related physiological activity. Automatic vigilance or other forms of implicit or unconscious cognitive processing, such as after subliminal emotional stimulation, have not been tested for their physiological effects with the exception of relatively subtle effects on brain activity (Morris, Öhman, & Dolan, 1999), startle reflex (Ruiz-Padial & Vila, 2007) and skin conductance (Öhman & Mineka, 2001).

Finally, the role of mood in recovery from stressors remains unclear. It seems common sense that state negative mood is associated with cardiac activity. However, in several ambulatory (Brosschot et al., 2007) and laboratory studies (Verkuil et al., in press; Key et al., 2008) state mood was measured and was found to be unrelated to heightened or prolonged cardiovascular activity. In other studies of PC and recovery this was not tested, although effects of trait hostility on slowed blood pressure recovery have been reported (Anderson, Linden, & Habra, 2005). Therefore, in the present study we also investigated the effects of state anxiety and state sadness.

Summarizing, this study tested the hypothesis that slowed cardiac recovery after a stressor is predicted by high trait PC, especially trait worry, and by explicit and implicit state PC (negative intrusive thoughts and automatic vigilance) and negative affect. To test this, we used an unsolvable cognitive task, which consisted of an intelligence test of which the participants were made to believe that it predicted future career success, thereby creating an evaluative environment. This task has been previously used to evoke automatic vigilance (Koole, Smeets, van Knippenberg, & Dijksterhuis, 1999).

Materials and Methods

Participants

Fifty-nine undergraduate students from Leiden University participated in this study (mean age = 22.4 years, SD = 3.66; 12 males, 47 females). The sample was predominantly Caucasian (80%); 12% identified themselves as Black, 5% as Hispanic and 3% as Asian. They received € 4.50 or course-credits for their participation. This study was approved by our Institutional Review Board. All subjects provided written informed consent.

Instruments

Cardiac activity. HR and HRV were continuously measured, in a non-invasive manner, with the Polar s810i wristwatch and the Polar Wearlink 31 belt band, which has a sampling rate of 1000 Hertz (Polar Electro Nederland BV; Gamelin et al., 2006). Before analyzing HR and HRV, the raw interbeat intervals (IBIs) were preprocessed for artifacts using the Polar Precision Software. The corrected IBI series were subsequently processed with the HRV Analysis program, using the smoothness priors based approach which removes the low frequency trend component of the IBIs (Niskanen et al., 2004). For every 6-minute phase of the experiment (baseline, mental challenge, recovery) mean HR (in beats per minute, BPM) was calculated. In addition, to obtain a measure of HRV and vagal activity, spectral analyses using an autoregressive algorithm following the Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology (Task Force of the

European Society of Cardiology the North American Society of Pacing, 1996) guidelines were performed. Mean High Frequency (HF; 0.15 to 0.40 Hz) power (in milliseconds squared), was calculated for every phase of the experiment. In addition, the root mean of squared successive differences, RMSSD, in milliseconds was calculated for every phase.

Trait perseverative cognition (PC)

Penn State Worry Questionnaire (PSWQ; Meyer et al., 1990; Dutch translation; van Rijsoort et al., 1999). This questionnaire consists of 16 self-report items. Items are directed at the excessiveness, duration and uncontrollability of worry, for example: 'Once I start worrying, I can't stop'. The PSWQ has demonstrated high reliability as well as high temporal stability and substantial construct and predictive validity in the assessment of trait worry (Verkuil et al., 2007).

Ruminative Response Scale (RRS; Treynor et al., 2003; Dutch translation: Raes, Hermans & Eelen, 2003). The RRS consists of 22 items measuring ruminative responses to depressed mood. These items form three subscales: Brooding, defined as 'a passive comparison of one's current situation with some unachieved standard', (cf. Treynor et al., 2003); Reflection, defined as 'a purposeful turning inward to engage in cognitive problem solving to alleviate one's depressive symptoms'; and a Depression scale. Only the rumination scales were used in this study: Reflection, consisting of five items (e.g., 'I analyze recent events to try to understand why I am depressed') and Brooding, consisting of three items (e.g., 'I think "What am I doing to deserve this?" '). The RRS possesses good internal consistency and of its subscales, the Brooding subscale correlated most highly with measures of chronic strain, providing evidence for its maladaptive features.

Cognitive stress task

Manipulated IQ task (derived from: Koole et al., 1999). The cognitive stress task consisted of six verbal analogies that were modeled after a normal IQ test. Each analogy consists of two blank spaces that have to be filled after one minute. Example: "____" relates to 'but' as 'however' relates to " ____". For each blank space, four possible answers were given, one of which the participants had to choose, although all analogies were unsolvable and they were sufficiently ambiguous to allow giving bogus (positive and negative) feedback (see Procedure). After the recovery phase the participants were asked to report, on a Likert scale (ranging from 'Not at all' to 'A great deal'), how much effort they had spend on trying to solve the analogies.

