Accepted for publication in "Emotion"

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Autonomic Regulation in Response to Stress: the Influence of Anticipatory Emotion Regulation Strategies and Trait Rumination

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This research was supported by the Research Foundation Flanders (Grant 3G015614, awarded to RDR and MAV). Preparation of this paper was also supported by Grant BOF10/GOA/014 for a Concerted Research Action of Ghent University (awarded to RDR). The authors report no conflicts of interest, either financial or scholarly.

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The raw and processed data discussed in this article is publicly available at https://osf.io/4yn8e/?view_only=2be6637308db4d72b91bd713cca90a8d

Abstract

According to the neurocognitive framework for regulation expectation, adaptively regulating emotions in anticipation of a stressful event should help individuals deal with the stressor itself. The goal of this study was twofold: first, we compared the influence of adaptive vs maladaptive anticipatory emotion regulation (ER) on the autonomic system during anticipation of, confrontation with, and recovery from a stressor; second, we explored whether trait rumination moderated this relationship. We collected data from 56 healthy female undergraduates during a public speaking task. The task involved four phases: baseline, anticipatory ER, stressor, and recovery. Participants were assigned to one of two anticipatory ER instructions (reappraisal or catastrophizing). Heart rate variability (HRV) indexed autonomic regulation. Results confirmed that HRV was higher in the reappraisal than in the catastrophizing group (over all time points, except for baseline). Trait rumination levels moderated the effect of anticipatory ER strategy on HRV during the stressor phase. Specifically, whereas for low ruminators reappraisal (versus catastrophizing) in the anticipation phase led to higher HRV when confronted to the stressor, high ruminators demonstrated lower HRV in that same condition. To conclude, over all participants, using reappraisal during the anticipation phase allowed participants to better cope with stress. However, only low, but not high ruminators could profit from the beneficial effect of anticipatory reappraisal on autonomic regulation. Even though further research is needed, this study suggests that, in female undergraduates, the tendency to ruminate is associated with abnormal anticipatory ER that might hinder an adaptive response to a stressor.

Keywords: anticipation, emotion regulation, rumination, public speaking task, heart rate variability.

Introduction

We all experience stress at some point during our life, which affects our mood, behaviour, and well-being. Even though stress is a common experience, individuals differ greatly in the way they respond to it, at both psychological and physiological levels (i.e., stress regulation). For instance, hindered stress regulation has been shown to play a role in the onset, maintenance and relapse of depressive symptoms (e.g., de Kloet, Joëls, & Holsboer, 2005; Hankin, 2008; Hooley, Orley, & Teasdale, 1986; Lupien, McEwen, Gunnar, & Heim, 2009; Morris, Ciesla, & Garber, 2010). However, the relationship between stress and depression is very complex and results from an interaction of biological, psychological and environmental factors (Gotlib, Joormann, Minor, & Hallmayer, 2008; Raedt & Koster, 2010). A better understanding of the mechanisms underlying successful and unsuccessful stress regulation would contribute to the improvement of prevention and treatment interventions for depression and other mental disorders.

For this purpose, De Raedt and Hooley integrated different literatures into the neurocognitive framework for regulation expectation (De Raedt & Hooley, 2016). In this framework, the authors formulated a comprehensive model of cognitive and neural mechanisms underlying stress regulation and how they are related to each other. These mechanisms can lead, through different pathways, to either successful or unsuccessful stress regulation (as seen for instance in depressed individuals). In this study we focused on one important mechanism of this framework, which is how the anticipation of a stressful event influences stress regulation itself.

Adaptive stressor anticipation: proactive emotion regulation

Emotion regulation (ER) is the ability to influence (automatically or voluntarily) our emotions (including stress) in order to maintain our emotional balance and to achieve our goals (Aldao, Sheppes, & Gross, 2015; Gross & Thompson, 2007). Interestingly, individuals not only regulate their emotions while being confronted with an emotional event but also when anticipating such events (i.e., anticipatory ER). Within the neurocognitive framework for regulation expectation (De Raedt and Hooley, 2016), proactive deployment of ER strategies in anticipation of a stressor is a key factor for successful stress regulation. This proactive anticipation involves preparatory processes (i.e., maintenance of goal-relevant information) associated with sustained anticipatory activity of the dorsolateral prefrontal cortex (DLPFC; Braver, 2012; Herwig et al., 2007). Previous studies have observed that, when individuals proactively anticipate an emotional stimulus, lower cognitive effort is exerted when the stimulus occurs (Vanderhasselt, Remue, Ng, & De Raedt, 2014). In addition, prefrontal control decreases amygdala activation, which is associated with the experience of negative emotions, via the cortical-subcortical pathway (Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008). To conclude, according to the neurocognitive framework (De Raedt and Hooley, 2016), when individuals proactively anticipate a stressor, preparatory processes and anticipatory DLPFC activity facilitate online stress regulation and decrease negative affect.

Maladaptive stressor anticipation: rumination

Whereas the previous paragraph describes a successful regulation scenario, the framework also accounts for unsuccessful stress regulation in depression. De Raedt and Hooley (2016) suggest that when anticipating a stressful event, depressed individuals tend to ruminate, that is, "*repetitively and passively focusing on symptoms of distress and on the possible causes and consequences of these symptoms*" (Susan Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008, p. 400). By compromising the individuals' cognitive resources (Davis & Nolen-Hoeksema, 2000; Disner, Beevers, Haigh, & Beck, 2011; Hertel, 1998; Watkins & Brown, 2002), this negative self-referential thinking may prevent them from engaging in proactive anticipation. Based on the neurocognitive framework (De Raedt and Hooley, 2016), this would lead to increased amygdala activity and negative affect, and therefore result in difficulties regulating the stress response. Results from several studies are in line with this hypothesis of the neurocognitive framework (De Raedt and Hooley, 2016). Waugh, Panage, Mendes, and Gotlib (2010) found a specific physiological cost (i.e., incomplete cardio-vascular recovery) associated with a lack of affective recovery from stressful anticipation. Vanderhasselt and colleagues (2014) observed, with ERPs, abnormal proactive and reactive cognitive control in depressed patients. Finally, amygdala hyperactivity during the anticipation of affective images was reported in anxious (Denny et al., 2015) and depressed individuals (Abler et al., 2010; Abler, Erk, Herwig, & Walter, 2007).

Aims and methods of the current study

With this study, we aimed to better understand the role of anticipatory ER and trait rumination during autonomic regulation in response to stress. Specifically, we investigated the influence of adaptive vs maladaptive anticipatory ER on the autonomic system during anticipation of, confrontation with, and recovery from a stressful event. In addition, we also explored whether the tendency to ruminate would prevent individuals from using the adaptive anticipatory ER strategy efficiently and hence hamper subsequent autonomic regulation.

To this purpose, participants were told that they would have to prepare and give a speech, which has been consistently shown to induce social stress and is characterized by high ecological validity (Allen, Kennedy, Cryan, Dinan, & Clarke, 2014). In addition, social stressors are of particular relevance in depression as they have a causal role in its onset (Kendler, Thornton, & Gardner, 2000). As previous research has shown that the speech preparation phase acts, per se, as a stressor (Fredrickson, Mancuso, Branigan, & Tugade, 2000; Waugh et al., 2010), participants were not actually asked to give the speech. When participants were anticipating to give a job interview, we instructed them to use either an adaptive or a maladaptive cognitive ER strategy, respectively, reappraisal or catastrophizing (Garnefski, Kraaij, & Spinnhoven, 2001). Cognitive reappraisal is an adaptive ER strategy that entails modifying the meaning attributed to the emotion-eliciting event. For instance, when facing an aversive event, individuals might try to focus on the positive aspects of the situation in order to decrease their distress. Several studies associated the use of reappraisal with prefrontal activation (Dillon & Pizzagalli, 2013; Nelson, Fitzgerald, Klumpp, Shankman, & Phan, 2015; Uchida et al., 2014; Urry, van Reekum, Johnstone, & Davidson, 2009; Vanderhasselt, Baeken, Van Schuerbeek, Luypaert, & De Raedt, 2013). On the other hand, catastrophizing is described as a "*tendency to magnify a perceived threat and overestimate the seriousness of its potential consequences*" (Gellatly & Beck, 2016, p. 441). It is thus a maladaptive ER strategy that also entails modifying the meaning attributed to the emotion-eliciting event, but now in a negatively biased way. By interacting with attentional and interpretative biases and anxiety/somatic symptoms, this maladaptive cognitive ER strategy might play a causal role in the onset and maintenance of psychopathology (Gellatly & Beck, 2016).

