# The influence of cognitive control training on stress reactivity and rumination in response to a lab stressor and naturalistic stress

Kristof Hoorelbeke*, Ernst H.W. Koster, Marie-Anne Vanderhasselt, Siebren Callewaert, and Ineke Demeyer

Ghent University, Belgium

*Corresponding author:

Kristof Hoorelbeke

Department of Experimental Clinical and Health Psychology

Ghent University

Henri Dunantlaan 2

B-9000 Gent, Belgium

+32 9-264-94-16

e-mail: Kristof.Hoorelbeke@UGent.be

**Abstract**

Cognitive control impairments have been identified as an underlying mechanism for rumination, a key predictor of depression. Literature suggests that cognitive control training (CCT) targeting working memory functioning can increase effectiveness of existing antidepressant treatments to reduce rumination. However, it remains unclear whether CCT can also be implemented as a preventive intervention for depression, increasing resilience. For this purpose, at-risk undergraduate students (high trait ruminators) were allocated to a CCT or active control condition, consisting of 10 online training sessions. Working memory functioning was assessed preceding and following the training and reactivity to a lab stressor was assessed directly following training. Finally, at four weeks follow-up, brooding – the maladaptive form of rumination – was re-assessed in response to a naturalistic stressor (examination period). Although we did not find direct transfer effects of CCT on working memory functioning, increase in working memory functioning following CCT was related to post-training brooding and resilience levels. Moreover, participants receiving CCT demonstrated lower stress reactivity in the lab and a decrease in brooding following a naturalistic stressor at follow-up, indicating temporal stability of our findings. These findings suggest that CCT can be considered a promising preventive intervention to reduce stress reactivity and rumination.

Keywords: rumination, depression, cognitive control, working memory, training

Depression is an important mental health problem (Kessler & Wang, 2009; WHO, 2012), associated with major individual suffering and high societal costs (IsHak et al., 2013; Luppa, Heinrich, Angermeyer, Konig, & Riedel-Heller, 2007). Current treatments of depression show rather limited success concerning effect size and long-term outcome (for a review, see Cuijpers, Andersson, Donker, & van Straten, 2011). This suggests that these interventions fail to influence key depressogenic mechanisms. Hence, identifying and changing such mechanisms is a major challenge for depression research.

Rumination – a maladaptive emotion regulation strategy that is characterized by the tendency to respond to a stressful event with repetitive, perseverative, and negative thinking – has been identified as an important risk factor for depression, influencing the course of a current episode as well as predicting future depressive episodes (Nolen-Hoeksema & Morrow, 1991; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Moreover, rumination shows relative stability when taking into account changes in depressive symptomatology (Nolen-Hoeksema et al., 2008). In particular brooding – the depressive subtype of rumination that is characterized by a passive style of moody pondering, self-blame and criticism (Treynor, Gonzalez, & Nolen-Hoeksema, 2003) – has been linked to negative information processing biases (Joormann, Dkane, & Gotlib, 2006) and future depressive symptomatology (Treynor et al., 2003). Furthermore, brooding has shown to moderate the relation between stress and depressive symptomatology (Cox, Funasaki, Smith, & Mezulis, 2012).

Accordingly, several researchers have argued that targeting rumination and stress reactivity in therapy could be an important strategy to prevent the (re-)occurrence of depressive episodes as well as enhance treatment (e.g., van Vugt, Hitchcock, Shahar, & Britton, 2012; Watkins et al., 2011). In the current study, we sought to examine whether training cognitive control, a key mechanism implied in rumination, can be beneficial to reduce stress reactivity, rumination, and brooding in particular in an at-risk sample characterized by high rumination scores. We start by considering the relationship between cognitive control, rumination, and depression.

Cross-sectional (Davis & Nolen-Hoeksema, 2000; Joormann, 2006; Joormann & Gotlib, 2010) as well as prospective studies (Connolly et al., 2014; Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Zetsche & Joormann, 2011) have consistently linked rumination to impaired cognitive control (for a review, see Joormann & D'Avanzato, 2010)[1]. Importantly, cognitive control impairments have been identified in at-risk (Owens, Koster, & Derakshan, 2012), currently depressed (De Lissnyder, Koster, Everaert, et al., 2012), and remitted depressed populations (Vanderhasselt & De Raedt, 2009), and predict higher levels of rumination and depressive symptoms in response to stress (De Lissnyder, Koster, Goubert, et al., 2012; Zetsche & Joormann, 2011). Moreover, it has been suggested that cognitive control impairments reflect increased biological vulnerability to depression (i.e., hypofrontality), which through rumination and its detrimental effects (e.g., sustained negative mood) is thought to further increase cognitive *and* biological vulnerability for recurrent depression (for a conceptual framework on the relation between cognitive control impairments and increasing biological and cognitive vulnerability in recurrent depression, see De Raedt & Koster, 2010).

To examine whether cognitive control plays a causal role in depression vulnerability, experimental designs manipulating cognitive control and examining subsequent effects on stress reactivity and rumination are of crucial importance. In recent years, important progress has been made in this area, using modified working memory training tasks such as the adaptive Paced Auditory Serial Addition Task (PASAT; e.g., Siegle, Ghinassi, & Thase, 2007) to train cognitive control. During the adaptive PASAT, participants are presented with a stream of auditory presented digits and are instructed to indicate the sum of the last two digits, which relies on continuously updating working memory. Depending on the accuracy of the responses, the inter stimulus interval (ISI) would decrease or increase, modifying task difficulty. Siegle et al. (2007) demonstrated the added value of combining cognitive control training (CCT) with treatment as usual (TAU), which led to a greater reduction in rumination and depressive symptomatology compared to a TAU control group. These findings have recently been replicated and extended, showing a reduced need for outpatient services one year following the combined intervention (Siegle et al., 2014). Importantly, Siegle et al. (2014) argue that changes in depressive symptomatology are secondary to changes in rumination.

These findings suggest a causal role of cognitive control in depressive rumination and demonstrate an added value of combining CCT with regular treatment (e.g., Siegle et al., 2014). However, until now it remains unclear whether working memory based CCT can also be implemented for *preventive purposes*. Rumination forms an important predictor for depression, and at-risk populations – characterized by heightened levels of rumination – might benefit from CCT given that cognitive control impairments predict higher levels of rumination in response to stress (De Lissnyder, Koster, Goubert, et al., 2012; Zetsche & Joormann, 2011). Moreover, rumination is known to mediate the relation between stressful events and depressive symptomatology (Michl, McLaughlin, Shepherd, & Nolen-Hoeksema, 2013). Training cognitive control thus holds the potential to improve emotion regulation in the wake of stress as increased cognitive control might reduce the extent to which subjects respond to a stressful event with rumination, increasing resilience to depression. This would fit the recent plea to invest in preventive programs and innovative treatment delivery methods to increase the quality of mental health care in order to reduce the burden of mental illness (Kazdin & Blase, 2011). Hence, a main goal of this study is to explore whether CCT can be used to increase stress resilience in an at-risk population.

Furthermore, there are still a number of remaining questions about clinically oriented CCT studies using the adaptive PASAT. First, in above mentioned studies (Siegle et al., 2007; Siegle et al., 2014), CCT consisted of the adaptive PASAT *as well as* the Wells' attention training, during which participants are instructed to focus on auditory stimuli (Wells, 2000). Therefore, it was not clear to what extent observed improvements in cognitive control are due to the PASAT training. However, since performance on the PASAT has been related to DLPFC activity (Lazeron, Rombouts, de Sonneville, Barkhof, & Scheltens, 2003) and pilot work indicates that stimulating the left DLPFC can increase therapeutic effects of CCT (Segrave, Arnold, Hoy, & Fitzgerald, 2014; but see Brunoni et al., 2014), it is plausible that an important part of the therapeutic effects reported in previous CCT studies can be attributed to the adaptive PASAT component. Moreover, Brunoni et al. (2014) have recently provided evidence for the effectiveness of the adaptive PASAT in absence of the Wells' attention training in reducing depressive symptomatology in a clinical sample. Given these findings, we will only use the adaptive PASAT as CCT.