State perseverative cognition (PC)

Implicit PC: Implicit PC concerning the cognitive stress task was operationalized as automatic vigilance and measured with a lexical decision task (LTD; cf. Koole et al., 1999). The LDT is typically used to assess implicit activation of cognitive schemata, for example in studies concerning persistent activation of information related to goal discrepancies or intentions (e.g., Forster, Liberman, & Higgins, 2005; Marsh, Hicks, & Bink, 1998) and therefore very well suited to measure implicit activation of cognitive representations related to the stress task.

Participants were seated in front of a computer screen. They were told that on each trial of the task they were about to perform they would be shown a string of letters and that the task was to decide if the string was a word or a non-word. They could indicate their response by pressing one of two buttons on a response box and were asked to do this as quickly and accurately as possible. Each trial started with a fixation cross that lasted 2000 ms. Thereafter the letter strings were presented, with a maximum of 1000 ms per trial. The task started with ten practice trials. Subsequently, sixty-four words and non-words were shown. The order of the presentation of the trials was randomized for each participant. The task was programmed in E-Prime 1.1 software.

We used 8 words that were related to intelligence (e.g., ‘smart’, ‘intelligent’), 8 control words that were unrelated to intelligence but reflected generally positive characteristics (e.g. ‘brave’, ‘tolerant’) and 16 neutral distracter words (‘piano’, ‘eyes’). The remaining 32 words were non-words. Intelligence related and control words were matched on word length and word frequency. The index for *Automatic Vigilance* was calculated by subtracting the reaction times (RTs) to intelligence related words from the RTs to control words.

Explicit PC. To measure state PC related to the task, we used 7 items of the Sarason Cognitive Interference Scale (Sarason, 1978) which measures the level of distracting, intrusive thoughts of the participants experienced after the IQ task, during the recovery period (e.g. ‘After the IQ task, I was thinking about how bad I had performed on the IQ task’). The CIQ has been used frequently in test anxiety literature, and possesses good psychometric properties with internal consistency (Cronbach’s alpha) estimates ranging from .71 to .91. Studies using the CIQ have demonstrated that it is sensitive to changes in intrusive thoughts that are related to individual and situational factors (cf Pierce, et al., 1998).

Mood states. During the baseline and recovery phases the levels of state anxiety and state sadness were assessed using visual analog scales (Brosschot et al., 1992; Johansson, 1976). Participants first indicated how they usually felt on this 100mm scale and thereafter rated their current levels of anxiety and sadness. We used the difference between ‘mood as usual’ and ‘current mood’ as indices of state anxiety and state sadness. This method is relatively insensitive to the shifting of internal standards for reporting ones mood.

Biobehavioral variables. Participants were asked to report the number of cigarettes, the number of cups of coffee and the number of alcoholic beverages they had consumed since awaking on the day of participation, as these factors could influence their cardiac activity. For the same reason, participants were also asked to report their height and weight, use of medication and whether they suffered from a chronic disease.

Procedure

The experiment started with a 6-minute baseline recording of HR and HRV during which participants reported their mood state on the visual analogue scales. Thereafter, participants were instructed to perform an intelligence test. They were told that “this test is a good measure of analytic ability and is a reliable predictor of future success in numerous careers”. The six analogies appeared one by one on the computer screen (see ‘Instruments’). After every analogy participants received feedback (“that was not the correct answer” or “that was the correct answer”). To manipulate the level of negative feedback (high versus low levels), half of the participants received negative feedback after each analogy, the other half received negative feedback after two analogies and positive feedback after four analogies. In both conditions, the computer informed the participants that 8 percent of the other attendants had the same score, i.e. zero or four respectively. However, we found no significant different effects of this feedback manipulation on cardiac activity or on the state PC variables, nor any interaction effects with trait or state PC and mood states. Given that the task itself was sufficiently stressful to increase cardiac activity independent of feedback (see results), we therefore discarded the latter in the rest of the analyses.

After the cognitive task, participants performed a simple filler task (rate the attractiveness of several paintings) while HR and HRV were measured continuously, to allow a period of cardiac recovery for later analysis. After this 6-minute recovery phase, participants rated their current level of anxiety and sadness and performed the LDT (implicit PC). After these tasks had been completed, participants filled in the questionnaires, (including the explicit PC questionnaires), and were debriefed.