Next to self-reports of stressful feelings to check the effectiveness of our stress induction, heart rate variability (HRV) was assessed as an index of autonomic regulation (Lane et al., 2009; Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012; Appelhans & Luecken, 2006). In their Neurovisceral Integration model (Lane et al., 2009; Thayer & Lane, 2000), Thayer and Lane explain in detail how top–down appraisals of a situation influence, through cortical-subcortical pathways, activity of the brainstem and of the autonomic nervous system (ANS). In turn, the dynamic interplay of the sympathetic and parasympathetic branches of the ANS on the sinoatrial node of the heart affects the variability of the beat-to-beat intervals. In other words, variations in the heart rate reflect the individual's ability to adapt his/her autonomic response and behaviour to a changing environment. Indeed, whereas low HRV is usually linked to stress, disease, and an increased mortality risk, high HRV has been consistently linked with higher long-term wellbeing (Kemp & Quintana, 2013; Thayer et al., 2012; Thayer, Yamamoto, & Brosschot, 2010; Thayer & Lane, 2007) and, importantly, with successful ER (Appelhans & Luecken, 2006; Denson, Grisham, & Moulds, 2011; Fabes & Eisenberg, 1997; Lane et al., 2009). The relationship between HRV and ER is twofold (Thayer et al., 2012). On the one hand, higher tonic HRV is associated with greater ER abilities (Appelhans & Luecken, 2006; Geisler, Vennewald, Kubiak, & Weber, 2010; Lane et al., 2009), whereas low tonic HRV is typically observed in individuals with affective disorders, who are characterized by deficient ER (Faurholt-Jepsen, Kessing, & Munkholm, 2017; Kemp et al., 2010; Thayer, Friedman, & Borkovec, 1996; Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000). On the other hand, successful ER during experimental tasks is associated with phasic HRV increase (Butler, Wilhelm, & Gross, 2006; Ingjaldsson, Laberg, & Thayer, 2003). Importantly, trait and state ER and HRV are not independent from each other. It has been observed that, in challenging situations, individuals with good ER abilities and high baseline HRV react with a further HRV increase, while those with a lower HRV react with a further HRV dampening (Aldao & Mennin, 2012).

Hypotheses of the current study

Based on the premises of the neurocognitive framework for regulation expectation (De Raedt & Hooley, 2016), we hypothesized that using an adaptive (i.e., reappraisal) or a maladaptive (i.e., catastrophizing) ER strategy during the anticipation phase would not only influence autonomic regulation during the anticipation itself, but also during the following stressor and recovery period, even though no ER instructions were given during these two latter phases. Specifically, we predicted that participants using reappraisal would better cope with the stressor (i.e. lower self-reported stress and increased autonomic regulation, as indexed by higher HRV) during all three phases of the task (i.e., anticipation, interview preparation, and recovery) than participants who catastrophized the situation.

Second, we explored whether this effect of anticipatory ER strategy would depend on the individual's tendency to ruminate. Based on the neurocognitive framework, we predicted that a tendency to ruminate would be associated with poorer ability to deploy anticipatory reappraisal as an adaptive ER strategy. Indeed, ruminating should prevent individuals from engaging in proactive anticipation by capturing their cognitive resources, with decreased DLPFC and increased amygdala activity (e.g., Gotlib & Hamilton, 2008; Ochsner et al., 2004; Ray et al., 2005; Siegle, Carter, & Thase, 2006), hampering stress regulation. Hence, we expected that high ruminators would display lower HRV (index of autonomic regulation) than low ruminators during anticipatory ER, confrontation with the stressor, and recovery.

Several studies have observed that rumination is associated with lower HRV (for a systematic review and meta-analysis, see Ottaviani et al., 2015). However, predictions about the interaction of rumination with maladaptive cognitive strategies (such as catastrophizing) and stress regulation are less obvious, since no previous study has investigated this interaction, and those who have explored similar topics reported inconsistent findings. For instance, Ciesla and Roberts (2007) observed that rumination interacted with negative cognitions in predicting dysphoric symptoms, whereas Martin and Dahlen (2005) found that only rumination but not catastrophizing predicted perceived stress in daily life. Hence, we consider the possible moderating effect of rumination on the relationship between catastrophizing and autonomic regulation as an open research question.

Confirmation of our hypotheses would a) stress the importance of implementing proactive anticipation of a stressor, and b) allow us to know whether ruminators are able to do so. From a broader perspective, these results would provide a validation of a core aspect of the neurocognitive framework (De Raedt & Hooley, 2016). Empirical evidence in support of this theoretical model is of clinical relevance as it would help identifying which different aspects of stress resilience should be targeted by therapeutic interventions and how to better tailor such interventions.

Method

Participants

Fifty-nine healthy female undergraduates at Ghent University, Flemish and between 18 and 29 years old (*M* = 21.76; *SD* = 2.05), were recruited via Experimetrix Momentum^{TM} experiment scheduling system. Because emotional responding and cognitive emotion regulation (including rumination) are subject to gender differences (Garnefski, Teerds, Kraaij, Legerstee, & van den Kommer, 2004; Montagne, Kessels, Frigerio, de Haan, & Perrett, 2005; Susan Nolen-Hoeksema, Larson, & Grayson, 1999; Stroud, Salovey, & Epel, 2002), participation was restricted to female volunteers. Participants were selected according to the following criteria: they were native Dutch speakers, right handed, had normal or corrected to normal vision, they reported no drugs or medication use, and had no current (or history of) neurological or psychiatric illness. In addition, participants were asked to abstain from caffeine, alcohol, nicotine, or engage in strenuous exercise for at least three hours prior to the appointment. No obese individuals were included in the study. Finally, all participants were Caucasian.

All participants signed an informed consent (protocol approved by the local Ethical Committee) before the start of the experiment and were compensated with a payment of € 10. They were informed about their right to leave the experiment at any time without consequence. All participants completed the experiment.

To determine the sample size, we conducted an a-priori power analysis (G*Power) for a between-subjects, repeated-measures ANOVA. As this analysis focused on the main effect of

ER, the moderation analyses have to be considered exploratory. The a-priori power analyses indicated that the approximate sample size to identify a medium effect size with a power of 0.8 is 58 (parameters: effect size f = 0.31, α = 0.05, number of groups = 2, repetitions = 3, correlation among repeated measures = 0.5, non-sphericity correction = 1).

Procedure

The study was advertised as an experiment investigating communication skills. It consisted of four phases: baseline, anticipatory ER, interview preparation, and recovery. The first three phases (i.e., baseline, anticipatory ER, and interview preparation) followed the same structure: a sentence was displayed in the centre of the screen for five seconds, followed by a fixation cross for ten seconds[1]. During these ten seconds participants were required to think about the content of the sentence they had just read. Each phase lasted five minutes (Hansen, Johnsen, & Thayer, 2003) and was composed of a total of 21 trials, displaying seven sentences three times each, in random order. All sentences are reported in the supplementary materials. R-to-R intervals (i.e., the time interval between heartbeats), were recorded online, while affect self-reports were collected at the end of each phase. During the recovery phase no visual stimuli were displayed, hence only R-to-R intervals and mood self-report were assessed. The task was programmed in E-Prime® extension for Tobii™ (Psychology Software Tools, Inc.).

First of all, the equipment to record R-to-R intervals was set up (POLAR RS300X watch and heart-rate monitor belt). Immediately afterwards, participants were presented with several questionnaires to fill in online via LimeSurvey. In this way, they had approximately 15 minutes to familiarize with the lab environment and with wearing the Polar watch and

[1] This task was designed to collect tonic changes in pupil dilation. However, we realized that this outcome measure poses interpretation issues in experiments inducing emotional responses in order to investigate their regulation. In fact, dilation of the pupil is associated with both arousal and cognitive effort. Because of this limitation, we do not report the pupillary responses results. However, the interested reader can contact the authors.

belt. After completing the questionnaires, participants started the baseline, during which they read sentences of neutral content. As, to the best of our knowledge, no standardized set of Dutch neutral sentences has yet been developed, we created 14 sentences using neutral words from the study of Hermans and De Houwer (1994). Based on a pilot in 49 students, the 7 sentences rated most neutral were selected[2].

Participants were then told that they would have to simulate a job interview and that an expert in public speaking would play the interviewer and evaluate their performance. In addition, they were told that the interview would also be recorded so that other two independent experts could score it.

We then told participant that since giving job interviews is very stressful, they would first undergo a guided stress management procedure (anticipatory ER phase) which would help them reach the right state of mind to perform at their best (Philippot, Vrielynck, & Muller, 2010). Participants were randomly assigned to one of two anticipatory ER instructions (reappraisal VS catastrophizing, see full text in the Appendix). Through the adaptive ER instructions participants were taught to reappraise the situation in a more positive way and to put possible mistakes into perspective, while through the maladaptive instructions they were led to catastrophize the implications of failure and to imagine the worst possible outcome (Gellatly & Beck, 2016). To ensure that participants correctly understood the ER instructions, they were asked to read them carefully and then to explain their content in their own words. Finally, sentences taken from the ER instructions were displayed on the eye-tracker screen (i.e., anticipatory ER phase), and participants were asked to focus on their meaning.