Second, while previous CCT studies have compared training effects with a passive control group, the lack of an active control group with regard to the computerized training does not allow to rule out placebo effects. Related to the latter point, Calkins, McMorran, Siegle, and Otto (in press) demonstrated the potential of the combined CCT in reducing depressive symptomatology compared to an adaptive version of the Peripheral Vision task. Other researchers have proposed to use the adaptive Visual Search task as an active control group in working memory training studies (Harrison et al., 2013; Redick et al., 2013). During this visual search training (VST), participants respond to the orientation of a target letter in the presence of distractors. Task difficulty is modified based on individual performance levels. The adaptive component allows researchers to control for effects of performing a computerized training (Shipstead, Redick, & Engle, 2012) without the task being related to working memory functioning (Kane, Poole, Tuholski, & Engle, 2006; Redick et al., 2013). Furthermore, in contrast to tasks used in previous CCT studies (Calkins, Deveney, Weitzman, Hearon, & Siegle, 2011; Calkins et al., in press), the VST allows researchers to check whether training progress was made in both conditions leaving only the specific content (i.e., whether or not targeting working memory) as the experimental manipulation. Given that this approach allows a more clear interpretation of training effects (Harrison et al., 2013; Redick et al., 2013; Shipstead et al., 2012), we used the VST as an active control group.

**Current Study**

Cognitive training focusing on remediating cognitive control impairments shows potential as an intervention for depression given that previous studies have demonstrated that impaired cognitive control increases the chance of deploying rumination in response to stressful events. This is important, as rumination – and more specifically, brooding – have shown to predict the occurrence of future depressive symptomatology. The current study examined whether working memory based CCT can heighten resilience to stress and reduce rumination in the wake of stress. Undergraduate students showing a tendency to ruminate were followed over time as they approached their examination period. Participants were randomly allocated to a CCT or VST condition, the latter being the active control group (Time 1). To determine the effectiveness of CCT in increasing resilience towards depression, we measured stress reactivity in the lab (i.e., positive and negative affect, and state rumination) directly following two weeks of training (Time 2), as well as brooding levels in confrontation with a naturalistic stressor (examinations) four weeks following training (Time 3).

As a manipulation check, we hypothesize that – although both groups will show progress throughout the training sessions – transfer effects of training on working memory will only occur in the CCT group (Hypothesis 1). Related to the increase in cognitive control, as operationalized by working memory performance, we expected participants from the CCT group to be more resilient when confronted with a stressful event in a highly controlled lab context. Specifically, we expected to find smaller effects of the stress-induction procedure on ratings of mood and on a behavioral measure of state rumination (content and intensity of momentary thought intrusions) in the CCT group (Hypothesis 2). Furthermore, we expected to find the CCT to increase resilience when confronted with a naturalistic stressor: we expected participants from the CCT condition to report lower levels of brooding compared to the active control group while participants are confronted with an ecological valid stressor (examinations; Hypothesis 3).

# Method

## Participants

Based on an online pre-screening of undergraduate-students of Ghent University, participants showing heightened trait rumination levels (above percentile 70) were invited. This was operationalized by a Ruminative Response Scale-score ≥ 43 (RRS; Nolen-Hoeksema & Morrow, 1991). 53 participants responded to the invitation (27%), completed the baseline assessment and were randomly assigned to a CCT or VST. Due to individual technological problems (e.g., using incompatible operating systems, experiencing problems with unpacking, installing or running the program) four participants dropped out during the training period. 49 participants completed the post-training assessment session, from which one participant was excluded from data-analysis due to not having performed the training sessions as instructed (as shown by an accuracy rate < 10% on the last two sessions; see Table 1 for mean accuracy rates), and one participant due to not having delivered the training data. Results concerning effects of CCT on working memory functioning and emotional reactivity to the lab stressor are based on the remaining 47 participants (CCT group: *n* = 25; VST group: *n* = 22). Finally, another 4 participants were excluded due to not responding to the follow-up assessment call within the time limit and 6 due to not having started the examination period at follow-up. This brings us to a sample size of 37 for the follow-up results (CCT group: *n* = 20; VST group: *n* = 17). Participants were reimbursed for participating (€40). This study was approved by the local ethical committee of Ghent University and all participants provided written informed consent.

## Apparatus and Material

The Automated O-Span task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005) and adaptive PASAT task were programmed and run using the INQUISIT Millisecond software package. The VST and Breathing Focus task (Borkovec, Robinson, Pruzinsky, & Depree, 1983) were run on E-Prime 2.0. Tasks were run on a Dell Dimension 4600 computer with a 72 Hz, 17-inch color monitor.

### Questionnaires.

*Depressive symptomatology* was assessed using the Beck Depression Inventory (BDI-II-NL; Beck, Steer, & Brown, 1996; Van der Does, 2002). This 21-item self-report measure has proven to have good psychometric properties. Second, a short version of the Mood and Anxiety Symptom Questionnaire (MASQ-D30; Clark & Watson, 1991; Wardenaar et al., 2010) was used as a transdiagnostic measure for *depressive and anxious symptomatology*. This validated questionnaire is based on the Tripartite model of anxiety and depression (Clark & Watson, 1991), containing three subscales: general distress, anhedonic depression, and anxious arousal.

The tendency to respond to a stressor with *rumination* was assessed using the Ruminative Response Scale (RRS-NL-EXT; Nolen-Hoeksema & Morrow, 1991; Treynor et al., 2003). In addition to a rumination total score, the RRS-NL-EXT provides a Brooding and a Reflection subscale, of which Brooding is viewed as the most maladaptive form of rumination (Joormann et al., 2006; Treynor et al., 2003). The Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990; van Rijsoort, Vervaeke, & Emmelkamp, 1997) was used to measure *worrying*. Both measures exhibit adequate psychometric properties (Treynor et al., 2003; van Rijsoort, Emmelkamp, & Vervaeke, 1999).

We used the Positive and Negative Affect Schedule (PANAS; Engelen, De Peuter, Victoir, Van Diest, & Van den Bergh, 2006; Watson, Clark, & Tellegen, 1988) to assess *positive and negative affective states*, comprising 10 items each. Self-reported *attentional control* was measured using the 20-item Attentional Control Scale (ACS-NL; Derryberry & Reed, 2002; Verwoerd, Cieraad, & de Jong, 2007). The ACS shows adequate psychometric properties (Judah, Grant, Mills, & Lechner, 2014). Finally, the 25-item Dutch Resilience Scale (RS-NL; Portzky, 2008; Wagnild & Young, 1993) was used to take into account self-reported levels of *resilience*. All questionnaires were administered at Time 1 and Time 2. For the follow-up assessment (Time 3), all questionnaires but the BDI-II-NL were presented online.

**Training Tasks.**

**Cognitive control training (CCT) task**. We used a modified version of the PASAT (Gronwall, 1977; Siegle et al., 2007) to train cognitive control. Participants were presented with series of auditory digits and were asked to continuously respond to the sum of the last two digits by clicking on the corresponding number. All possible responses (1 – 18) were continuously presented on the screen throughout the course of the training task. Task difficulty was modified within the task depending on the participants' performance. Each session of the adaptive PASAT started with an inter stimulus interval (ISI) of 3000 ms. Every four consecutive accurate responses, the ISI decreased with 100 ms, increasing task difficulty. Vice versa, four consecutive inaccurate responses were followed by an increase in the ISI of 100 ms. Each session participants completed 400 trials of this task uninterrupted, after having completed 5 practice trials during which feedback was presented. This corresponds to 20 min of training on an average ISI of 3000 ms. Median ISI per session will be used as an indicator of task performance and the altering ISI was visible for the participant during the training. Moreover, participants are provided with an online representation of the current amount of consecutive (in)correct responses.

**Visual search training (VST) task.** The VST (Harrison et al., 2013; Redick et al., 2013) was used as an active control group. During the VST task, participants were presented with an array of letters, existing of one target letter (letter "F", presented as a standard "F" or mirror-reversed "F") and a variable amount of distractors depending on the array size (letters "E", mirror-reversed "E", and/or inverted "T"). Following a fixation dot in the center of the screen, the array was presented for 500 ms, followed by presentation of a mask during 2500 ms (a 16 x 16 array of black squares). Participants had to indicate the orientation of the target letter by pressing "w" or ";" (on an AZERTY keyboard) using their left or right index finger respectively. Each training session started from difficulty level one with a 2 x 2 array (1 target and 3 distractors). Task difficulty was modified based on performance of the participant at block level. Each block consisted out of 24 trials, participants were subjected to 10 blocks (20 min) per training session. Following each block, participants received feedback on their performance. They were aware that a within-block accuracy rate of ≥ 87.5% led to an increase in the amount of distractors for the following block, while an accuracy rate of ≤ 75% was followed by a decrease. Depending on task difficulty level, distractors were homogeneous (odd-numbered levels) or heterogeneous (even-numbered levels). In line with previous studies, mean difficulty levels were used.