Statistical analysis

HF power and RMSSD were transformed logarithmically to normalize the distributions (consequently we refer to them as lnHF power and lnRMSSD). To test whether trait PC was associated with delayed cardiac recovery, we used multilevel growth curve modeling (Singer and Willett, 2003) with HR or HF power as dependent variables1, and linear and quadratic time trends, based on visual inspection of the time curves of the cardiac data, and the PSWQ and the RRS subscales as predictors. The interactions of interest were the interactions between the linear Time trend and the PSWQ or the RRS subscales. Significant interactions were further explored by Pearson correlations and by analyses of (co)variance using the median splits of the trait scales. Only the biobehavioral variables that had a significant bivariate correlation with HR or HRV and that significantly improved the fit of the models (cf. Singer & Willett, 2003) were entered as covariates, (i.e. smoking and age in the HR and HRV analyses, respectively). This was also done as the number of measured biobehavioral variables was so large that entering them all would decrease the degrees of freedom too much for the present sample size. To examine whether trait PC was associated with negative intrusive thoughts, anxiety, sadness or automatic vigilance, we conducted analyses of variance and Pearson correlations. To test the hypothesis that these state PC variables and the mood states variables mediated the effect of trait PC on cardiac recovery, we conducted hierarchical multilevel regression analyses (Baron & Kenny, 1986). All independent variables were centered on their grand mean in order to reduce multicollinearity (Aiken & West, 1991). All analyses involved two-tailed tests, with alpha set at .05.

Results

Descriptive statistics

Table 1 shows the means and standard deviations of the variables measured in this study. In line with previous studies females scored higher on Brooding, and had a trend for higher Trait Worry scores. Because of technical problems, cardiac measures of two participants were not available. Therefore the analyses of the cardiac variables are based upon 57 participants. Females had higher baseline HR, but no different lnHF power than men. The amount of effort spent on the task was rated above the scale’s midpoint (M = 4.24, SD = 0.68).

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[1] The same analyses were also conducted with lnRMSSD as outcome variable and yielded the same pattern of results.

Table 1. *Descriptive statistics*

Gender	Female (*N* = 47)		Male (*N* = 12)		
	M	*SD*	*M*	*SD*	*p*
PSWQ	49.17	12.32	41.83	9.60	.07
RRS	40.70	9.28	35.66	11.54	.12
Brooding	6.51	1.77	5.17	1.59	.02
Reflection	11.04	3.76	10.00	3.86	.40
Baseline heart rate (bpm)	79.70	8.60	70.47	9.80	.00
Baseline HF power (ms²)	579.07	714.39	534.91	654.51	.80
Baseline RMSSD (ms)	55.89	43.93	58.71	33.71	.40
RT intelligence related words	558	73	560	85	.95
RT control	536	69	545	63	.68
Negative Intrusive Thoughts	14.21	6.92	16.50	5.87	.30
State anxiety	1.55	1.20	1.49	1.13	.46
State Sadness	1.57	1.52	1.50	1.75	.88