[2] Participants were asked to rate the valence of each sentence on a 7-point Lickert scale, where 1 indicated “very negative” and 7 “very positive”. A score of 4 corresponded to “neutral”. A one-sample t-test indicated that the sentences average rating (*M* = 4.04, *SD* = 0.27) did not significantly differ from 4, $t(48) = 1.14$, $p = .261$.

Participants were then given five minutes to prepare the job interview (i.e., interview preparation phase) while questions commonly asked during job interviews were displayed on the screen. This phase was the actual stressor.

At this point, when participants were supposed to move to another room and perform the job interview, the experimenter feigned a technical problem with the cameras needed for the recording and stated the impossibility to continue with the experiment. For the recovery period, participants were asked to relax with their eyes closed for five more minutes.

To conclude, we asked participants whether they believed our cover story, and debriefed them immediately over the real purpose of the study.

Measures

The Ruminative Responses Style Scale. The Ruminative Responses Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003), was completed, together with other questionnaires[3], via LimeSurvey at the beginning of the experiment. This 22-item scale is a measure of self-reported trait rumination with good psychometric properties.

Self-reported affective responses. At the end of each phase (i.e., baseline, ER, interview preparation, recovery), six Visual Analogue Scales (VAS) were displayed on the screen to assess how stressed, tired, sad, happy, angry, and agitated participants felt at that moment (McCormack, Horne, & Sheather, 1988). To answer, participants had to click on each ten-centimetre-long horizontal line where they perceived that it best reflected their affective state between two anchors. Since self-reported stress was of primary interest for this research, we will focus on the results of this item in the main article. However, we reported

[3] Specifically, participants filled in the Mood and Anxiety Symptoms Questionnaire (MASQ; Wardenaar et al., 2010), the Rosenberg Self-Esteem Scale (RSES; Rosenberg, 1965), the Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski & Kraaij, 2007). These questionnaires were collected with the sole purpose of ensuring that the two groups did not differ at any of these relevant traits and that participants did not display clinical levels of anxious or depressive symptoms.

the analyses and results of each self-report item in the supplementary materials. This outcome indexed the emotional response targeted by the ER processes. The anchors were "not at all" and "as stressed as I can imagine".

HRV. R-to-R intervals were recorded via POLAR RS800X watch and heart-rate monitor belt during baseline, ER, interview preparation and recovery. Each phase lasted five minutes. Data was processed with Artiifact software (Kaufmann, Sütterlin, Schulz, & Vögele, 2011) as follows: first, artifact rejection was performed semi-automatically coupling the program's algorithm and visual inspection, then cubic spline interpolation was applied to correct for the identified artifacts. Finally, we calculated the normalized high-frequency spectral power (HFnu, 0.15–0.4 Hz) for each five-minute segment via Artiifact software. Compared to other HRV indexes, HFnu are less sensitive to several practical issues in our design (e.g. block length, windowing) and therefore more reliable and replicable (Burr, 2007). In addition, normalization reduces the skew inherent to HRV-all physiological data, allowing us to use parametric tests. Normalized HF reflect the influence of the vagus nerve on the heart (Burr, 2007; Thayer et al., 2012).

Data Analytic Plan.

To take into account the large inter-individual variability that characterizes both self-reported stress and HRV, we calculated reactivity scores by subtracting the baseline value from anticipatory ER, interview preparation, and recovery values (see for example Hughes & Stoney, 2000). This is also important because tonic and phasic HRV are not independent from each other, whereas we were solely interested in phasic HRV changes [4].

To investigate a) whether our procedure successfully induced stress, and b) how anticipatory ER strategies influenced stress and autonomic regulation during the different

[4] HRV can also be indexed based on RMSDD. However, our RMSSD data is not normally distributed, and cannot be normalized with transformations. When running analyses using RMSSD (both parametric and non-parametric), no effects were observed.

task phases, we performed two 3 (time: anticipatory ER, interview preparation, recovery) by 2 (group: reappraisal, catastrophizing) mixed ANOVAs, with time as a within-subject factor and group as a between-subjects factor, with respectively self-reported stress and HRV changes as dependent variables. Deviations from sphericity were corrected using the Greenhouse-Geisser procedure. Significant results were followed-up with t-tests and corrected for multiple comparisons with the Bonferroni method. We reported 95% confidence intervals around the effect size (Cohen's d).

Finally, to explore whether the effect of ER strategy on self-reported stress and HRV- was moderated by rumination, we tested the interaction of time (anticipatory ER, interview preparation, recovery) by ER group (reappraisal, catastrophizing) by trait rumination with a custom model ANOVA (including all interaction terms). A significant interaction was followed-up with three moderation analyses, one for each level of time (i.e., anticipatory ER, interview preparation, and recovery). To run these analysis, we used the PROCESS macro for SPSS (Hayes, 2012). Similarly to Cristea and colleagues (2014), we entered anticipatory ER group (i.e., catastrophizing coded as 0 and reappraisal coded as 1) as predictor, HRV as outcome, and RRS scores as moderator. Ranges of RRS scores where the relationship between anticipatory ER group and online ER was significant were identified with the Johnson–Neyman (J–N) technique (Johnson & Fay, 1950).

Results

Because of non-systematic technical malfunctions in the HRV recording, three participants were excluded from the analyses leaving a final sample of 56 participants, of which 27 belonging to the catastrophizing group, and 29 to the reappraisal group. The two groups did not differ at baseline in any of the dependent variables (i.e., all six self-reported affect items, HRV) nor in their scores of the questionnaires, all *t*s < 1.32, *p*s $> .14$. Of all participants, only one did not believe in our cover story about the job interview, and only two participants of the catastrophizing condition did not believe that "preparing for the worst case scenario" is a helpful strategy to deal with stress. However, removing these participants from the analyses did not significantly alter the results, therefore, we reported the results of the whole sample.

Self-reported stress

Following up a significant effect of time, $F(1.69, 91.21)= 89.48$, $p < .001$, $\eta_p^2= .62$, we observed that participants' stress stayed constant from anticipatory ER to interview preparation, $t(55) = -1.39$, $p = .171$, $d = -0.11$, CI [-0.48, 0.26], and decreased from interview preparation to recovery, $t(55) = 10.82$, $p < .001$, $d = 1.24$, CI [0.84, 1.65]. Stress levels were significantly lower after recovery compared to after anticipatory ER, $t(55) = 10.31$, $p < .001$, $d = 1.15$, CI [0.75, 1.55]. No main effect of group, $F(1, 54)= .24$, $p = 0.63$, $\eta_p^2= .004$, nor a time by group interaction was observed, $F(1.69, 91.21)= 0.12$, $p = .89$, $\eta_p^2= .002$. See Figure 1 for the descriptive statistics of each phase, per group.

HRV

In line with the self-reported stress response, also HFnu did not show an interaction effect of time and group, $F(1.71, 92.39) = 0.67$, $p = .49$, $\eta_p^2 = .01$. A significant main effect of time $F(1.71, 92.39) = 6.16$, $p = .005$, $\eta_p^2 = .10$, revealed significantly lower HFnu during anticipatory ER, $t(55) = -2.93$, $p = .015$, $d = -0.62$, CI [0.24, 1.00], and interview preparation, $t(55) = -2.66$, $p = .030$, $d = 0.40$, CI [0.028, 0.78], compared to recovery over all participants. High frequency power spectrum did not differ between anticipatory ER and interview preparation, $t(55) = -.44$, $p = .67$, $d = -0.06$, CI [-0.43, 0.31].

Finally, we observed a main effect of group, $F(1, 54) = 4.65$, $p = .036$, $\eta_p^2 = .08$, indicating a larger decrease in HFnu from baseline in participants in the catastrophizing condition ($M = -7.01$, $SD = 13.52$) than in those belonging to the reappraisal condition (M = -

0.18, *SD* = 10.07) over all time points (i.e., anticipatory ER, interview preparation, recovery)[5]. See Figure 2 for an overview of HFnu change values.

Moderation by Rumination

The time (anticipatory ER, interview preparation, recovery) by ER group (reappraisal, catastrophizing) by trait rumination interaction was not significant for self-reported stress, $F(3.34, 86.78) = 0.52$, $p = .69$, $\eta_p^2 = .02$. Instead, the same interaction was significant when using HFnu as dependent variable[6], $F(3.48, 90.57) = 4.48$, $p = .004$, $\eta_p^2 = .15$, and was followed-up with three moderation analyses, one for each level of time (i.e., anticipatory ER, interview preparation, and recovery).

During anticipatory ER, we observed a trend significant moderation of rumination on the relationship between anticipatory ER strategy and HFnu (see Table 1 for an overview of the linear model). For individuals with RRS scores below 32.18, reappraisal was associated with higher HFnu scores than catastrophizing. However, no difference between the two ER strategies was observed for individuals with RRS scores above 32.18.

Trait rumination significantly moderated the relationship between anticipatory ER strategy and HFnu during interview preparation (see Table 2 for an overview of the linear model). Specifically, reappraisal was associated with higher HFnu than catastrophizing in low ruminators (RRS scores below 31.12). No difference between the two anticipatory ER strategies was found for individuals who scored between 31.12 and 57 on the RRS. Finally, reappraisal led to lower HFnu values than catastrophizing in high ruminators (RRS scores above 57).