In both conditions, participants were not informed about the purpose of the cognitive training.

**Transfer Tasks.**

**Operation-span task (O-Span).** Cognitive control was operationalized as 'working memory functioning', which was assessed using the Automated O-Span task (Turner & Engle, 1989; Unsworth et al., 2005) preceding and following training. The Automated O-Span task is a complex working memory span task. During this task, participants are sequentially presented with mathematical problems and letters (F, H, J, K, L, N, P, Q, R, S, T, or Y). Each trial started with the presentation of a math problem that needed to be solved as fast and accurately as possible, after which participants were presented with a possible solution and had to report whether this was correct. Each math problem was followed by the presentation of a letter that remained on screen for 800 ms. After a variable amount of sequentially presented math problems and letters (3 – 7), participants had to identify the recalled letters in correct order on a 4 x 3 matrix. The task started with a practice phase focusing on the recall of series of letters (two trials of two letters), followed by a practice phase during which 15 math problems were presented (e.g., "(7 x 3) – 3 = ?"). During the latter phase, participants' reaction times were administered. Based on performance during this phase, a time limit was calculated (mean RT math problems practice phase plus 2.5 SDs) which restricted future presentation duration of math problems. In a third practice phase, both tasks were combined in three series, each containing two math problems and two letters. During the test phase participants were presented with 75 math problems and letters, divided over 15 series. Participants were instructed to keep accuracy rates above 85% while solving the math problems as fast as possible in order to prevent participants from mentally rehearsing the letters. An O-Span score was generated, comprising the sum of recalled letters of accurate series.

**Stress induction.**

***Induction task.*** We used a validated procedure to induce stress in the lab (Rossi & Pourtois, 2012) and modified the cover story so that it would fit the context of our study. Importantly, a written script was used to standardize the induction procedure. Participants were led to believe that the training sessions aimed to increase sustained attention and that they should be able to perform the following sustained attention task above average. Moreover, they were told that they participated in a replication study and that their performance would be compared to the performance of 42 undergraduate students from an American university. To increase social pressure, participants were led to believe that results would be presented at an important upcoming international conference and that they are expected to perform well in order to make such a presentation possible. Following instructions, participants were subjected to a visual oddball task in which tilted lines were presented during 250 ms each. The task started with a learning phase during which participants became familiar with the standard line (35°). Next, participants were instructed to mentally count the amount of times a divergent line was presented (target). Participants completed three blocks of 100 stimuli, each containing 20 target lines. The difference between the standard line and the target lines increased over blocks, from 3° during the first block, to 5° during the second, and 10° during the third block. Stimuli were presented with an ISI ranging from 1150 ms to 1500 ms. On 50 of the 100 trials, horizontal peripheral distractors were presented during 250 ms. At the end of each block, participants had to enter the amount of targets that were presented, followed by false feedback on their performance. Feedback consisted out of a neutral face and a 'personalized' text balloon stating the participants' performance was poor, scoring beneath the average of the norm group. This was accompanied by a scatterplot, illustrating the poor performance compared to the norm group. As task difficulty decreased, their relative performance did not increase, inducing stress (Nummenmaa & Niemi, 2004).

***Induction assessment.*** In line with Rossi and Pourtois (2012), seven visual analogue scales (VAS) were adopted from the Profile Of Mood States (McNair, Lorr, & Dropplemann, 1992) to assess effects of the stress induction on mood. Three scales provided a mean estimate of positive affect (Dutch equivalents of 'energetic', 'satisfied', and 'happy'), another three scales provided a mean estimate of negative affect (Dutch equivalents of 'angry', 'tense', and 'depressed'). One scale provided an estimate of fatigue. As a manipulation check, one item assessed the extent to which participants attributed task outcome internally, while another item assessed the extent to which performance was influenced by task difficulty. All VASs were presented horizontally, 10 cm long with scores ranging from 0 to 100.

A modified version of the Breathing Focus task (Borkovec et al., 1983; Hirsch, Hayes, & Mathews, 2009; Ruscio & Borkovec, 2004) was used as a behavioral measure to study the effects of the induction procedure on thought processes (positive and negative thought intrusions). During the Breathing Focus task, participants were asked to focus attention on their respiration during five minutes. Every 20 or 40 sec a tone was presented (10 times), after which participants had to indicate whether at the time of the tone they were (a) completely focused on their respiration, (b) distracted by positive thoughts, (c) distracted by negative thoughts, (d) distracted by neutral thoughts, or (e) their state did not fit the other options. In the latter case, participants had to write down a brief description of the state before pressing the 'e'-key on the keyboard. In all other cases, participants responded with the corresponding letter ('a', 'b', 'c', or 'd'), after which they were asked to focus on their respiration again (presented during 2000 ms) and a new trial started. Both the VASs and the Breathing Focus task were administered twice: once preceding the induction procedure and once directly following the induction procedure.

**Procedure**

The study comprised of two assessment sessions in sound attenuated booths at the faculty of Psychology and Educational Sciences of Ghent University (Time 1, Time 2), 10 online homework sessions, and an online follow-up assessment during the examination period, four weeks following training (Time 3; see Figure 1).

At Time 1, participants filled out the questionnaires after having read and agreed to the informed consent. This was followed by the Automated O-Span task and an explanation on how to install and perform the training tasks at home. Participants were randomly assigned to the CCT or the VST condition. A written manual was provided, including the necessary software and their subject number. Participants were instructed to complete 10 training sessions over a period of 14 days, preferentially only performing one session a day. During the training period, participants could contact the researchers for technical support. Participants were asked to provide us with the data at least the evening before Time 2 and were reminded of their appointment by e-mail.

Fourteen days following Time 1, participants returned to the faculty where they filled out the questionnaires and were subjected to a post-training assessment of cognitive control, using the Automated O-Span task. Following this phase, participants entered the stress induction procedure, in which they were subjected to the pre-induction Breathing Focus task, followed by the VASs, the cover story and the stress induction task. This was followed by a post-induction assessment of mood, using the VASs, and the post-induction Breathing Focus task. The second lab session ended with giving a (partial) debriefing on the stress induction procedure, instructions concerning the follow-up assessment, and payment of €40.

At four weeks follow-up – during the first or second week of the examination period – participants were invited to fill out the online questionnaires within 48 h (Time 3). Simultaneously participants replied to whether they had already entered the examination period (i.e., had completed at least one exam) and provided us with the amount of days that had passed since their most recent exam by selecting the corresponding date. This indicator of elapsed time between naturalistic stressor and follow-up assessment will be taken into account when analyzing training effects on brooding. After having completed the online questionnaires, participants received a written debriefing and were provided the chance to discuss the study.

# Results

## Group Characteristics

Participants were randomly divided into a CCT ($n$ = 25) or VST ($n$ = 22) condition. Descriptive information for both groups can be found in Table 2. Both groups did not differ significantly at baseline concerning the self-report measures (all $t$s < 1.07)[2]. An independent samples $t$-test revealed that the CCT group ($M$ = 20.84; $SD$ = 2.27) did not differ from the VST group ($M$ = 20.45; $SD$ = 1.97) concerning age, $t(45) = 0.62$, $p = .54$. The training groups differed significantly concerning gender distribution: the VST group contained four male participants whereas there were no male participants in the CCT group, $\chi^2(1, n = 47) = 4.97$, $p < .05$.

## Progress on Training Tasks

In line with previous studies, median ISI levels were used to check progress on the PASAT, while mean difficulty levels were used in the VST condition. While an increase in difficulty level is indicative for progress in the VST condition, a decrease in median ISI is indicative for progress in the CCT condition. We used two Repeated Measures ANOVA's to examine the effect of Time (10 sessions) on task performance. For the CCT group, we found a significant main effect of Time (10 sessions) on median ISI, $F(9, 16) = 81.54$, $p < .001$, $\eta^2 = .98$. The main effect of Time was also significant in the VST group, $F(9, 13) = 7.56$, $p < .01$, $\eta^2 = .84$. Both training groups improved with practice (see Figure 2A and B).