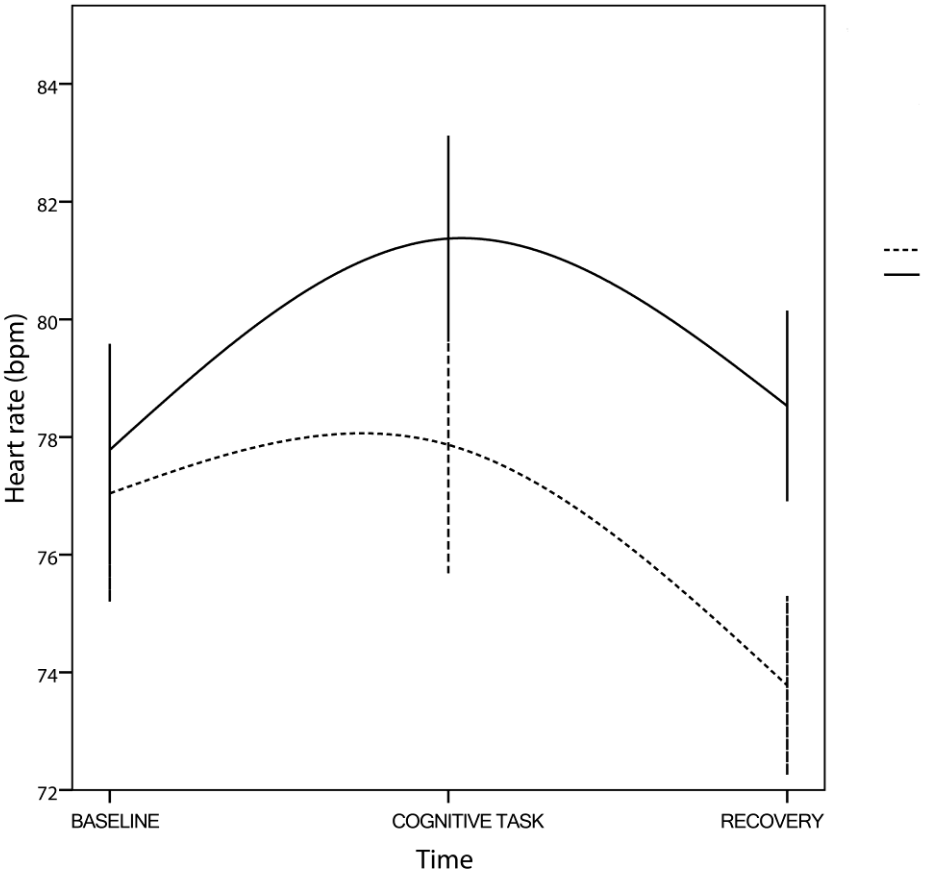
Trait PC and cardiac recovery

Heart rate (HR). Preliminary inspection of graphs of the HR responses suggested that a quadratic time trend best described the data (see Figures 1 and 2). First, a baseline multilevel growth curve model was fitted with HR as dependent variable, and linear and quadratic time trends as predictor variables. Thereafter, Trait Worry, Brooding, Reflection and smoking were entered into the model as predictor variables. Adding these variables significantly improved the fit of the model (χ^2 = 18.26, df = 7, $p < .05$). It was also apparent that a significant amount of variance in the data was due to correlations between the repeated cardiac measurements (AR rho = -.36, 95% CI: -.60 to -.05). Results showed a significant main effect of Time linear (B = 4.86, 95% CI: 1.91 – 7.82) and Time quadratic (B = -2.89, 95% CI = -4.34 to -1.44). Follow up paired t-tests showed that the cognitive stressor led to an increase in HR (M = 79.56, SD = 10.62) compared to baseline (M = 77.62, SD = 9.60); during the recovery period (M = 76.02, SD = 8.49) HR decreased below the baseline HR level (*p*s <

.05). Furthermore, the Time-linear x Trait Worry interaction was significant (B = .09, 95% CI: .03 - .15, $p < .05$), as was the Time-linear x Brooding interaction (B = -.66, 95% CI: -1.21 to -.20, $p < .05$). As

Figure 1. Mean level of heart rate during the experiment for low and high trait worriers. Error bars show mean +/- 1 standard error.

shown by the sign of the B values, the effects of Trait Worry and Brooding were in the opposite direction. To explore whether and how they influenced each other we tested whether the interaction between Time-linear x Trait Worry x Brooding was significant, which was not the case. No other main or interaction effects were significant. Figure 1 shows the effect of Trait Worry on HR recovery. For illustrative purposes Trait Worry scores were median split. High trait worriers had a higher HR (M = 78.52, SD = 8.27) during the recovery period than low trait worriers (M = 73.77, SD = 8.17), while controlling for HR during baseline and during the cognitive task ($F(1,53) = 4.57$, $p < .05$). Figure 2 suggests that high Brooders had lower HR during the cognitive task, but not during baseline or recovery. Yet, follow up univariate tests did not reveal significant differences between the Brooding groups.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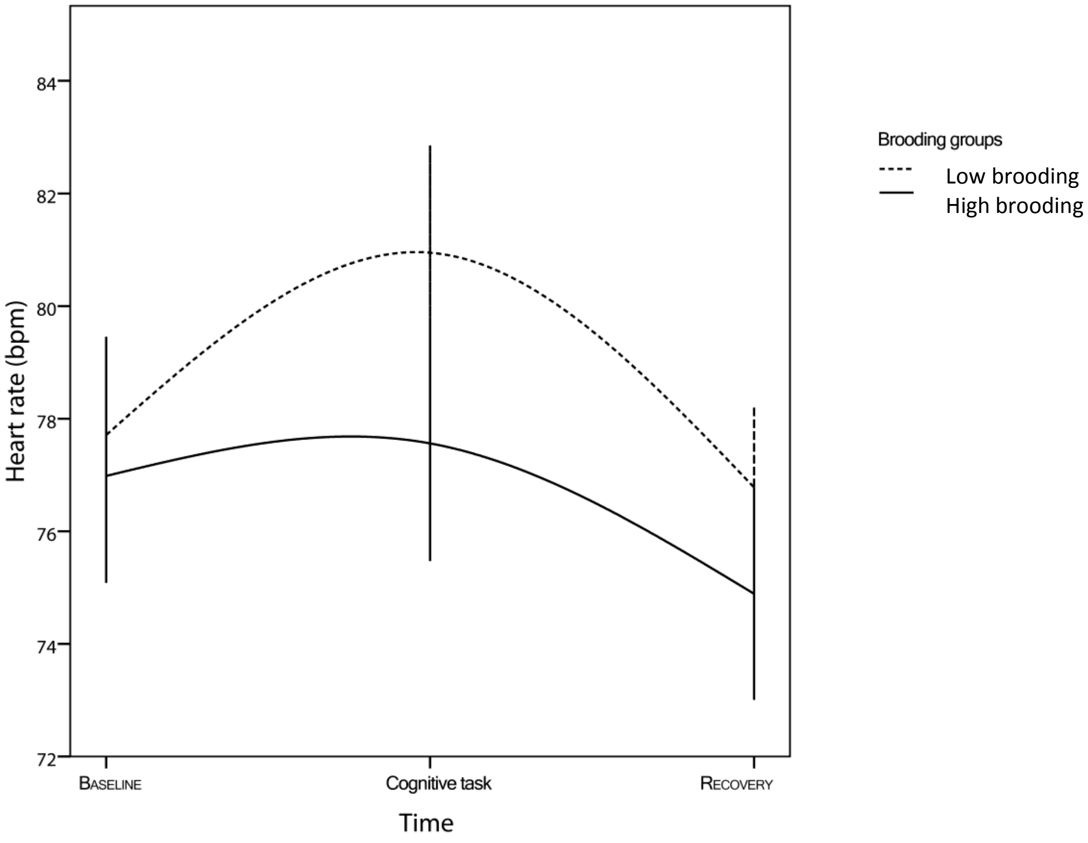