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[5]HRV can also be indexed based on RMSDD. However, our RMSSD data is not normally distributed, and cannot be normalized with transformations. When running analyses using RMSSD (both parametric and non-parametric), no effects were observed.

[6] We also tested the same model using the subscales of the RRS (i.e., brooding and reflection) as moderator (instead of the total RRS score). Neither subscale alone resulted in a significant interaction.

Lastly, no significant moderation was found for HFnu during recovery (see Table 3 for an overview of the linear model).

See Figure 3 for a graphical representation of the results of each moderation analysis.

Discussion

In this study, we investigated whether the use of different ER strategies in anticipation of a stressful event would influence the experience of stress and autonomic regulation during anticipation, confrontation and recovery from a stressor. In addition, we explored whether this relationship would be moderated by trait rumination. To answer these questions, we asked 56 Flemish female undergraduate students to prepare a job interview (i.e., the stressor). As anticipatory ER strategies, we compared an adaptive and a maladaptive cognitive ER strategy, respectively, reappraisal and catastrophizing. Autonomic regulation was indexed via normalized high-frequency heart-rate variability, while the emotional response was assessed through stress self-reports. We predicted that reappraising during the anticipatory phase would lead to increased autonomic regulation (i.e., higher HRV) during all task phases (i.e., anticipation, interview preparation, and recovery) compared to catastrophizing. In addition, we expected that high ruminators would benefit less than low ruminators from the adaptive anticipatory ER, hence showing lower HRV during anticipation, interview preparation, and recovery. However, we made no predictions on the presence and direction of an interaction of rumination with the use of a maladaptive anticipatory ER (catastrophizing) on autonomic regulation.

First of all, self-reported stress indicated that preparing the job interview successfully induced stress. Indeed, compared to recovery, participants experienced more stress during the preparation stressor phase. This is consistent with previous research on public speaking tasks showing that speech preparation is, per se, a stressor (Fredrickson et al., 2000; Waugh et al., 2010). Increased HRV during the recovery phase shows that participants were regulating their autonomic response following the interview preparation.

Second, we observed a main effect of ER strategy on HRV values. As predicted, individuals who reappraised the situation in positive terms showed higher HRV, over all phases after baseline, than those who catastrophized over it. In other words, even if no further ER instructions were given after the anticipation phase, participants who reappraised could still better regulate their autonomic responses in later phases, namely, during interview preparation and recovery. When we interpret these findings according to the neurocognitive framework for regulation expectation of De Raedt and Hooley (2016), anticipatory ER would have induced proactive prefrontal activation, with decreased amygdala activity and negative affect, hence facilitating successful online autonomic regulation, which was indexed by increased HRV. Possibly, the opposite occurred when participants used catastrophizing. Namely, this strategy may have caused stressful anticipation, which might have compromised prefrontal activity causing increased amygdala activation, consequently increasing negative affect and hampering online autonomic regulation, as indexed by lower HRV. Surprisingly, we did not observe an effect of ER strategy on self-reported stress. However, explicit ratings are susceptible to social desirability and emotional insight. In addition, this could reflect a difference in the experiential and physiological effects of stress. Indeed, a similar lack of effect of ER strategies on self-reported affect paired with significant effects on physiological measures has been observed in previous studies (e.g., Denson, Creswell, Terides, & Blundell, 2014; Hofmann, Heering, Sawyer, & Asnaani, 2009; Jamieson, Nock, Mendes, & James, 2012).

As predicted, the main effect of ER strategy on HRV was moderated by trait rumination. This interaction was nearly significant in the anticipation phase, where we observed that, for low ruminators, reappraisal was associated with higher HRV than catastrophizing. Instead, we observed no difference between these two ER strategies for medium and high ruminators. Hence, it appears that only low ruminators, but not high ruminators, could profit from the beneficial effect of anticipatory reappraisal on autonomic regulation. Individuals with higher levels of trait rumination might have dwelled on negative self-referential thoughts when anticipating a self-threatening event such as social evaluation. If we interpret this result within the neurocognitive framework for regulation expectation, this passive stressful anticipation prevented them from engaging in anticipatory ER. This would be associated with decreased DLPFC activity and HRV. In line with this hypothesis, perseverative thinking has been associated with reduced prefrontal-amygdala functional connectivity and diminished HRV (Makovac et al., 2016). On the other hand, low ruminators could proactively deploy their cognitive resources and successfully engage in anticipatory reappraisal, which lead to increased DLPFC activity and HRV. Indeed, previous research has shown that increased HRV is linked to prefrontal activity, which underlies preparation and anticipatory ER (Thayer & Lane, 2000).

Importantly, acute stress seemed to exacerbate the role of rumination, leading to a significant interaction featuring opposite HRV patterns for low and high ruminators during the interview preparation phase. Within low ruminators, individuals who used reappraisal during the anticipation phase were more successful in regulating their autonomic responses to stress (higher HRV) than individuals who used catastrophizing. This result is in line with the hypothesis based on the neurocognitive framework that proactive ER facilitates online ER. On the contrary, within high ruminators, individuals who reappraised the situation were less successful in regulating their autonomic responses (lower HRV) than individuals who catastrophized it. It is possible that, because high ruminators could not deploy proactive cognitive control efficiently during the anticipation phase, their regulation during the interview preparation phase was hampered. Instead, higher HRV in high ruminators who used catastrophizing (as compared to reappraisal) might reflect greater engagement as a consequence of their expectation that such strategy would be effective (see the role of expectation in De Raedt & Hooley, 2016). Indeed, it is known that ruminators may have positive metacognitions about the function of rumination as a helpful coping strategy (Papageorgiou & Wells, 2009; Roelofs et al., 2007). Catastrophizing can be considered similar to rumination as it is a passive, negative way of thinking. So, as high trait ruminators are induced to catastrophize, they may believe that this familiar strategy is beneficial. Indeed, the RRS includes items concerning not only brooding but also reflection, which refers to *"purposeful turning inward to engage in cognitive problem solving to alleviate one's depressive symptoms"* (Treynor et al., 2003, p. 256). Interestingly, we can clearly see that HRV was highest for low ruminators who reappraised, suggesting that participants belonging to this group could regulate their autonomic responses most successfully. This is in line with the predictions of the neurocognitive framework for regulation expectation that a) anticipatory ER is crucial for successful online ER, and b) rumination interferes with the deployment of proactive ER and ultimately with the regulation of the stress response.

Finally, any moderating effect of rumination on HRV disappeared in the recovery phase. Generally, HRV appears to be higher for participants who used reappraisal than those who used catastrophizing, independently of trait rumination levels. It is possible that we did not observe a moderating effect of rumination during recovery because participants did not actually have to perform the job interview. Indeed, recovery after the actual performance would likely have be related to self-referential thinking, resulting in worse autonomic regulation (Brosschot, Gerin, & Thayer, 2006; Glynn, 2002) for high than for low ruminators. This hypothesis is in line with the results of Quinn and Joormann (2015), who observed that brooding moderated the relationship between executive control and depressive symptoms only after a stress induction.

Even though this study has several strengths, a few limitations need to be discussed. First, even though previous research as well as our data indicate that the interview preparation successfully induced stress, the fact that participants did not actually simulate the job interview might have hindered the ecological validity of the recovery phase. Second, it would have been interesting to have an extra control condition in which participants did not use an anticipatory ER strategy. This would have allowed us to draw stronger conclusions on the beneficial/detrimental effects of the two different ER strategies. Third, no manipulation check of the implementation of the two ER strategies was collected. However, we first ensured that participants understood the contents of the ER instructions and then we provided them with the sentences on which they had to focus which. Indeed, the main effect of ER strategy on HRV when no difference at baseline was present supports that participants effectively implemented these instructions. Finally, it is important to remember that the generalizability of our results is limited given that our sample was very homogeneous (female, Caucasian, Flemish undergraduates), and that demographic variables may affect HRV, stress response and ER.

To conclude, our results are in line with the idea, central to the neurocognitive framework for regulation expectation, that anticipatory ER is linked to online ER and even recovery from a stressful, self-relevant event. Specifically, we observed that using anticipatory reappraisal, compared to catastrophizing, fostered autonomic regulation during anticipation, confrontation and recovery from a stressful event. In addition, our results show that an increased tendency to ruminate interfered with the beneficial effect of anticipatory reappraisal on autonomic regulation. However, as both emotion regulation and rumination are affected by gender, future studies should investigate whether the interaction of anticipatory ER and rumination on stress regulation is affected by this demographic variable.