## Effects of Training

### Working memory.

A 2 (Time: Baseline vs. Post-training) x 2 (Group: CCT vs. VST) Mixed ANOVA was used to examine transfer effects of training to O-Span performance, an indicator for working memory functioning and cognitive control (Hypothesis 1). This revealed a significant main effect of Time, $F(1, 45) = 19.66$, $p < .001$, $\eta^2 = .30$. This is indicative for a general increase in working memory performance (Pre: $M = 44.66$, $SD = 15.40$; Post: $M = 53.43$, $SD = 15.29$). We did not find a significant Time x Group interaction, $F(1, 45) = 0.51$, $p = .48$, $\eta^2 = .01$ (main effect of Group: $F < 0.33$).

In order to ensure whether any observed changes in stress reactivity and rumination were associated with changes in cognitive control, we have used regression analyses to assess effects of change in working memory functioning (Δ O-Span score = O-Span post – O-Span pre; a positive value is indicative for an increase in working memory functioning) on post-training emotional outcomes (self-report measures) while controlling for baseline scores. Interestingly, for participants of the CCT group, increase in working memory functioning was a significant predictor for post-training brooding ($\beta = -.23$, $t(22) = 2.41$, $p < .05$) while controlling for baseline levels of brooding ($\beta$ = .81, $t(22) = 8.63$, $p < .001$). Similarly, while controlling for baseline resilience ($\beta$ = .88, $t(22) = 11.81$, $p < .001$), increase in working memory functioning predicted increased resilience following training ($\beta$ = .21, $t(22) = 2.77$, $p < .05$; all other *t*s < 1.22). Importantly, increase in working memory performance was *not* related to any of the post-training self-report measures while controlling for baseline functioning in the VST group (all *t*s < 0.82)[3].

**Stress resilience in lab context.**

To check for effects of CCT on stress resilience in a lab context (Hypothesis 2), we used 2 (Time: Pre- vs. Post stress induction) x 2 (Group: CCT vs. VST) Mixed ANOVA's with state rumination (Breathing Focus Task) or VAS mood ratings as dependent variables.

***Breathing focus task***. For the behavioral measure of state rumination / content of thought intrusions, a main effect of Time indicated that participants from both training groups reported being less focused on their respiration following the stress induction procedure, $F(1, 45) = 9.67$, $p < .01$, $\eta^2 = .18$ (Pre: $M = 5.17$, $SD = 2.19$; Post: $M = 4.47$, $SD = 2.46$; all other *F*s < 1.80). Concerning the amount of positive thoughts that were reported, we found a significant Time x Group interaction ($F(1, 45) = 5.99$, $p < .05$, $\eta^2 = .12$; all other *F*s < 2.15). Follow-up paired samples *t*-tests revealed a drop in positive thoughts following the stress induction for the VST group, $t(21) = 2.82$, $p < .05$, $d = .85$, while the mean amount of positive thoughts remained stable in the CCT group, $t(24) = 0.69$, $p = .50$, $d = .14$ (see Table 3 for descriptives). For negative thoughts, analysis revealed a significant main effect of Time ($F(1, 45) = 23.55$, $p < .001$, $\eta^2 = .34$) and a significant Time x Group interaction ($F(1, 45) = 4.74$, $p < .05$, $\eta^2 = .10$; main effect of Group: $F < 1.27$). The stress induction led to an increased amount of negative thoughts in the VST ($t(21) = 4.18$, $p < .001$, $d = .97$) and CCT condition ($t(24) = 2.32$, $p < .05$, $d = .42$).

However, independent samples *t*-tests revealed that this increase was more pronounced in the VST group: whereas both groups did not differ in levels of reported negative thoughts before undergoing the stress induction procedure ($t(45) = 0.16$, $p = .87$), we found a trend towards significance following the stress induction ($t(45) = 1.73$, $p = .09$). Finally, the induction procedure did not affect the amount of reported neutral thoughts, however, overall participants of the CCT group reported experiencing more neutral thoughts (CCT: $M = 2.42$, $SD = 1.57$; VST: $M = 1.52$, $SD = 1.43$), main effect of Group, $F(1, 45) = 4.13$, $p < .05$, $\eta^2 = .08$ (all other *F*s < 0.39).

***Visual analogue scales.*** Using the VAS, participants reported experiencing a general decrease in positive affect following the induction procedure (Pre: $M = 53.11$, $SD = 16.91$; Post: $M = 35.53$, $SD = 16.32$), $F(1, 45) = 112.16$, $p < .001$, $\eta^2 = .71$ (all other *F*s < 2.29). For negative affect we also found a main effect of Time, $F(1, 45) = 13.69$, $p < .01$, $\eta^2 = .23$. Importantly, we found a significant Time x Group interaction, $F(1, 45) = 7.45$, $p < .01$, $\eta^2 = .14$ (main effect of Group: $F < 0.21$). Whereas the VST group was characterized by an increase in negative affect ($t(21) = 3.46$, $p < .01$, $d = .82$), we did not observe this change in the CCT group ($t(24) = 1.06$, $p = .30$, $d = .12$; see Table 3).

In general, an increase in experienced task difficulty was reported using VAS ($F(1, 45) = 10.55$, $p < .01$, $\eta^2 = .19$; Pre: $M = 43.40$, $SD = 20.86$; Post: $M = 57.23$, $SD = 21.44$; all other *F*s < 1.98). The induction procedure did not influence the extent to which participants experienced being in control of task outcome, which served as a manipulation check (all *F*s < 1.28; Pre: $M = 65.21$, $SD = 21.77$; Post: $M = 60.43$, $SD = 25.37$). Neither did the induction procedure influence reported feelings of being numb / tired (all *F*s < 1.41; Pre: $M = 48.94$, $SD = 22.54$; Post: $M = 46.13$, $SD = 24.35$).

**Stress resilience in response to naturalistic stress.**

We used a 2 (Time: Pre-training vs. Follow-up) x 2 (Group: CCT vs. VST) Mixed ANOVA to examine effects of CCT on stress resilience in a naturalistic context. Stress resilience was operationalized by brooding scores (RRS; dependent variable), the more depressive subtype of rumination (Cox et al., 2012). The following results are based on the subsample which completed the follow-up assessment during the first two weeks of their examination period (CCT group: $n = 20$; VST group: $n = 17$). The amount of days that have passed since the most recent exam, which forms an indicator of elapsed time between stressor and assessment, was added as covariate to control for individual differences in intensity of the stress induction (both groups did not differ in the amount of days that had elapsed since the most recent exam, $t(35) = 1.04$, $p = .306$; $M = 2.51$, $SD = 2.46$). This is important as rumination has proven to show a linear or quadratic decrease as days pass following an exam, with the strongest decrease in rumination occurring during the first two days (Grant & Beck, 2010).

This approach revealed a significant main effect of Time, $F(1, 34) = 12.45$, $p < .01$, $\eta^2 = .27$, and a significant Time x Group interaction, $F(1, 34) = 4.27$, $p < .05$, $\eta^2 = .11$ (all other $F$s < 1.17)[4]. Follow-up paired samples $t$-tests indicate that, whereas brooding remained stable in the VST group (based on estimated marginal means; pre: $M = 13.17$, $SE = 0.82$; follow-up: $M = 12.59$, $SE = 0.79$), $t(16) = 1.48$, $p = .16$, the CCT group was characterized by decreased brooding (pre: $M = 13.11$, $SE = 0.76$; post: $M = 11.20$, $SE = 0.73$), $t(19) = 4.12$, $p < .01$. This confirms our third hypothesis, indicating CCT shows potential in reducing brooding after confrontation with a stressor[5].

When looking at the CCT group ($n = 20$), change in brooding over time (Time 1 – Time 3; positive scores indicate a decrease) was related to stress susceptibility during the stress induction procedure in lab context directly following training. Participants that were more susceptible to the stress induction procedure, as shown by reporting less positive thoughts and more neutral thoughts following the induction, showed the tendency to experience a smaller decrease in brooding scores over time (Positive thoughts: $r = .41$, $p = .076$; Neutral thoughts: $r = -.46$, $p < .05$; all other *r*s < .30). Moreover, participants reporting more general negative affect following the induction (as assessed by the VAS negative affect compound score), were characterized by the tendency to experience more brooding at follow-up ($r = .42$, $p = .066$). This seems to be due to the extent to which participants experienced depressive feelings following the induction procedure (VAS feeling depressed; $r = .49$, $p < .05$; all other *r*s < .29).