Figure 2. Mean level of heart rate during the experiment for low and high brooders. Error bars show mean +/- 1 standard error.

Heart rate variability (HRV). A baseline multilevel growth curve model was fitted with lnHF power as dependent variable, and linear and quadratic time trends as predictor variables. Adding Trait Worry, Brooding, Reflection and age as predictor variables significantly improved the fit of the model when compared to the baseline growth curve model (χ^2 = 18.57, df = 7, *p* < .05). The results showed a significant main effect of Time (linear, B = -.68, 95% CI: -1.05 to -0.32; quadratic, B = .32, 95% CI: .14 - .50). Follow up paired t-tests showed that the cognitive task led to an overall decrease in lnHF power (M = 5.34, SD = 1.23) compared to baseline (M = 5.69, SD = 1.21; *p* < .05). During the recovery period (M = 5.59, SD = 1.29) lnHF power did not differ from baseline. In addition, a main effect of Trait Worry appeared, with high trait worriers showing higher lnHF during the experiment (B = .03, 95% CI: .0001 - .061, *p* < .05). The expected effects of Time-linear x Trait Worry (B = -.01, 95% CI: -.02 - .00, *p* < .05) and Time-linear x Brooding (B = .08, 95% CI: .01 - .16, *p* < .05) were significant. In line with the results from the analyses on HR, the effects of Trait Worry and Brooding on lnHF during the experiment were in the opposite direction. Explorative analysis showed that these two-way interactions were subsumed by a significant three-way interaction between Time-linear x Trait Worry x Brooding (B = .006, 95% CI: .001 - .010, *p* < .05). Figure 3 shows that whilst Trait Worry was associated with low lnHF power during recovery, this effect was moderated by the level of Brooding: when Brooding was low, high trait worriers had a significantly lower lnHF during recovery than low trait worriers (*F*(1,32) = 4.24, *p* < .05). On the other hand when Brooding was high (figure 2B), lnHF power was also high during recovery, irrespective of Trait Worry status. No further main or interaction effects were significant.

