Effects of cognitive control training on the dynamics of (mal)adaptive emotion regulation in daily life

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Abstract

Cognitive control plays a key role in both adaptive emotion regulation, such as positive reappraisal, and maladaptive emotion regulation, such as rumination, with both strategies playing a major role in resilience and well-being. As a result, cognitive control training targeting working memory functioning (CCT) may have the potential to reduce maladaptive emotion regulation and increase adaptive emotion regulation. The current study explored the effects of CCT on positive reappraisal ability in a lab context, and deployment and efficacy of positive appraisal and rumination in daily life. A sample of undergraduates (n = 83) was allocated to CCT or an active control condition, performing 10 online training sessions over a period of 14 days. Effects on regulation of affective states in daily life were assessed using experience sampling over a seven-day post-training period. Results revealed a positive association between baseline cognitive control and self-reported use of adaptive emotion regulation strategies, whereas maladaptive emotion regulation strategies showed a negative association. CCT showed transfer to working memory functioning on the dual n-back task. Overall, effects of CCT on emotion regulation were limited to reducing deployment of rumination in low positive affective states. However, we did not find beneficial effects on indicators of adaptive emotion regulation. These findings are in line with previous studies targeting maladaptive emotion regulation, but suggest limited use in enhancing adaptive emotion regulation in a healthy sample.

Keywords: positive reappraisal, rumination, resilience, cognitive control, training

How people respond to stressful events and negative emotions has important consequences for their mental health. For instance, responding with negative and repetitive moody pondering (i.e., brooding, a subtype of rumination; Treynor, Gonzalez, & Nolen-Hoeksema, 2003) to negative affect following a stressful event such as loss of job is known to be an important risk factor for developing mood disorders (D'Avanzato, Joormann, Siemer, & Gotlib, 2013; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). In contrast, applying a strategy such as cognitive (re-)appraisal in which the emotion-eliciting value of a stressful situation is reduced through cognitive strategies (Gross, 2002) is known to have beneficial effects on well-being and mental health (Gross & John, 2003; Haga, Kraft, & Corby, 2009; Hu et al., 2014). This process of influencing which emotions one has, when one experiences these emotions, and how these emotions are experienced and expressed is known as emotion regulation (p. 275; Gross, 1998) and plays an important role in maintaining and ameliorating mental health (Gross & Jazaieri, 2014). Given their differential effects on mental health, rumination (among strategies such as catastrophizing, self-blame, etc.) has been conceptualized as a maladaptive emotion regulation strategy, whereas cognitive reappraisal (among strategies such as putting into perspective, positive refocusing, etc.) has been categorized as an adaptive emotion regulation strategy (Garnefski, Kraaij, & Spinhoven, 2001). Furthermore, adaptive emotion regulation strategies form an important predictor for resilience, the phenomenon of maintaining one’s mental health even when confronted with adversity (Kalisch, Müller, & Tüscher, 2015).

Importantly, research indicates that cognitive control processes, such as shifting, inhibition, and updating of representations in working memory (Miyake et al., 2000), form an important underlying mechanism for emotion regulation (for a review see Joormann & D'Avanzato, 2010). That is, these executive processes are key to efficient deployment of limited working memory capacity, which is central to goal-directed behavior. Malfunctioning of these top-down processes following confrontation with an external or internal stressor may underlie maladaptive responses such as perseverative negative thinking. Indeed, a vast amount of cross-sectional and prospective studies have provided evidence for an association between impaired cognitive control and deployment of maladaptive emotion regulation strategies, for instance brooding and rumination (De Lissnyder et al., 2012; Demeyer, De Lissnyder, Koster, & De Raedt, 2012; Joormann, 2006; Joormann & Gotlib, 2008; Zetsche & Joormann, 2011). Given the role of cognitive control and maladaptive emotion regulation strategies in developing depressive symptomatology (e.g., Demeyer et al., 2012; Nolen-Hoeksema et al., 2008), this has led researchers to develop computerized training tasks to remediate cognitive control impairments.

Siegle, Ghinassi, and Thase (2007) have developed an adaptive version of the Paced Auditory Serial Addition Task (PASAT; Gronwall, 1977). This cognitive control training (CCT) targeting working memory functioning has shown to reduce emotional reactivity and brooding in undergraduate students at-risk for developing depressive symptomatology (Hoorelbeke, Koster, Vanderhasselt, Callewaert, & Demeyer, 2015). Moreover, administering CCT in depressive patients has shown not only to reduce rumination (Siegle et al., 2007; Siegle et al., 2014; Vanderhasselt et al., 2015), but also depressive symptomatology (Brunoni et al., 2014; Siegle et al., 2007). Importantly, it has been suggested that the effects of CCT on depressive symptomatology are secondary to changes in emotion regulation (Siegle et al., 2014). These findings highlight the potential of CCT targeting working memory functioning in reducing maladaptive emotion regulation (e.g., rumination), and in turn, depressive symptomatology.