## Discussion

We set out to examine whether CCT targeting working memory functioning has beneficial effects on stress reactivity and rumination in individuals at-risk for depression. Compared to the active control group, we expected to find that CCT would exert direct effects on working memory functioning, and boost resilience, as operationalized by stress reactivity and rumination in response to a lab stressor directly following two weeks of training and brooding in response to naturalistic stress four weeks following training.

Although both training groups showed an increase in performance on the training task throughout the 10 training sessions, we did not find clear transfer effects of CCT on working memory performance as assessed by the Automated O-Span task. However, participants who showed a higher increase in working memory functioning – which was used as an indicator of increase in cognitive control – reported less ruminative brooding and higher self-reported resilience following training, while controlling for baseline levels of brooding or resilience. Importantly, increase in working memory functioning was *not* related to any of the self-report measures in the active control group. These findings suggest that an increase in working memory functioning in response to training may predict an adaptive response to stressful situations.

The absence of transfer of CCT on working memory functioning as assessed by the Automated O-Span task might be due to several causes. First, the general increase in O-Span scores might reflect a repetition learning effect. Second, since the sample consisted of undergraduate students, ceiling effects might have hampered us from finding bigger transfer effects on working memory functioning in the CCT group. Third, the Automated O-Span task might lack sensitivity in finding transfer effects caused by the CCT. Research using the adaptive PASAT has typically used the non-adaptive PASAT or Digit Sorting task to investigate transfer effects (Siegle et al., 2007; Siegle et al., 2014). Given that these tasks require participants to mentally manipulate the to be remembered content, they might have been a better indicator for close transfer. Perhaps if a more challenging and sensitive transfer task would have been used, a larger increase in working memory functioning would have been observed in the CCT group. Fourth, in combination with the methodological factors described above, the general increase in working memory task performance might also be due to another issue that is directly related to the use of an active control condition in training studies. That is, all cognitive training tasks will influence attentional processes to some extent. Although visual search has previously shown to be unrelated to performance on working memory capacity tasks (Kane et al., 2006), it is likely that daily practice with the VST task trains other cognitive factors (e.g., sustained attention) that can influence performance on cognitive transfer tasks. Accordingly, increased working memory task performance in the CCT and VST group might reflect two *distinctive processes* (e.g., VST: increased sustained attention rather than working memory functioning; CCT: both increased attention processes *and* working memory functioning), from which only actual increase in working memory functioning is related to stress reactivity and brooding. Indeed, the finding that increased working memory task performance only predicted decreased brooding and increased resilience in the CCT group whereas no such relation occurred in the VST group seems to confirm this interpretation. Nonetheless, the lack of clear transfer effects on working memory functioning requires some caution in drawing causal conclusions about the role of working memory in stress reactivity and rumination since we cannot fully exclude the possibility that task characteristics of CCT (unrelated to working memory) differentially influenced stress reactivity and brooding.

Importantly, results indicate that CCT was successful in increasing resilience: confrontation with a lab stressor did not lead to a decrease in positive thoughts in the CCT group in contrast to the active control group, which showed to be more reactive to stress as indicated by a decrease in positive thoughts and a trend towards a stronger increase in negative thoughts. Furthermore, in contrast to participants of the control group, participants of the CCT group did not respond to the induction procedure with an increase in self-reported negative affect. Interestingly, these positive effects of CCT on reactivity to stress in the lab were accompanied by – and predicted – a decrease in brooding at follow-up when confronted with a naturalistic stressor. This suggests that the demonstrated transfer effects of CCT on stress reactivity and emotion regulation reflect increased cognitive control when confronted with a stressful event. During the adaptive PASAT, the demand on working memory is high and even gradually increases, this increased task difficulty is associated with greater emotional reactivity (e.g., frustration, negative thoughts, small amount of negative affect). As a result, cognitive control is trained in an emotional task context (Siegle et al., 2007), which means that the frontolimbic circuits are triggered. Increased cognitive control then might allow subjects to employ more adaptive emotion regulation strategies when confronted with a stressful event, reducing brooding and increasing resilience to depression.

Although our findings confirm the hypothesized relationship between cognitive control, stress reactivity and brooding in response to lab and naturalistic stressors, there is a discrepancy between the immediate effects of CCT on stress reactivity and rumination in response to the lab stressor and self-reported brooding directly following training (Time 2; e.g., Table 2). We propose three factors that might have contributed to these findings. First, given that cognitive control was trained in an emotional / stressful task context (Siegle et al., 2007) we believe that this discrepancy reflects the need to assess ruminative processes in at-risk undergraduate students in the presence of stressors. Second, the relation between cognitive control and emotion regulation is reciprocal and CCT could induce a mutually reinforcing increase in both cognitive control and emotion regulation over time. Third, when analyzing rumination directly following training using retrospective self-report questionnaires, evaluation will be more strongly biased by situations occurring before the training took place or during first days of training than when including a follow-up assessment or a behavioral measure of rumination.

The current study is the first to show the potential of CCT targeting working memory functioning in increasing resilience towards depression in an at-risk population. CCT showed transfer on emotion regulation in response to a lab stressor and a naturalistic stressor at follow-up. This adds to the ecological validity of our findings and provides evidence for the temporal stability of CCT effects in increasing resilience. Our findings are in line with emerging research focusing on increasing cognitive control over emotional stimuli using other training tasks (Cohen, Mor, & Henik, in press; Daches & Mor, 2014). Moreover, the current study extends recent findings indicating that CCT forms a promising intervention to reduce brooding as it is the first to demonstrate the effectiveness of the adaptive PASAT in absence of the Wells' attention training, compared to an active control group. In general, our findings show the potential of CCT as a highly accessible preventive intervention for depression.

However, several limitations should be taken into account. The lack of a transparent relation between CCT and increase in working memory performance forms a first limitation of this study. Furthermore, we have only used one indicator of working memory capacity. Second, the single-blind design might have influenced assessment of stress reactivity in the lab. However, a detailed script was used for the induction procedure and our findings were further validated by the decrease in brooding scores when confronted with a naturalistic stressor. Third, we did not assess stress reactivity in the lab at baseline to safeguard credibility of the induction procedure following training. Fourth, experienced difficulty of both training tasks was not assessed, which does not allow to rule out effects of potential group differences in training task difficulty (e.g., habituation to stress) on responses to the stress induction procedure. However, during the stress induction procedure both groups did not differ in experienced task difficulty and experienced control over performance on this task. Fifth, although both groups mainly contained female participants, a gender difference occurred: the control group contained more men ($n$ = 4) than the CCT group ($n$ = 0). As women are more prone to brooding (Johnson & Whisman, 2013), this might have influenced chances of finding beneficial effects of computer training sessions on brooding in the CCT group compared to the active control group. However, re-analyzing the data excluding the male participants did not alter our main findings. Sixth, due to nonresponse and differences in students having examinations at follow-up (individual differences in academic trajectories), follow-up results are based on a limited sample size (*n* = 37). Cautious interpretation of these findings is thus warranted. Finally, based on existing research (Grant & Beck, 2010) the current study has assessed a limited amount of characteristics concerning the naturalistic stressor (i.e., time since previous exam) whereas other factors might also have been of importance but were not taken into account in this study (e.g., perceptions concerning the examinations).

Future studies should focus on further elucidating the involvement of working memory functioning in brooding, stress reactivity, and resilience in general, using different indicators of working memory functioning. On top of the suggestions that have been made throughout the discussion, follow-up studies should use a double-blind design and target a sample with more variability in cognitive functioning. Furthermore, it would be important to get a clear view on potential individual differences predicting effectiveness of CCT in order to identify specific subgroups of vulnerable populations that might benefit from CCT.

## Summary

The current experimental study provides evidence for the effectiveness of a working memory based cognitive control training (CCT) in increasing resilience to depression in an at-risk population. Compared to an active control group, CCT was associated with reduced stress reactivity in response to a lab stressor, as indicated by ratings of mood and a behavioral measure of rumination. Furthermore, CCT showed to reduce brooding four weeks following training as participants were confronted with a naturalistic stressor, providing evidence for the temporal stability and ecological validity of our findings. Implications and limitations were discussed, suggestions for future studies were made.