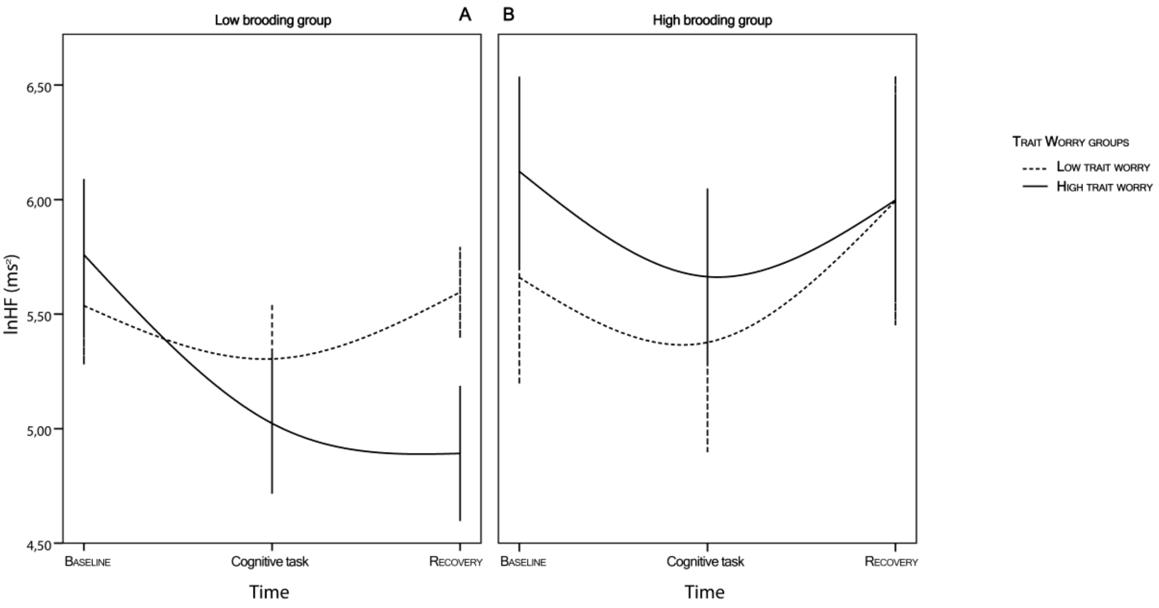

Figure 3. Interaction between Trait Worry and Brooding on lnHF power recovery. Error bars show mean +/- 1 standard error.

State PC and mood states after cognitive stress

First we inspected whether the cognitive task led to implicit PC, as indexed by automatic vigilance. The reaction times (RTs) to the intelligence-related words on the LDT were significantly slower than the RTs to control words (see table 1). The Automatic Vigilance Index (RTs IQ – RTs control = - 21 ms) differed significantly from zero (*t*(58) = 3.15, *p* < .05),. Trait Worry was not associated with different responding to IQ-related versus control words on the LDT. However, an exploratory analysis showed that Trait Worry was associated with a general slowing down on *all* LDT trials (mean *r*(58) = .30, *p* < .05). No associations were found between Brooding or Reflection and LDT reaction latencies. In addition, the Automatic Vigilance index was also not associated with the amount of negative intrusive thoughts during recovery (*r*(58) = .05, ns).

With regard to changes in mood states during the experiment, we found that state anxiety and state sadness during recovery were not significantly different from baseline.

Effects of explicit and implicit PC and mood states on cardiac recovery

Multilevel regression analyses were conducted to test whether state PC and the mood states influenced cardiac activity during recovery, and whether they could add to the effects of the PSWQ and Brooding on HR recovery. The results of these analyses are presented in Table 2. When state PC (Automatic vigilance index and negative intrusive thoughts) and mood states were entered into the model already containing Trait Worry and Brooding (see above), the fit of the model significantly improved ($\chi^2 = 14.46$, df = 6, $p < .05$). As shown in Table 2, in addition to the effects reported above (i.e. of Smoking, Time x Trait Worry, Time x Brooding), significant effects were also found for Time x Automatic Vigilance and, although marginally but still in the predicted direction, for Time x Negative intrusive thoughts. Exploration of the effect of Automatic Vigilance on HR recovery made clear that slower responding to *control* words, instead of IQ words, was associated with increased HR during recovery ($r(55) = .28$, $p = .034$). Importantly, by entering the cognitive emotional variables, the effect of trait worry was not reduced. Both Automatic Vigilance and Negative intrusive thoughts had independent effects on cardiac recovery.

The same steps were repeated for lnHF power. However, entering the PC and mood states variables into the model did not significantly improve the fit of the model, and no significant effects were found for these variables. As females had higher brooding scores and previously also have been shown to have higher baseline HRV (Thayer et al., 1998; Chambers and Allen, 2007), we also checked whether gender could possibly account for these results. This was not the case however.

Table 2. *Multilevel regression analysis predicting HR (bpm)*

Predictor	*B*	*SE*	*P*	*95% Confidence Interval*	
				Lower Bound	Upper Bound
Intercept	77.12	1.23	.00	74.67	79.56
Time, linear	4.58	1.54	.00	1.51	7.66
Time, quadratic	-2.68	0.74	.00	-4.26	-1.28
Smoking	0.62	0.30	.04	0.03	1.21
Trait Worry	0.09	0.12	.46	-0.15	0.30
Brooding	-0.33	0.75	.65	-1.82	1.16
Sadness	0.03	0.49	.95	-0.93	0.99
Anxiety	-0.20	0.48	.67	-1.16	0.74
Automatic Vigilance	-0.01	0.02	.76	-0.05	0.04
Negative Intrusive Thoughts	-0.17	0.18	.34	-0.54	0.19
Time-linear * Trait Worry	0.07	0.03	.04	0.00	0.13
Time-linear * Brooding	-0.52	0.20	.01	-0.91	-0.11
Time-linear * Sadness	-0.35	0.33	.29	-1.02	0.32
Time-linear * Anxiety	0.42	0.38	.27	-0.33	1.19
Time-linear * Automatic Vigilance	0.01	0.01	.03	-0.02	0.00
Time-linear * Negative Intrusive Thoughts	0.10	0.05	.06	-0.00	0.19