To the best of our knowledge, this is the first study to directly test some of the predictions of the neurocognitive framework for regulation expectation. We believe that future research should continue this line of work and aim to test the model as a whole, as this framework has important "*implications for a broad range of disorders and conditions in which stress regulation plays a role, and can be used to guide the use of recently developed clinical interventions*" (De Raedt & Hooley, 2016, p. 45). Indeed, the here described findings point towards the need to develop a training of anticipatory ER aimed to changing patients' negative cognitions with positive reappraisal, with possible long-term benefits on the patients' mental and physical health. In addition, as our study suggests that rumination is associated with the inability to benefit from adaptive anticipatory ER, it might be necessary for therapists to decrease rumination tendencies *before* teaching depressed individuals to proactively anticipate a stressful event.

References

Abler, B., Erk, S., Herwig, U., & Walter, H. (2007). Anticipation of aversive stimuli activates extended amygdala in unipolar depression. *Journal of Psychiatric Research*, *41*(6), 511–522. http://doi.org/10.1016/j.jpsychires.2006.07.020

Abler, B., Hofer, C., Walter, H., Erk, S., Hoffmann, H., Traue, H. C., & Kessler, H. (2010). Habitual emotion regulation strategies and depressive symptoms in healthy subjects predict fMRI brain activation patterns related to major depression. *Psychiatry Research - Neuroimaging*, *183*(2), 105–113. http://doi.org/10.1016/j.pscychresns.2010.05.010

Aldao, A., & Mennin, D. S. (2012). Paradoxical cardiovascular effects of implementing adaptive emotion regulation strategies in generalized anxiety disorder. *Behaviour Research and Therapy*, *50*(2), 122–130. http://doi.org/10.1016/j.brat.2011.12.004

Aldao, A., Sheppes, G., & Gross, J. J. (2015). Emotion Regulation Flexibility. *Cognitive Therapy and Research*, 263–278. Retrieved from http://dx.doi.org/10.1007/s10608-014-9662-4

Allen, A. P., Kennedy, P. J., Cryan, J. F., Dinan, T. G., & Clarke, G. (2014). Biological and psychological markers of stress in humans: Focus on the Trier Social Stress Test. *Neuroscience and Biobehavioral Reviews*, *38*, 94–124. http://doi.org/10.1016/j.neubiorev.2013.11.005

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, *10*(3), 229–240. http://doi.org/10.1037/1089-2680.10.3.229

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. http://doi.org/10.1016/j.tics.2011.12.010

Brosschot, J. F., Gerin, W., & Thayer, J. F. (2006). The perseverative cognition hypothesis: A review of worry, prolonged stress-related physiological activation, and health. *Journal of Psychosomatic Research*, *60*(2), 113–124. http://doi.org/10.1016/j.jpsychores.2005.06.074

Burr, R. L. (2007). Interpretation of normalized spectral heart rate variability indices in sleep research: a critical review. *Sleep*, *30*(7), 913–919. http://doi.org/17682663

Butler, E. A., Wilhelm, F. H., & Gross, J. J. (2006). Respiratory sinus arrhythmia, emotion, and emotion regulation during social interaction. *Psychophysiology*, *43*(6), 612–622. http://doi.org/10.1111/j.1469-8986.2006.00467.x

Ciesla, J. A., & Roberts, J. E. (2007). Rumination, negative cognition, and their interactive effects on depressed mood. *Emotion (Washington, D.C.)*, *7*(3), 555–565. http://doi.org/10.1037/1528-3542.7.3.555

Cristea, I. A., Valenza, G., Scilingo, E. P., Szentágotai Tătar, A., Gentili, C., & David, D. (2014). Autonomic effects of cognitive reappraisal and acceptance in social anxiety : Evidence for common and distinct pathways for parasympathetic reactivity. *Journal of Anxiety Disorders*, *28*, 795–803. http://doi.org/10.1016/j.janxdis.2014.09.009

Davis, R. N., & Nolen-Hoeksema, S. (2000). Cognitive inflexibility among ruminators and nonruminators. *Cognitive Therapy and Research*, *24*(6), 699–711. http://doi.org/10.1023/A:1005591412406

de Kloet, E. R., Joëls, M., & Holsboer, F. (2005). Stress and the brain: from adaptation to disease. *Nature Reviews Neuroscience*, *6*(6), 463–475. http://doi.org/10.1038/nrn1683

De Raedt, R., & Hooley, J. M. (2016). The Role of Expectancy and Proactive Control in Stress Regulation: A Neurocognitive Framework for Regulation Expectation. *Clinical Psychology Review*, *45*, 45–55. http://doi.org/10.1016/j.cpr.2016.03.005

Denny, B. T., Fan, J., Liu, X., Ochsner, K. N., Guerreri, S., Mayson, S. J., … Koenigsberg, H. W. (2015). Elevated amygdala activity during reappraisal anticipation predicts anxiety in avoidant personality disorder. *Journal of Affective Disorders*, *172*, 1–7. http://doi.org/10.1016/j.jad.2014.09.017

Denson, T. F., Creswell, J. D., Terides, M. D., & Blundell, K. (2014). Cognitive reappraisal increases neuroendocrine reactivity to acute social stress and physical pain. *Psychoneuroendocrinology*, *49*, 69–78. http://doi.org/10.1016/j.psyneuen.2014.07.003

Denson, T. F., Grisham, J. R., & Moulds, M. L. (2011). Cognitive reappraisal increases heart rate variability in response to an anger provocation. *Motivation and Emotion*, *35*(1), 14–22. http://doi.org/10.1007/s11031-011-9201-5

Dillon, D. G., & Pizzagalli, D. A. (2013). Evidence of successful modulation of brain activation and subjective experience during reappraisal of negative emotion in unmedicated depression. *Psychiatry Research - Neuroimaging*, *212*(2), 99–107. http://doi.org/10.1016/j.pscychresns.2013.01.001

Disner, S. G., Beevers, C. G., Haigh, E. A., & Beck, A. T. (2011). Neural mechanisms of the cognitive model of depression. *Nat Rev Neurosci*, *12*(8), 467–477. http://doi.org/10.1038/nrn3027

Fabes, R. A., & Eisenberg, N. (1997). Regulatory control and adults' stress-related responses to daily life events. *Journal of Personality and Social Psychology*, *73*(5), 1107–17. http://doi.org/10.1037/0022-3514.73.5.1107

Faurholt-Jepsen, M., Kessing, L. V., & Munkholm, K. (2017). Heart rate variability in bipolar disorder: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews*. http://doi.org/10.1016/j.neubiorev.2016.12.007

Fredrickson, B. L., Mancuso, E. A, Branigan, C., & Tugade, M. M. (2000). The undoing effect of positive emotions. *Motivation and Emotion*, *24*(4), 237–258. Retrieved from c:%5CEXAM%5Caffect%5CFredrickson_positive_affect_cardiovascular_2000.pdf

Garnefski, N., & Kraaij, V. (2007). The Cognitive Emotion Regulation Questionnaire. *European Journal of Psychological Assessment*, *23*(3), 141–149. http://doi.org/10.1027/1015-5759.23.3.141

Garnefski, N., Kraaij, V., & Spinnhoven, P. (2001). Negative life events, cognitive emotion regulation and emotional problems. *Personality and Individual Differences*, *30*(8), 1311–1327. http://doi.org/10.1016/S0191-8869(00)00113-6

Garnefski, N., Teerds, J., Kraaij, V., Legerstee, J., & van den Kommer, T. (2004). Cognitive emotion regulation strategies and depressive symptoms: Differences between males and females. *Personality and Individual Differences*, *36*(2), 267–276. http://doi.org/10.1016/S0191-8869(03)00083-7

Geisler, F. C. M., Vennewald, N., Kubiak, T., & Weber, H. (2010). The impact of heart rate variability on subjective well-being is mediated by emotion regulation. *Personality and Individual Differences*, *49*(7), 723–728. http://doi.org/10.1016/j.paid.2010.06.015

Gellatly, R., & Beck, A. T. (2016). Catastrophic Thinking: A Transdiagnostic Process Across Psychiatric Disorders. *Cognitive Therapy and Research*, *40*(4), 441–452. http://doi.org/10.1007/s10608-016-9763-3

Glynn, L. M. (2002). The Role of Rumination in Recovery from Reactivity: Cardiovascular

Consequences of Emotional States. *Psychosomatic Medicine*, *64*(5), 714–726. http://doi.org/10.1097/01.PSY.0000031574.42041.23

Gotlib, I. H., & Hamilton, J. P. (2008). Neuroimaging and depression: Current status and unresolved issues. *Current Directions in Psychological Science*, *17*(2), 159–163. http://doi.org/10.1111/j.1467-8721.2008.00567.x

Gotlib, I. H., Joormann, J., Minor, K. L., & Hallmayer, J. (2008). HPA Axis Reactivity: A Mechanism Underlying the Associations Among 5-HTTLPR, Stress, and Depression. *Biological Psychiatry*, *63*(9), 847–851. http://doi.org/10.1016/j.biopsych.2007.10.008

Gross, J. J., & Thompson, R. A. (2007). Emotion regulation: Conceptual foundations. *In J.J. Gross (Ed.), Handbook of Emotion Regulation. New York: Guilford Press.*, 3–24. http://doi.org/10.1080/00140130600971135

Hankin, B. L. (2008). Cognitive vulnerability-stress model of depression during adolescence: Investigating depressive symptom specificity in a multi-wave prospective study. *Journal of Abnormal Child Psychology*, *36*(7), 999–1014. http://doi.org/10.1007/s10802-008-9228-6

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. http://doi.org/10.1016/S0167-8760(03)00073-4

Hayes, A. F. (2012). PROCESS: A versatile computational tool for observed variable mediation, moderation, and conditional process modeling. *White Paper*. http://doi.org/978-1-60918-230-4

Hermans, D., & De Houwer, J. (1994). Affective and subjective familiarity ratings of 740 Dutch words. Psychologica Belgica, 34(2-3).