However, Joormann and D'Avanzato (2010) have suggested that the role of cognitive control is not confined to maladaptive emotion regulation strategies, but that cognitive control impairments also “discourage the use of more effective emotion regulation strategies, such as reappraisal” (p. 928; p. 412; Joormann & Vanderlind, 2014). Indeed, research suggests that cognitive control plays an important role in the deployment of adaptive emotion regulation strategies (Buhle et al., 2014; Moser, Hartwig, Moran, Jendrusina, & Kross, 2014; Vanderhasselt et al., 2014). Moreover, it has been argued that these cognitive emotion regulation strategies rely on a network of neural activation involving structures implicated in cognitive control and reduced emotional processing (Hajcak, MacNamara, & Olvet, 2010). For instance, Ochsner, Bunge, Gross, and Gabrieli (2002) have provided evidence for the involvement of the prefrontal cortex in reappraisal, which forms a central region for cognitive control (Miller & Cohen, 2001). Furthermore, meta-analytic findings suggest activation of cognitive control regions during reappraisal, which attenuates amygdala activity (Buhle et al., 2014). Yet, compared to research exploring the role of cognitive control in maladaptive emotion regulation, evidence for a causal relation between cognitive control underlying adaptive emotion regulation is more limited. Interestingly, despite the emerging evidence for the potential of CCT in reducing maladaptive emotion regulation, so far no study has addressed the potential of CCT targeting working memory functioning in facilitating the use of adaptive emotion regulation strategies (see Joormann & Vanderlind, 2014). This forms an important impetus, as deployment of adaptive emotion regulation strategies is considered an important resilience factor (Kalisch et al., 2015). Maintaining a unilateral focus on reducing maladaptive emotion regulation strategies and psychopathology thus limits the potential applications and benefits of CCT. For instance, next to reducing maladaptive processes, CCT might also be used to increase resilience and thus ameliorate well-being and mental health.

Another issue that might limit our understanding of the causal influence of cognitive control on adaptive and maladaptive emotion regulation is that CCT studies have typically relied on lab assessments and self-report questionnaires that were administered at limited time points to assess effects of training (e.g., Calkins, McMorran, Siegle, & Otto, 2015;

Hoorelbeke, Koster, et al., 2015; Siegle et al., 2014). However, such an approach does not allow to directly test whether CCT impacts emotion regulation in a naturalistic context, nor does it allow to study its effects on the complex dynamics between affective state[1] and emotion regulation. Consequently, it would be beneficial to assess the interplay between affect and emotion regulation in daily life using experience sampling methodology (ESM; Larson & Csikszentmihalyi, 1983). This technique allows multiple assessments of affective state and emotion regulation during the course of a day, where ratings are made related to that specific moment and situation (e.g., Moberly & Watkins, 2008; Pe, Raes, & Kuppens, 2013). Using this technique, Pe, Raes, Koval, et al. (2013) have found that cognitive control moderates the impact of regulation of affect in daily life: impaired cognitive control was related to increased negative affect following rumination, and reduced efficacy of reappraisal in regulating affective states. These findings illustrate the specific involvement of cognitive control in the deployment of adaptive and maladaptive emotion regulation strategies in relation to positive and negative affect. However, to date ESM has not been implemented to assess effects of CCT on regulation of affective states. Accordingly, we used this technique to explore whether CCT can be used to increase deployment and efficacy of an adaptive emotion regulation strategy, and to reduce the use and impact of maladaptive emotion regulation strategies.