Discussion

The present study aimed to test whether cardiac recovery from a cognitive task could be predicted by trait PC, especially worry, and whether the effects of trait PC on delayed cardiac recovery would be due to heightened levels of explicit and implicit PC or negative mood states after this task. The results partially confirm our expectations and are in line with previous studies that have tested the perseverative cognition hypothesis (see Brosschot et al., 2006). As predicted, high trait worriers had a slower HR recovery from the cognitive task compared to low trait worriers. This adds to previous studies showing that trait PC is associated with slowed cardiovascular recovery after stress (Brosschot et al., 2006; Brosschot et al., 2007; Pieper et al., 2007; Glynn et al., 2002; Gerin et al., 2006; Key et al., 2008). The health effects of trait worry were recently also made clear by another study in which it was shown that high trait worriers showed enhanced heart rate, although not reduced HRV, during the anticipation and recovery phases of several laboratory tasks and also during the performance of these tasks (Knepp & Friedman, 2008). Given this accumulating amount of evidence, it is likely that trait worry exerts its damaging health effects (Kubzansky et al., 1997) by prolonging the total physiological load that stressors have on the human body. The fact that this slowed recovery effect was restricted to trait worry is consistent with the results of a recent review (Brosschot et al., 2006) showing stronger effects of trait worry than other trait PC variables, such as trait depressive rumination. In fact, the effect of one of the rumination scales, Brooding, i.e. tendencies to dwell upon ones negative mood which is considered as a maladaptive aspect of rumination, was even reversed. Even more, trait worry and brooding had an interacting effect on HRV recovery; only when brooding tendencies were low, high trait worry was associated with slow HRV recovery. This suggests that Brooding attenuates the suppressing effect of trait worry on HRV recovery. Although we did not particularly expect these findings for brooding, they seem to be in line with several studies showing enhanced HRV levels in depressed women (Thayer, Smith, Rossy, Sollers, & Friedman, 1998; Chambers & Allen, 2007). Our sample consisted for the most part of women (80%). The increases in HRV in depressed women that have been previously found have been suggested to be a biological ‘compensatory response’ to counteract the detrimental effects of stress on cardiac activity. More specifically, increased HRV in women might reflect a compensatory response which counteracts the perseveration of negative thoughts and mood: a higher HRV is positively associated with emotion regulation and frontal cortical activity which are thought to modulate the subcortical activity involved in sustained emotional reactivity (Thayer & Lane, 2000). As brooding can be considered an emotion regulation strategy, although often unsuccessful, this idea fits the finding that women who respond to stress with brooding thoughts show enhanced HRV levels during recovery. As high HRV levels are cardioprotective, these speculations may also offer an explanation for the findings that women suffering from (sub-clinical) depression are at reduced risk for cardiovascular health problems when compared with men (Hybels, Pieper, & Blazer, 2002; Wulsin et al., 1999). They may also explain the present findings, and suggest that gender clearly is an important factor to be more systematically investigated in future studies.

Our second aim was to examine whether the effects of trait worry and brooding on delayed cardiac recovery would be due to heightened levels of explicit and implicit PC after the cognitive stress task. The expected effect of negative intrusive thoughts on cardiac recovery was only found for HR recovery and was merely a statistical trend when using two tailed significance tests. Still, this finding is in line with the perseverative cognition hypothesis and with studies showing that state worry is associated with enhanced HR (Lyonfields et al., 1995; Thayer et al., 1996; Verkuil et al., in press; Pieper et al., 2007). The results concerning our hypothesis about the cardiac effects of implicit PC were less straightforward and cannot be easily explained. First of all, in contrast to what has been previously found, that is faster responses to concern related words compared to control words, we found that for all participants the responses to the control words were faster than to the IQ-related words. Second, although we found that slow cardiac recovery was associated with automatic vigilance after the mental challenge, follow up tests showed that delayed cardiac recovery was associated with slowed responses to control words on the LDT. A tentative explanation for these unexpected findings might be the following. Slowed LDT responses have been suggested to reflect an inability to disengage attention from the emotional value of the LDT words at the expense of attending to other aspects of the words (cf the 'affective interference hypothesis' posed by Siegle, Ingram & Matt, 2002). This might explain why for all participants reactions to the IQ words were slower than to the control words. In our LDT the control words reflected positive personality characteristics that were unrelated to intelligence. In this case, those participants that showed a slower HR recovery were those for who the cognitive task had most strongly threatened their *general* self-esteem, reflected specifically in slower responses to positive characteristics. However, these tentative suggestions should be examined in future studies for example by using other tasks measuring implicit cognition, like the Implicit Association Task (IAT) or flanker tasks (Rothermund, 2003). In addition, future studies should include concern related negative words as a limitation of this study was that we only included concern related positive and more general positive words. Studying implicit PC seems especially warranted as a large part of our information processing in daily life occurs relatively automatically. Focusing on explicit reports about stressful experiences could result in an underestimation of the effects that stressful events have on physiological functioning. Investigating whether and how implicit processing of stress-related information has adverse effects on physiological functioning might lead to a better understanding of how stress can eventually lead to somatic disease and therefore seems an essential venture for future studies.