Hertel, P. T. (1998). Relation between rumination and impaired memory in dysphoric moods. *Journal of Abnormal Psychology*, *107*(1), 166–172. http://doi.org/10.1037/0021-843X.107.1.166

Herwig, U., Baumgartner, T., Kaffenberger, T., Brühl, A., Kottlow, M., Schreiter-Gasser, U., … Rufer, M. (2007). Modulation of anticipatory emotion and perception processing by cognitive control. *NeuroImage*, *37*(2), 652–662. http://doi.org/10.1016/j.neuroimage.2007.05.023

Hofmann, S. G., Heering, S., Sawyer, A. T., & Asnaani, A. (2009). Behaviour Research and Therapy How to handle anxiety : The effects of reappraisal , acceptance , and suppression strategies on anxious arousal. *Behaviour Research and Therapy*, *47*(5), 389–394. http://doi.org/10.1016/j.brat.2009.02.010

Hooley, J. M., Orley, J., & Teasdale, J. D. (1986). Levels of expressed emotion and relapse in depressed patients. *British Journal of Psychiatry*, *148*(JUNE), 642–647. http://doi.org/10.1192/bjp.148.6.642

Hughes, J. W., & Stoney, C. M. (2000). Depressed mood is related to high-frequency heart rate variability during stressors. *Psychosomatic Medicine*, *62*(6), 796–803. http://doi.org/0033-3174/00/6206-0796

Ingjaldsson, J. T., Laberg, J. C., & Thayer, J. F. (2003). Reduced heart rate variability in chronic alcohol abuse: Relationship with negative mood, chronic thought suppression, and compulsive drinking. *Biological Psychiatry*, *54*(12), 1427–1436. http://doi.org/10.1016/S0006-3223(02)01926-1

Jamieson, J. P., Nock, M. K., Mendes, W. B., & James, W. (2012). Mind Over Matter : Reappraising Arousal Improves Cardiovascular and Cognitive Responses to Stress, *141*(3), 417–422. http://doi.org/10.1037/a0025719

Johnson, P. O., & Fay, L. C. (1950). The Johnson-Neyman technique, its theory and application. *Psychometrika*, *15*(4), 349–367. http://doi.org/10.1007/BF02288864

Kaufmann, T., Sütterlin, S., Schulz, S. M., & Vögele, C. (2011). ARTiiFACT: a tool for heart rate artifact processing and heart rate variability analysis. *Behavior Research Methods*, *43*(4), 1161–70. http://doi.org/10.3758/s13428-011-0107-7

Kemp, A. H., & Quintana, D. S. (2013). The relationship between mental and physical health: Insights from the study of heart rate variability. *International Journal of Psychophysiology*. http://doi.org/10.1016/j.ijpsycho.2013.06.018

Kemp, A. H., Quintana, D. S., Gray, M. A., Felmingham, K. L., Brown, K., & Gatt, J. M. (2010). Impact of Depression and Antidepressant Treatment on Heart Rate Variability: A Review and Meta-Analysis. *Biological Psychiatry*, *67*(11), 1067–1074. http://doi.org/10.1016/j.biopsych.2009.12.012

Kendler, K. S., Thornton, L. M., & Gardner, C. O. (2000). Stressful life events and previous episodes in the etiology of major depression in women: An evaluation of the “kindling” hypothesis. *American Journal of Psychiatry*, *157*(8), 1243–1251. http://doi.org/10.1176/appi.ajp.157.8.1243

Lane, R. D., McRae, K., Reiman, E. M., Chen, K., Ahern, G. L., & Thayer, J. F. (2009). Neural correlates of heart rate variability during emotion. *NeuroImage*, *44*(1), 213–222. http://doi.org/10.1016/j.neuroimage.2008.07.056

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. *Nature Reviews Neuroscience*, *10*(6), 434–445. http://doi.org/10.1038/nrn2639

Makovac, E., Meeten, F., Watson, D. R., Herman, A., Garfinkel, S. N., D. Critchley, H., & Ottaviani, C. (2016). Alterations in Amygdala-Prefrontal Functional Connectivity Account for Excessive Worry and Autonomic Dysregulation in Generalized Anxiety Disorder. *Biological Psychiatry*, *80*(10), 786–795. http://doi.org/10.1016/j.biopsych.2015.10.013

Martin, R. C., & Dahlen, E. R. (2005). Cognitive emotion regulation in the prediction of depression, anxiety, stress, and anger. *Personality and Individual Differences*, *39*(7), 1249–1260. http://doi.org/10.1016/j.paid.2005.06.004

McCormack, H. M., Horne, D. J., & Sheather, S. (1988). Clinical applications of visual analogue scales: a critical review. *Psychological Medicine*, *18*(4), 1007. http://doi.org/10.1017/S0033291700009934

Montagne, B., Kessels, R. P. C., Frigerio, E., de Haan, E. H. F., & Perrett, D. I. (2005). Sex differences in the perception of affective facial expressions: do men really lack emotional sensitivity? *Cognitive Processing*, *6*(2), 136–41. http://doi.org/10.1007/s10339-005-0050-6

Morris, M. C., Ciesla, J. A., & Garber, J. (2010). A Prospective Study of Stress Autonomy versus Stress Sensitization in Adolescents at Varied Risk for Depression. *J Abnorm Psychol*, *119*(2), 341–354. http://doi.org/10.1126/scisignal.2001449.Engineering

Nelson, B. D., Fitzgerald, D. A., Klumpp, H., Shankman, S. A., & Phan, K. L. (2015). Prefrontal engagement by cognitive reappraisal of negative faces. *Behavioural Brain Research*, *279*, 218–225. http://doi.org/10.1016/j.bbr.2014.11.034

Nolen-Hoeksema, S., Larson, J., & Grayson, C. (1999). Explaining the gender difference in depressive symptoms. *Journal of Personality and Social Psychology*, *77*(5), 1061–1072.

http://doi.org/10.1037/0022-3514.77.5.1061

Nolen-Hoeksema, S., & Morrow, J. (1991). A prospective study of depression and posttraumatic stress symptoms after a natural disaster: the 1989 Loma Prieta Earthquake. *Journal of Personality and Social Psychology*, *61*(1), 115–121. http://doi.org/10.1037/0022-3514.61.1.115

Nolen-Hoeksema, S., Wisco, B. E., & Lyubomirsky, S. (2008). Rethinking Rumination. *Perspectives on Psychological Science*, *3*(5), 400–424. http://doi.org/10.1111/j.1745-6924.2008.00088.x

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D. E., & Gross, J. J. (2004). For better or for worse: Neural systems supporting the cognitive down- and up-regulation of negative emotion. *NeuroImage*, *23*(2), 483–499. http://doi.org/10.1016/j.neuroimage.2004.06.030

Ottaviani, C., Thayer, J. F., Verkuil, B., Lonigro, A., Medea, B., Couyoumdjian, A., & Brosschot, J. F. (2015). Physiological Concomitants of Perseverative Cognition: A Systematic Review and Meta-Analysis. *Psychological Bulletin*, *142*(3), 231–259. http://doi.org/10.1037/bul0000036

Papageorgiou, C., & Wells, A. (2009). A Prospective Test of the Clinical Metacognitive Model of Rumination and Depression. *International Journal of Cognitive Therapy*, *2*(2), 123–131. http://doi.org/10.1521/ijct.2009.2.2.123

Philippot, P., Vrielynck, N., & Muller, V. (2010). Cognitive Processing Specificity of Anxious Apprehension: Impact on Distress and Performance During Speech Exposure. *Behavior Therapy*, *41*(4), 575–586. http://doi.org/10.1016/j.beth.2010.04.003

Quinn, M. E., & Joormann, J. (2015). Stress-Induced Changes in Executive Control Are

Associated With Depression Symptoms: Examining the Role of Rumination. *Clinical Psychological Science*, 2167702614563930. http://doi.org/10.1177/2167702614563930

Raedt, R. De, & Koster, E. (2010). Understanding vulnerability for depression from a cognitive neuroscience perspective: A reappraisal of attentional factors and a new conceptual framework. *Cognitive, Affective, & Behavioral Neuroscience, 32*(1), 50–70. http://doi.org/10.3758/CABN.10.1.50