Current Study

The current study examined the relation between cognitive control and emotion regulation by exploring the effects of a working memory based CCT on the ability of positive reappraisal in lab context and regulation of affective states in daily life. That is, training effects were explored on the deployment *and* efficacy of adaptive (positive appraisal) as well as maladaptive (depressive rumination) emotion regulation strategies in daily life using ESM, taking evaluation of CCT to the next level. This approach is useful in exploring the potential of CCT in increasing resilience and mental well-being, given that adaptive emotion regulation strategies such as positive (re-)appraisal have been put forward as an important resilience factor (Kalisch et al., 2015). This study specifically targeted an unselected undergraduate student sample in order to explore whether stimulating cognitive control in a population that is not specifically characterized by cognitive control deficits can be used to foster predictors of resilience and well-being. The combination of examining the effect of cognitive control on positive reappraisal in the lab and positive appraisal in daily life has key benefits. That is, positive reappraisal has been theorized as a component of the general process of positive appraisal (Kalisch et al., 2015). Exploring how participants perform on an instructed reappraisal exercise in the lab allows to test the involvement of cognitive control in this subcomponent of positive appraisal. For this purpose we rely on recall of an autobiographical memory of a negative situation as autobiographical memories have previously been used to explore the involvement of cognitive processes in emotion regulation and the underlying neural correlates (e.g., Holland & Kensinger, 2013; Kross, Davidson, Weber, & Ochsner, 2009). Furthermore, the type of episodic autobiographic information recollected during such an exercise implies at least partially re-experiencing this negative event (Wheeler, Stuss, & Tulving, 1997). This allows to explore effects of cognitive control on emotion regulation ability in the context of a well-defined emotionally relevant situation. In contrast, the ESM measures provide information concerning the dynamics of positive appraisal in relation to daily life stressors. However, this information is unspecific concerning the type and content of stressor.

Participants were randomly allocated to either a working memory based CCT or an active control training condition after having completed a baseline assessment of emotion regulation (cfr. self-report questionnaires) and working memory functioning as an indicator of cognitive control (Time 1). Cognitive control was reassessed immediately after two weeks of online training (working memory based CCT or active control), followed by a lab assessment of the ability to positively reappraise a negative past event (Time 2). Following the post-training assessments, daily fluctuations in affect, positive appraisal, and rumination were registered over a period of seven days (eight assessments a day; ESM). In line with previous findings, we hypothesized that performance at baseline assessment of cognitive control (i.e., working memory functioning) would be positively related to adaptive emotion regulation strategies as assessed by self-report measures, whereas maladaptive emotion regulation strategies would show an inverse relation. Second, the CCT group would show a more distinct increase in cognitive control following training. Third, we expected to find beneficial effects of CCT on adaptive emotion regulation, as shown by (1) an increased ability of positive reappraisal of a negative autobiographical memory upon instruction in the lab, and (2) increased deployment and efficacy of positive appraisal in daily life, in contrast to the maladaptive emotion regulation strategy, rumination.

Method

Participants

Unselected undergraduate-students of Ghent University were recruited using an online system. Eighty-three participants completed the baseline assessment and were randomly assigned to a CCT or active control condition (sham training). Ten participants did not complete the training sessions due to individual technological problems (e.g., incompatible operating systems, unstable internet connection; *n* = 6) or reasons unrelated to technical aspects of the training (e.g., impossibility to return to the lab two weeks following baseline assessment, physical health reasons unrelated to the experiment; *n* = 4) and were excluded from data-analysis. Another 12 participants did not take into account the explicit instructions concerning dose regulation of training (i.e., did not complete training, performed multiple sessions a day in order to reach the deadline). 61 participants adequately completed training within the two week period (CCT: n = 29, sham: n = 32). During the experiment, three participants were tested sequentially in sound attenuated booths. Participants were reimbursed for participating (€60). The local ethical committee of Ghent University approved this study and all participants provided written informed consent.

Apparatus and Material

The dual n-back task (Jaeggi et al., 2010) and both training tasks were programmed and run using the INQUISIT Millisecond software package. The dual n-back task was run on Dell Dimension 4600 computers with 72 Hz, 17-inch color monitors. The training was performed online in-browser using the INQUISIT Web application. Participants' own smartphones were used to assess affect and emotion regulation during the ESM procedure, using a combination of SurveySignal software (Hofmann & Patel, 2015) and LimeSurvey. These questionnaires, experimental tasks, and training procedures will be explained in greater detail in the following sections.

Questionnaires.

We used the Beck Depression Inventory (BDI-II-NL; Beck, Steer, & Brown, 1996; Van der Does, 2002) to assess *depressive symptomatology* at baseline and the Dutch Resilience Scale (RS-NL; Portzky, 2008; Wagnild & Young, 1993) to assess baseline *resilience*. The Positive and Negative Affect Schedule (PANAS; Engelen, De Peuter, Victoir, Van Diest, & Van den Bergh, 2006; Watson, Clark, & Tellegen, 1988) was used to assess *positive and negative affective states* at baseline and following training.