We also explored the role of negative affect in delaying cardiac recovery. Trait worry was associated with heightened negative affect after the cognitive task, but no evidence was found for an association between negative affect and delayed cardiac recovery. This finding is in line with other studies that also have not found effects of negative affect on cardiac recovery (Key et al., 2008; Verkuil et al., in press). However, one possible explanation for not finding effects of negative affect in the present study is that the level of negative affect was relatively low. The cognitive task did not lead to overall significant increases in negative affect. Also, manipulating the type of feedback did not cause differential effects on cardiac activity, mood states or state PC. This is in contrast with previous studies that have provided (bogus) negative and positive feedback after cognitive tasks (Koole et al., 1999; Thompson, Webber & Montgomery, 2002). This limits our results in the sense that our results may pertain to slow cardiac recovery after cognitively stressful tasks as opposed to more emotionally stressful tasks. All participants rated their effort on the task above average and performing the task resulted in the expected cardiac pattern. Thus, the task seems to have required effort and seems to have been perceived as relatively neutral by most participants. This kind of task might resemble the tasks that people frequently engage in at work. Recent studies have already shown that high trait worriers recover more slowly from emotionally demanding tasks like recalling emotional events (Glynn et al., 2002; Key et al., 2008; Gerin et al., 2006). The present study adds to this the possibility that high trait worriers also recover more slowly from more cognitively demanding tasks that are not particularly emotional for most people. It remains a future challenge to find out why, and by what mechanisms, this is the case. As emphasized, we believe that implicit cognitive mechanisms may play a crucial role.

Future studies could also examine other indices of the cardiovascular system. We focused on cardiac activity, that is, HR and HRV, and although these indices are associated with reduced future cardiovascular health, it remains unclear to what extent trait worry and brooding tendencies have differential effects on hemodynamic functioning, such as blood pressure, cardiac output and total peripheral resistance. Another limitation is that we used a relatively small, young and healthy sample. Although the sample of this study seemed to represent trait worriers on the full severity range, it would be useful to conduct a similar study with older participants and / or patients suffering from mood and anxiety disorders. Another limitation is that during the recovery period, participants performed a filler task that could have interfered with the experience of negative intrusive thoughts (e.g., Gerin et al., 2006) and therefore speeded up recovery. It is also possible that task performance during recovery slowed down recovery for all participants. In any case, it is possible that one or both of these mechanisms might have reduced diminishing the amount of variance in recovery that could be explained by trait and state PC. Thus, the prediction of recovery by worry might have been further improved when we had not used the filler task. Finally, one could argue that the cardiac effects of the current task were relatively small (e.g., 2 heart beats per minute) when compared to anger recall tasks (8 – 10 bpm). Yet, these latter tasks require participants to verbalize their thoughts possibly accounting for a part of these observed differences. More importantly, the increase of 2 heart beats per minute is in line with laboratory studies using a similar task (Weidner et al., 1989) and is in line with laboratory and ambulatory studies showing that stress and worry episodes increase heart rate with approximately 2 beats per minute (Verkuil et al., in press, Pieper et al., 2007). Still, it is possible that larger cardiac effects were obtained when the baseline period lasted longer than the six minutes that we currently used. Six minutes might have been too short to get a good estimation of baseline cardiac levels, especially since heart rate levels at the end of the recovery period were below baseline levels. Future studies should therefore include longer baseline periods.

In sum, the present study provides further evidence that delayed cardiac recovery is associated with PC, and shows that brooding attenuates the HRV suppressing effect of high trait worry. The results could not confirm a mediating role of several forms of state PC. Trait worry and brooding tendencies are central elements in mood and anxiety disorders which, in turn, are important risk factors for the development of cardiovascular diseases. Therefore, investigating the long term implications of the present findings seems an important goal for future research.