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**References**

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Manual for Beck Depression Inventory II*. San Antonio, Texas: Psychological Corporation.

Borkovec, T. D., Robinson, E., Pruzinsky, T., & Depree, J. A. (1983). Preliminary exploration of worry: Some characteristics and processes. *Behaviour Research and Therapy, 21*(1), 9-16. doi: 10.1016/0005-7967(83)90121-3

Brunoni, A. R., Boggio, P. S., De Raedt, R., Bensenor, I. M., Lotufo, P. A., Namur, V., . . . Vanderhasselt, M. A. (2014). Cognitive control therapy and transcranial direct current stimulation for depression: A randomized, double-blinded, controlled trial. *Journal of Affective Disorders, 162*, 43-49. doi: 10.1016/j.jad.2014.03.026

Calkins, A. W., Deveney, C. M., Weitzman, M. L., Hearon, B. A., & Siegle, G. J. (2011). The effects of prior cognitive control task exposure on responses to emotional tasks in healthy participants. *Behavioural and Cognitive Psychotherapy, 39*(2), 205-220. doi: 10.1017/s1352465810000652

Calkins, A. W., McMorran, K. E., Siegle, G. J., & Otto, M. W. (in press). The effects of computerized cognitive control training on community adults with depressed mood. *Behavioural and Cognitive Psychotherapy*. doi: 10.1017/S1352465814000046

Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: Psychometric evidence and taxonomic implications. *Journal of Abnormal Psychology*, *100*, 316-336.

Cohen, N., Mor, N., & Henik, A. (in press). Linking executive control and emotional response: A training procedure to reduce rumination. *Clinical Psychological Science*. doi: 10.1177/2167702614530114

Collette, F., Van der Linden, M., Laureys, S., Delfiore, G., Degueldre, C., Luxen, A., & Salmon, E. (2005). Exploring the unity and diversity of the neural substrates of executive functioning. *Human Brain Mapping, 25*(4), 409-423. doi: 10.1002/hbm.20118

Connolly, S. L., Wagner, C. A., Shapero, B. G., Pendergast, L. L., Abramson, L. Y., & Alloy, L. B. (2014). Rumination prospectively predicts executive functioning impairments in adolescents. *Journal of Behavior Therapy and Experimental Psychiatry, 45*(1), 46-56. doi: 10.1016/j.jbtep.2013.07.009

Cox, S., Funasaki, K., Smith, L., & Mezulis, A. H. (2012). A prospective study of brooding and reflection as moderators of the relationship between stress and depressive symptoms in adolescence. *Cognitive Therapy and Research, 36*(4), 290-299. doi: 10.1007/s10608-011-9373-z

Cuijpers, P., Andersson, G., Donker, T., & van Straten, A. (2011). Psychological treatment of depression: Results of a series of meta-analyses. *Nordic Journal of Psychiatry, 65*(6), 354-364. doi: 10.3109/08039488.2011.596570

Daches, S., & Mor, N. (2014). Training ruminators to inhibit negative information: A preliminary report. *Cognitive Therapy and Research, 38*(2), 160-171. doi: 10.1007/s10608-013-9585-5

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

De Lissnyder, E., Koster, E. H. W., Everaert, J., Schacht, R., Van den Abeele, D., & De Raedt, R. (2012). Internal cognitive control in clinical depression: General but no emotion-specific impairments. *Psychiatry Research, 199*(2), 124-130. doi: 10.1016/j.psychres.2012.04.019

De Lissnyder, E., Koster, E. H. W., Goubert, L., Onraedt, T., Vanderhasselt, M. A., & De Raedt, R. (2012). Cognitive control moderates the association between stress and rumination. *Journal of Behavior Therapy and Experimental Psychiatry, 43*(1), 519-525. doi: 10.1016/j.jbtep.2011.07.004

De Raedt, R., & Koster, E. H. W. (2010). Understanding vulnerability for depression from a cognitive neuroscience perspective: A reappraisal of attentional factors and a new conceptual framework. *Cognitive Affective & Behavioral Neuroscience, 10*(1), 50-70. doi: 10.3758/cabn.10.1.50

Demeyer, I., De Lissnyder, E., Koster, E. H. W., & De Raedt, R. (2012). Rumination mediates the relationship between impaired cognitive control for emotional information and depressive symptoms: A prospective study in remitted depressed adults. *Behaviour Research and Therapy, 50*(5), 292-297. doi: 10.1016/j.brat.2012.02.012

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111*, 225-236. doi: 10.1037/0021-84X.111.2.225

Engelen, U., De Peuter, S., Victoir, A., Van Diest, I., & Van den Bergh, O. (2006). Verdere validering van de Positive and Negative Affect Schedule (PANAS) en vergelijking van twee Nederlandstalige versies. *Psychologie en Gezondheid, 34,* 89-102.

Grant, D. M., & Beck, J. G. (2010). What predicts the trajectory of rumination?: A prospective evaluation. *Journal of Anxiety Disorders, 24*(5), 480-486. doi: 10.1016/j.janxdis.2010.03.004

Gronwall, D. (1977). Paced Auditory Serial-Addition Task: A measure of recovery from concussion. *Perceptual and Motor Skills, 44*, 367-373.

Harrison, T. L., Shipstead, Z., Hicks, K. L., Hambrick, D. Z., Redick, T. S., & Engle, R. W. (2013). Working memory training may increase working memory capacity but not fluid intelligence. *Psychological Science, 24*(12), 2409-2419. doi: 10.1177/0956797613492984

Hirsch, C. R., Hayes, S., & Mathews, A. (2009). Looking on the bright side: Accessing benign meanings reduces worry. *Journal of Abnormal Psychology, 118*(1), 44-54. doi: 10.1037/a0013473

IsHak, W. W., Balayan, K., Bresee, C., Greenberg, J. M., Fakhry, H., Christensen, S., & Rapaport, M. H. (2013). A descriptive analysis of quality of life using patient-reported measures in major depressive disorder in a naturalistic outpatient setting. *Quality of Life Research, 22*(3), 585-596. doi: 10.1007/s11136-012-0187-6

Johnson, D. P., & Whisman, M. A. (2013). Gender differences in rumination: A meta-analysis. *Personality and Individual Differences*, *55*(4), 367-374. doi: 10.1016/j.paid.2013.03.019

Joormann, J. (2006). Differential effects of rumination and dysphoria on the inhibition of irrelevant emotional material: Evidence from a Negative Priming Task. *Cognitive Therapy and Research, 30*, 149-160. doi: 10.1007/s10608-006-9035-8

Joormann, J., & D'Avanzato, C. (2010). Emotion regulation in depression: Examining the role of cognitive processes. *2010, 24*, 913-939. doi: 10.1080/02699931003784939

Joormann, J., Dkane, M., & Gotlib, I. H. (2006). Adaptive and maladaptive components of rumination? Diagnostic specificity and relation to depressive biases. *Behavior Therapy, 37*, 269-280.

Joormann, J., & Gotlib, I. H. (2010). Emotion regulation in depression: Relation to cognitive inhibition. *Cognition & Emotion*, *24*(2), 281-298. doi: 10.1080/02699930903407948

Joormann, J., & Quinn, M. E. (2014). Cognitive processes and emotion regulation in depression. *Depression and Anxiety, 31*, 308-315. doi: 10.1002/da.22264

Judah, M. R., Grant, D. M., Mills, A. C., & Lechner, W. V. (2014). Factor structure and validation of the attentional control scale. *Cognition & Emotion, 28*(3), 433-451. doi: 10.1080/02699931.2013.835254

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention". *Journal of Experimental Psychology-Learning Memory and Cognition, 32*(4), 749-777. doi: 10.1037/0278-7393.32.4.749

Kazdin, A. E., & Blase, S. L. (2011). Rebooting psychotherapy research and practice to reduce the burden of mental illness. *Perspectives on Psychological Science, 6*, 21-37.

Kessler, R. C., & Wang, P. S. (2009). The epidemiology of depression. In I. H. Gotlib & C. L. Hammen (Eds.), *Handbook of depression: 2nd edition*. New York: Guilford.