Ray, R. D., Ochsner, K. N., Cooper, J. C., Robertson, E. R., Gabrieli, J. D. E., & Gross, J. J. (2005). Individual differences in trait rumination and the neural systems supporting cognitive reappraisal. *Cognitive, Affective & Behavioral Neuroscience*, *5*(2), 156–68. http://doi.org/10.3758/CABN.5.2.156

Roelofs, J., Papageorgiou, C., Gerber, R. D., Huibers, M., Peeters, F., & Arntz, A. (2007). On the links between self-discrepancies, rumination, metacognitions, and symptoms of depression in undergraduates. *Behaviour Research and Therapy*, *45*(6), 1295–1305. http://doi.org/10.1016/j.brat.2006.10.005

Rosenberg, M. (1965). *Society and the adolescent self-image*. *Princeton, NJ: Princeton University Press* (Vol. 148). http://doi.org/10.1126/science.148.3671.804

Siegle, G. J., Carter, C. S., & Thase, M. E. (2006). Use of fMRI to predict recovery from unipolar depression with cognitive behavior therapy. *American Journal of Psychiatry*, *163*(4), 735–738. http://doi.org/10.1176/appi.ajp.163.4.735

Stroud, L. R., Salovey, P., & Epel, E. S. (2002). Sex differences in stress responses: Social rejection versus achievement stress. *Biological Psychiatry*, *52*(4), 318–327. http://doi.org/10.1016/S0006-3223(02)01333-1

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, *36*(2), 747–756. http://doi.org/10.1016/j.neubiorev.2011.11.009

Thayer, J. F., Friedman, B. H., & Borkovec, T. D. (1996). Autonomic characteristics of generalized anxiety disorder and worry. *Biological Psychiatry*, *39*(4), 255–266. http://doi.org/10.1016/0006-3223(95)00136-0

Thayer, J. F., Friedman, B. H., Borkovec, T. D., Johnsen, B. H., & Molina, S. (2000). Phasic heart period reactions to cued threat and nonthreat stimuli in generalized anxiety disorder. *Psychophysiology, 37*(3), 361–368. http://doi.org/10.1111/1469-8986.3730361

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*(3), 201–216. http://doi.org/10.1016/S0165-0327(00)00338-4

Thayer, J. F., & Lane, R. D. (2007). The role of vagal function in the risk for cardiovascular disease and mortality. *Biological Psychology*, *74*(2), 224–242. http://doi.org/10.1016/j.biopsycho.2005.11.013

Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *International Journal of Cardiology*. http://doi.org/10.1016/j.ijcard.2009.09.543

Treynor, W., Gonzalez, R., & Nolen-Hoeksema, S. (2003). Rumination reconsidered: A psychometric analysis. *Cognitive Therapy and Research, 27*(3), 247–259. http://doi.org/10.1023/A:1023910315561

Uchida, M., Biederman, J., Gabrieli, J. D. E., Micco, J., De Los Angeles, C., Brown, A., … Whitfield-Gabrieli, S. (2014). Emotion regulation ability varies in relation to intrinsic functional brain architecture. *Social Cognitive and Affective Neuroscience*, *10*(12), 1738–1748. http://doi.org/10.1093/scan/nsv059

Urry, H. L., van Reekum, C. M., Johnstone, T., & Davidson, R. J. (2009). Individual differences in some (but not all) medial prefrontal regions reflect cognitive demand while regulating unpleasant emotion. *NeuroImage*, *47*(3), 852–863. http://doi.org/10.1016/j.neuroimage.2009.05.069

Vanderhasselt, M.-A., De Raedt, R., De Paepe, A., Aarts, K., Otte, G., Van Dorpe, J., & Pourtois, G. (2014). Abnormal proactive and reactive cognitive control during conflict processing in major depression. *Journal of Abnormal Psychology*, *123*(1), 68–80. http://doi.org/10.1037/a0035816

Vanderhasselt, M.-A., Remue, J., Ng, K. K., & De Raedt, R. (2014). The interplay between the anticipation and subsequent online processing of emotional stimuli as measured by pupillary dilatation: The role of cognitive reappraisal. *Frontiers in Psychology*, *5*(MAR). http://doi.org/10.3389/fpsyg.2014.00207

Vanderhasselt, M.-A., Baeken, C., Van Schuerbeek, P., Luypaert, R., & De Raedt, R. (2013). Inter-individual differences in the habitual use of cognitive reappraisal and expressive suppression are associated with variations in prefrontal cognitive control for emotional information: An event related fMRI study. *Biological Psychology*, *92*(3), 433–439. http://doi.org/10.1016/j.biopsycho.2012.03.005

Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., & Ochsner, K. N. (2008). Prefrontal-Subcortical Pathways Mediating Successful Emotion Regulation. *Neuron*, *59*(6), 1037–1050. http://doi.org/10.1016/j.neuron.2008.09.006

Wardenaar, K. J., van Veen, T., Giltay, E. J., de Beurs, E., Penninx, B. W., & Zitman, F. G.

(2010). Development and validation of a 30-item short adaptation of the Mood and Anxiety Symptoms Questionnaire (MASQ). *Psychiatry Research*, *179*(1), 101–6. http://doi.org/10.1016/j.psychres.2009.03.005

Watkins, E., & Brown, R. G. (2002). Rumination and executive function in depression: an experimental study. *Journal of Neurology, Neurosurgery, and Psychiatry*, *72*(3), 400–2. http://doi.org/10.1136/jnnp.72.3.400

Waugh, C. E., Panage, S., Mendes, W. B., & Gotlib, I. H. (2010). Cardiovascular and affective recovery from anticipatory threat. *Biological Psychology*, *84*(2), 169–175. http://doi.org/10.1016/j.biopsycho.2010.01.010

Table 1

Linear model of predictors of HF-HRV during anticipatory ER

	b (CI)	SE B	t	p
Constant	41.28 [18.68, 63.88]	11.26	3.66	.0006
RRS	-0.16 [-0.72, 0.41]	0.28	-0.55	.586
ER strategy	37.46 [2.24, 72.67]	17.55	2.13	.037
RRS X ER strategy	-0.84 [-1.70, 0.02]	0.43	-1.95	.056

Table 2

Linear model of predictors of HFnu during interview preparation

	b (CI)	SE B	t	p
Constant	22.92 [-2.20, 48.03]	12.52	1.83	.072
RRS	0.36 [-0.27, 0.99]	0.32	1.14	.258
ER strategy	49.55 [10.42, 88.68]	19.550	2.54	.014
RRS X ER strategy	-1.20 [-2.15, -0.24]	0.48	-2.51	.015

Table 3

Linear model of predictors of HFnu during recovery

	b (CI)	SE B	t	p
Constant	67.76 [34.46, 101.06]	16.60	4.08	.0002
RRS	-0.70 [1.54, 0.13]	0.42	-1.69	.098
ER strategy	-10.84 [-62.73, 41.4]	25.86	-0.42	.067
RRS X ER strategy	0.47 [-0.80, 1.74]	0.63	0.75	.459

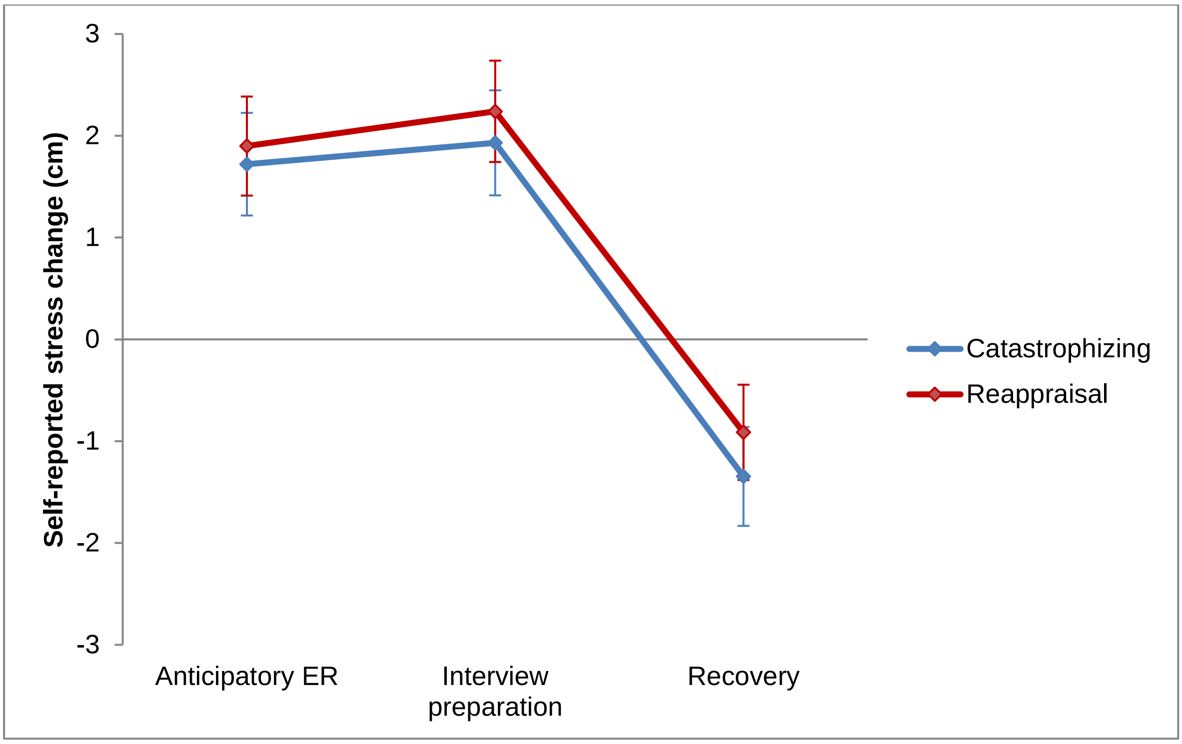

Figure 1. Changes in self-reported stress levels (in centimetres) from baseline per group. Means and standard errors.

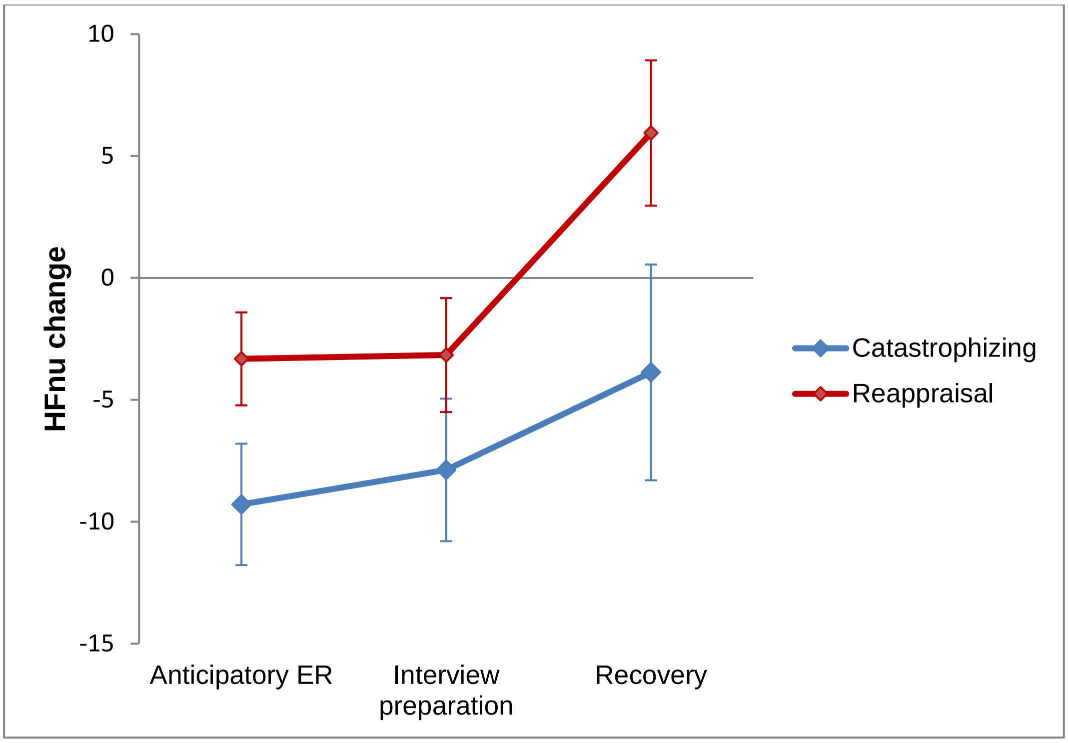

Figure 2. Heart rate variability (HFnu) changes from baseline per group at each time point. Means and standard errors.

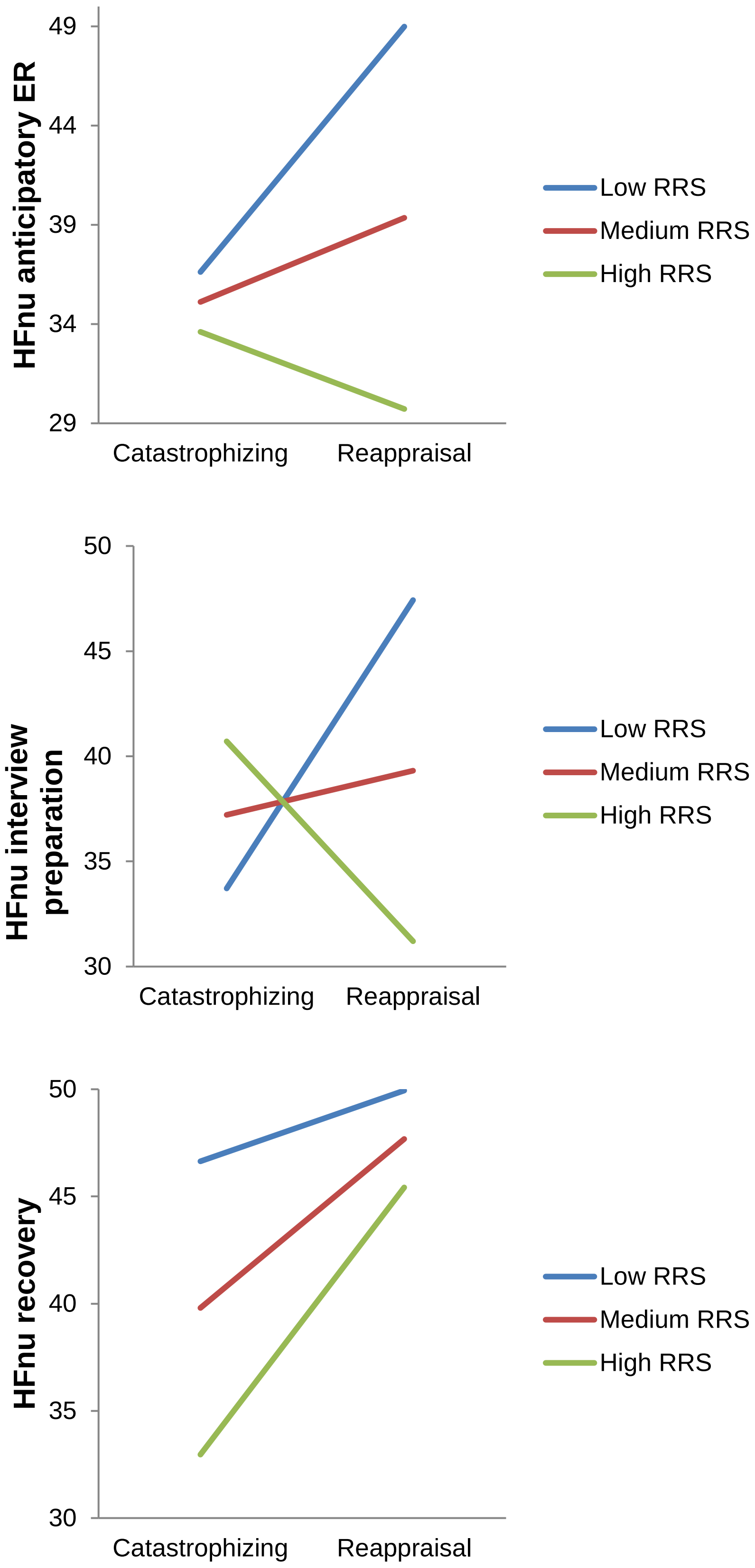

Fig. 3. Mean HFnu values at low, medium and high rumination scores by ER strategy during anticipatory ER, interview preparation and recovery.

Appendix

1. Adaptive reappraisal instructions

"Everyone experiences difficulties when being interviewed for a job and no one does it perfectly. Although some things can go wrong, small mistakes don't necessarily have negative consequences on the global impression you make on the interviewer. The best way to prepare is to imagine and to be ready to put these little mistakes into perspective. Think of this as a good experience to learn what to do better next time. Imagine that you stumble over a word, but you continue smoothly and nobody pays much attention to it. Imagine that you don't understand the question you have been asked, you simply ask to clarify it and then are able to answer. Imagine that your voice starts to tremble, you take a deep breath, clear your throat and continue."

2. Maladaptive reappraisal instructions

"Everyone knows that being interviewed is very stressful and that poor communication skills are linked to academic and professional failure. All kinds of things can go wrong during a job interview, and they will influence the global impression you make on the interviewer. The best way to prepare is to imagine and be ready for all that can go wrong. So we ask you to imagine all the worst things that could happen to you while being interviewed. Imagine that you stumble over a word, you lose focus and can't continue speaking. Imagine that you don't understand the question, you leave a long pause and feel very uncomfortable. Imagine that your voice trembles, you can't stop it and you are sure that the interviewer has noticed it."