Lazeron, R. H., Rombouts, S. A., de Sonneville, L., Barkhof, F., & Scheltens, P. (2003). A paced visual serial addition test for fMRI. *Journal of Neurological Science, 213*, 29-34.

Luppa, M., Heinrich, S., Angermeyer, M. C., Konig, H. H., & Riedel-Heller, S. G. (2007). Cost-of-illness studies of depression: A systematic review. *Journal of Affective Disorders, 98*, 29-43. doi: 10.1016/j.jad.2006.07.017

McNair, D. M., Lorr, M., & Dropplemann, L. F. (1992). *Manual: Profile of Mood States Revised*. San Diego, CA: Educational and Industrial Testing Service.

Meyer, T. J., Miller, M. L., Metzger, R. L., & Borkovec, T. D. (1990). Development and validation of the Penn State Worry Questionnaire. *Behaviour Research and Therapy, 28*, 487-495. doi: 10.1016/0005-7967(90)90135-6

Michl, L. C., McLaughlin, K. A., Shepherd, K., & Nolen-Hoeksema, S. (2013). Rumination as a mechanism linking stressful life events to symptoms of depression and anxiety: Longitudinal evidence in early adolescents and adults. *Journal of Abnormal Psychology, 122*(2), 339-352. doi: 10.1037/a0031994

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. doi: 10.1006/cogp.1999.0734

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. doi: 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. doi: 10.1111/j.1745-6924.2008.00088.x

Nummenmaa, L., & Niemi, P. (2004). Inducing affective states with success-failure manipulations: A meta-analysis. *Emotion, 4*(2), 207-214. doi: 10.1037/1528-3542.4.2.207

Owens, M., Koster, E. H. W., & Derakshan, N. (2012). Impaired filtering of irrelevant information in dysphoria: An ERP study. *Social Cognitive and Affective Neuroscience, 7*(7), 752-763. doi: 10.1093/scan/nsr050

Portzky, M. (2008). *RS-nl: Resilience Scale - Nederlandse versie*. Amsterdam: Harcourt Test Publishers.

Redick, T. S., Shipstead, Z., Harrison, T. L., Hicks, K. L., Fried, D. E., Hambrick, D. Z., . . . Engle, R. W. (2013). No evidence of intelligence improvement after working memory training: A randomized, placebo-controlled study. *Journal of Experimental Psychology-General, 142*(2), 359-379. doi: 10.1037/a0029082

Rossi, V., & Pourtois, G. (2012). State-dependent attention modulation of human primary visual cortex: A high density ERP study. *Neuroimage, 60*(4), 2365-2378. doi: 10.1016/j.neuroimage.2012.02.007

Ruscio, A. M., & Borkovec, T. D. (2004). Experience and appraisal of worry among high worriers with and without generalized anxiety disorder. *Behaviour Research and Therapy, 42*(12), 1469-1482. doi: 10.1016/j.brat.2003.10.007

Segrave, R. A., Arnold, S., Hoy, K., & Fitzgerald, P. B. (2014). Concurrent cognitive control training augments the antidepressant efficacy of tDCS: A pilot study. *Brain Stimulation, 7*(2), 325-331. doi: 10.1016/j.brs.2013.12.008

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? *Psychological Bulletin, 138*(4), 628-654. doi: 10.1037/a0027473

Siegle, G. J., Ghinassi, F., & Thase, M. E. (2007). Neurobehavioral therapies in the 21st century: Summary of an emerging field and an extended example of cognitive control training for depression. *Cognitive Therapy and Research, 31*(2), 235-262. doi: 10.1007/s10608-006-9118-6

Siegle, G. J., Price, R. B., Jones, N. P., Ghinassi, F., Painter, T., & Thase, M. E. (2014). You gotta work at it: Pupillary indices of task focus are prognostic for response to a neurocognitive intervention for rumination in depression. *Clinical Psychological Science, 2*, 455-471. doi: 10.1177/2167702614536160

Treynor, W., Gonzalez, R., & Nolen-Hoeksema, S. (2003). Rumination reconsidered: A psychometric analysis. *Cognitive Therapy and Research*, *27*, 247-259.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127-154. doi: 10.1016/0749-596X(89)90040-5

Unsworth, N., Heitz, R., Schrock, J., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*, 498-505. doi: 10.3758/bf03192720

Van der Does, A. J. W. (2002). *BDI-II-NL. Handleiding: De Nederlandse versie van de Beck Depression Inventory - 2nd edition*. Lisse: Harcourt Test Publishers.

van Rijsoort, S., Emmelkamp, P., & Vervaeke, G. (1999). The Penn State Worry Questionnaire and the Worry Domains Questionnaire: Structure, reliability and validity. *Clinical Psychology & Psychotherapy, 6*, 297-307. doi: 10.1002/(SICI)1099-0879(199910)6:4<297::AID-CPP206>3.0.CO;2-E

van Rijsoort, S., Vervaeke, G., & Emmelkamp, P. (1997). The Penn Sate Worry Questionnaire and the Worry Domains Questionnaire: First results in a normal Dutch population. *Gedragstherapie*, *30*, 121-128.

van Vugt, M. K., Hitchcock, P., Shahar, B., & Britton, W. (2012). The effects of mindfulness-based cognitive therapy on affective memory recall dynamics in despression: A mechanistic model of rumination. *Frontiers in Human Neuroscience, 6*, 13. doi: 10.3389/fnhum.2012.00257

Vanderhasselt, M.-A., & De Raedt, R. (2009). Impairments in cognitive control persist during remission from depression and are related to the number of past episodes: An event related potentials study. *Biological Psychology, 81*(3), 169-176. doi: 10.1016/j.biopsycho.2009.03.009

Verwoerd, J., Cieraad, R., & de Jong, P. J. (2007). ACS: Dutch translation of the Attentional Control Scale. Retrieved 08-03-2014 from http://www.ekgp.ugent.be/pages/nl/vragenlijsten/ACS-NL.pdf.

Wagnild, G. M., & Young, H. M. (1993). Development and psychometric evaluation of the resilience scale. *Journal of Nursing Measurement, 1*, 165-178.

Wardenaar, K. J., van Veen, T., Giltay, E. J., de Beurs, E., Penninx, B., & 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), 101-106. doi: 10.1016/j.psychres.2009.03.005

Watkins, E. R., Mullan, E., Wingrove, J., Rimes, K., Steiner, H., Bathurst, N., . . . Scott, J. (2011). Rumination-focused cognitive-behavioural therapy for residual depression: phase II randomised controlled trial. *British Journal of Psychiatry, 199*(4), 317-322. doi: 10.1192/bjp.bp.110.090282

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology, 54,* 1063-1070.

Wells, A. (2000). *Emotional disorders and metacognition innovative Cognitive Therapy*. New York: Wiley.

WHO. (2012). Depression: World Health Organization Fact sheet no 369. Accessed on 29-05-2014 from http://www.who.int/mediacentre/factsheets/fs369/en/.

Zetsche, U., & Joormann, J. (2011). Components of interference control predict depressive symptoms and rumination cross-sectionally and at six months follow-up. *Journal of Behavior Therapy and Experimental Psychiatry, 42*(1), 65-73. doi: 10.1016/j.jbtep.2010.06.001

**Footnote**

[1] 'Cognitive control' refers to the broad definition of the concept under which different executive functions are situated, including shifting, inhibition, and information updating in working memory (Collette et al., 2005; Miyake et al., 2000). Several researchers (Joormann & Quinn, 2014; Siegle et al., 2007) have argued that training cognitive control to improve working memory (CCT) could be of interest for treating the neurobiological and cognitive impairments underlying depression. Therefore, we focus on modified working memory training tasks.

[2] Excluding dysphoric participants based on their baseline BDI-scores (BDI ≥ 14) did not change the direction of any of the reported interaction effects. The beneficial effects of CCT on stress reactivity (in response to a lab stressor, using VAS mood ratings and a behavioral measure for state rumination) or brooding in response to a naturalistic stressor remained significant (except for the Time x Group interaction for amount of self-reported negative thoughts, that turned marginally significant given the smaller sample size).

[3] Using an alternative approach, correlating Δ O-Span scores with Δ self-reported brooding- and resilience scores provided similar findings (resilience: $r = .47$, $p < .05$; brooding: $r = .37$, $p = .069$), although the effect of brooding became marginally significant.

[4] Excluding the covariate Time since previous exam – i.e., not taking into account individual differences in confrontation with the naturalistic stressor – reduces the strength of the presented effects of CCT on brooding in response to a naturalistic stressor, resulting in a marginally significant Time x Group interaction, $F(1, 35) = 3.62$, $p = .065$, $\eta^2 = .09$ (main effect of Time: $F(1, 35) = 15.62$, $p < .001$, $\eta^2 = .31$; main effect of Group: $F(1, 35) = 0.44$, $p = .512$, $\eta^2 = .01$).

[5] Other self-report measures than brooding were assessed at baseline to check for baseline group differences and were further added for exploratory reasons. They did not show to be influenced

by CCT (interaction effects: all *F*s $< 1.45$). These data are available upon request (see Table 4). However, these findings are beyond the scope of this article and will not be further discussed.

**Table 1**

*Training session accuracy rates as a function of training condition*

| | Training condition | | | |
|---|---|---|---|---|
| | Cognitive control (*n* = 25) | | Visual search (*n* = 22) | |
| | *M % correct* | *SD* | *M % correct* | *SD* |
| Session 1 | 54.51 | 2.66 | 71.97 | 6.52 |
| Session 2 | 56.47 | 2.09 | 72.73 | 5.66 |
| Session 3 | 56.72 | 2.22 | 70.93 | 6.37 |
| Session 4 | 56.98 | 2.53 | 72.97 | 5.68 |
| Session 5 | 57.35 | 2.25 | 73.39 | 5.41 |
| Session 6 | 57.91 | 2.88 | 74.04 | 4.84 |
| Session 7 | 58.18 | 1.99 | 74.01 | 5.87 |
| Session 8 | 57.93 | 2.21 | 74.50 | 4.31 |
| Session 9 | 58.40 | 2.34 | 73.74 | 5.27 |
| Session 10 | 58.41 | 2.74 | 73.30 | 6.29 |

**Table 2**

*Group characteristics as a function of training condition*

| | Training condition | | | |
|---|---|---|---|---|
| | Cognitive control (*n* = 25) | | Visual search (*n* = 22) | |
| | Time 1 *M (SD)* | Time 2 *M (SD)* | Time 1 *M (SD)* | Time 2 *M (SD)* |
| Depressive symptomatology | 12.92 (9.73) | 12.12 (11.33) | 10.86 (7.75) | 9.41 (7.84) |
| General distress | 24.28 (10.13) | 23.76 (9.84) | 21.64 (7.38) | 19.59 (6.36) |
| Anhedonic depression | 33.16 (8.61) | 33.68 (9.16) | 32.09 (8.65) | 31.23 (7.43) |
| Anxious arousal | 16.24 (6.02) | 16.60 (7.25) | 16.36 (4.82) | 13.86 (4.21) |
| Worrying | 57.16 (13.18) | 55.12 (14.36) | 58.55 (8.85) | 56.00 (7.88) |
| Trait rumination | 51.84 (10.20) | 48.88 (11.27) | 53.32 (8.89) | 50.95 (9.88) |
| Brooding | 12.88 (3.77) | 11.76 (3.90) | 13.14 (2.88) | 12.55 (2.87) |
| Reflection | 11.60 (3.70) | 10.96 (3.78) | 10.55 (2.99) | 9.73 (3.47) |
| Attentional control | 47.52 (9.44) | 47.36 (9.05) | 47.27 (6.78) | 46.64 (7.01) |
| Positive affect | 28.64 (7.17) | 28.24 (8.29) | 28.64 (6.44) | 27.27 (6.09) |
| Negative affect | 16.60 (5.09) | 17.48 (7.56) | 15.68 (5.29) | 13.95 (3.39) |

| | | | | |
|---|---|---|---|---|
| Resilience | 70.92 (9.60) | 71.68 (9.83) | 72.27 (7.54) | 72.18 (7.71) |

*Note:* Independent *t*-tests indicate that both groups did not significantly differ at T1 or T2, except for T2 momentary negative affect ($t(34.18) = 2.11$, $p < .05$).

**Table 3**

*Effects of stress induction as a function of time and training condition*

| | Cognitive control (*n* = 25) | | | | Visual search (*n* = 22) | | | |
|---|---|---|---|---|---|---|---|---|
| | *Pre* | | *Post* | | *Pre* | | *Post* | |
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| *Breathing Focus Task* | | | | | | | | |
| Focused | 4.76 | 1.92 | 4.08 | 2.47 | 5.64 | 2.42 | 4.91 | 2.43 |
| Positive thoughts | 1.44 | 1.39 | 1.68 | 1.99 | 1.59 | 1.22 | .64 | 1.00 |
| Negative thoughts | 1.24 | 1.23 | 1.88 | 1.79 | 1.18 | 1.22 | 2.86 | 2.12 |
| Neutral thoughts | 2.52 | 1.66 | 2.32 | 1.75 | 1.50 | 1.50 | 1.55 | 1.68 |
| Other reactions | 0.04 | 0.20 | 0.04 | 0.20 | 0.09 | 0.29 | 0.05 | 0.21 |
| *VAS* | | | | | | | | |
| Positive affect | 54.19 | 18.01 | 38.97 | 14.40 | 51.88 | 15.88 | 31.61 | 17.77 |
| Negative affect | 20.07 | 16.25 | 22.11 | 16.90 | 16.33 | 13.64 | 29.85 | 19.03 |

**Table 4**

*Group characteristics as a function of training condition*

| | Training condition | | | | | |
|---|---|---|---|---|---|---|
| | Cognitive control (*n* = 20) | | | Visual search (*n* = 17) | | |
| | Time 1 *M* (*SD)* | Time 2 *M* (*SD)* | Time 3 *M* (*SD)* | Time 1 *M* (*SD)* | Time 2 *M* (*SD)* | Time 3 *M* (*SD)* |
| Depressive sympt. | 12.60 (9.95) | 11.40 (11.34) | / | 10.82 (7.73) | 9.41 (7.55) | / |
| General distress | 23.60 (9.97) | 23.50 (9.74) | 24.10 (6.23) | 22.41 (6.81) | 20.18 (6.42) | 24.29 (7.28) |
| Anhedonic depr. | 32.55 (8.05) | 33.40 (8.78) | 34.90 (6.64) | 32.41 (6.84) | 31.53 (6.76) | 35.29 (5.82) |
| Anxiety arousal | 16.30 (6.04) | 16.65 (7.80) | 18.45 (6.60) | 17.24 (5.12) | 14.41 (4.53) | 18.00 (6.03) |
| Worrying | 56.30 (14.12) | 53.70 (15.35) | 55.35 (13.78) | 58.18 (9.72) | 56.06 (8.66) | 56.06 (10.46) |
| Trait rumination | 52.30 (9.91) | 48.85 (11.22) | 50.05 (10.16) | 53.00 (7.34) | 52.06 (8.63) | 51.24 (8.74) |
| Brooding | 13.10 (3.65) | 11.90 (3.88) | 11.25 (3.34) | 13.18 (2.83) | 12.94 (2.75) | 12.53 (3.00) |
| Reflection | 12.20 (3.30) | 11.10 (3.18) | 11.20 (2.95) | 10.29 (2.89) | 9.76 (3.42) | 10.18 (3.68) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Attentional control | 47.25 (10.14) | 47.55 (9.62) | 48.00 (9.27) | 48.24 (7.08) | 47.41 (7.22) | 48.88 (7.56) |
| Positive affect | 28.95 (7.18) | 28.40 (8.48) | 26.15 (7.47) | 28.12 (5.93) | 26.35 (5.61) | 23.88 (6.25) |
| Negative affect | 16.40 (5.35) | 17.30 (8.16) | 20.20 (7.66) | 16.00 (4.82) | 14.12 (3.53) | 17.18 (5.34) |
| Resilience | 70.95 (9.84) | 71.45 (9.92) | 72.25 (8.88) | 72.76 (7.45) | 72.41 (7.53) | 73.82 (7.75) |

*Note:* Independent *t*-tests indicate that both groups did not significantly differ at T1, T2, or T3.

*Figure 1.* Procedure

*Figure 2A.* Cognitive control training progress

*Figure 2B.* Visual search training progress