Several questionnaires were used to assess *adaptive and maladaptive emotion regulation* at baseline. The Ruminative Response Scale (RRS-NL-EXT; Nolen-Hoeksema & Morrow, 1991; Treynor et al., 2003) assessed rumination, brooding and reflection. Furthermore, the Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski et al.,

2001) provided us with assessments of five adaptive (acceptance, positive refocusing, refocus on planning, positive reappraisal, and putting into perspective) and four less adaptive strategies (self-blame, rumination, catastrophizing, and blaming others). In line with Vanderhasselt et al. (2014), we have calculated a CERQ compound score for adaptive emotion regulation as well as maladaptive emotion regulation. Finally, the Response to Positive Affect Scale (RPA-NL; Feldman, Joormann, & Johnson, 2008; Raes, Daems, Feldman, Johnson, & Van Gucht, 2009) was used to explore how participants responded to positive affect, resulting in two adaptive strategies (self-focused and emotion focused positive rumination) and one less adaptive strategy (dampening of positive affect).

Training Tasks.

Cognitive control training. We used a modified version of the Paced Auditory Serial Addition Task (PASAT; Gronwall, 1977; Siegle et al., 2007) to train participants' cognitive control (CCT condition). Task characteristics were identical to the CCT described in Hoorelbeke, Koster, et al. (2015). During this task, participants had to add serially presented numbers (1 – 9), responding to the sum of the last two presented stimuli (2 – 18). Based on their within-session performance, the InterStimulus Interval (ISI) was automatically adjusted (baseline: 3000 ms, +/- 100 ms every 4 consecutive correct or incorrect responses). Following each training session (400 trials), mood was assessed ('energetic', 'tense', 'frustrated', 'sad', 'happy') using visual analogue scales (VAS; 1 – 100), as well as the extent to which participants have experienced negative thoughts and stress throughout training, and experienced task competence ('During the task I felt as if I was doing great').

Active control training. In search for a suitable active control task for the sham condition, we have developed a low cognitive load version of the adaptive PASAT. During this attention training, participants from the sham condition were instructed to respond to the auditory presented stimuli (1 – 18) immediately by clicking on the corresponding number. As in the adaptive PASAT, ISI was adjusted every four (in-)correct consecutive responses. All other task characteristics were similar to the adaptive PASAT, allowing to control for motivational effects of undergoing CCT and specifically filtering out the working memory component whereas attentional processes are trained in both conditions (e.g., sustained attention).

Transfer Tasks.

Cognitive control. The dual n-back task is a working memory task relying on several executive functions such as inhibition and updating (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi et al., 2010). Therefore, this task was used as an indicator of cognitive control. During this task, participants were confronted with a series of sequentially presented visual (squares) and auditory (letters) stimuli. Participants had to respond if at least one of the presented stimuli matched the stimuli presented n steps before (matching the visual stimulus: press “A”; matching the auditory stimulus: press “L”; matching both: press “A” and “L” simultaneously). Following 30 practice trials, cognitive control was assessed using 3 blocks of n = 2, n = 3, and n = 4, containing 20 trials each (total of 180 test trials). In line with Jaeggi et al. (2010), we used the proportion of hits minus false alarms averaged over the auditory and visual modality, averaged over all experimental blocks / n-back levels as our dependent variable.

Positive reappraisal ability. We assessed effects of CCT on the process of positive reappraisal using a pen and paper structured autobiographical memory recall procedure, followed by a structured reappraisal procedure. During each phase participants were provided with standardized verbal instructions and a written example illustrating the extent of details that should be provided and the direction of the exercise. In the first phase of this procedure, participants were asked to recall an autobiographic memory of a negative situation and imagine the related sensations, feelings, thoughts, and behaviors to stimulate integration of several types of information in order to promote re-experiencing the negative situation. Next, the participants were to write down this negative situation in a detailed manner. After thoroughly reading this situation, participants had to rate the extent to which the situation was experienced as negative, positive, and arousing at that moment, as well as vividness of the memory using VAS (1 – 100). In the second phase of the reappraisal ability assessment procedure, participants were instructed to formulate an alternative appraisal that would allow them to reflect upon the previously reported situation in a positive manner. Participants were provided a couple of minutes for this assignment and were asked to write down the alternative appraisal of the situation and read it. This was again followed by situation ratings of negativity, positivity, and arousal using VAS. One additional VAS was used to assess the experienced difficulty of positively reappraising the situation. Throughout this procedure, affect was assessed three times (preceding recall of a negative memory, following recall, following reappraisal), using six VAS that were adopted from the Profile Of Mood States (McNair, Lorr, & Dropplemann, 1992) in line with Rossi and Pourtois (2012). Three scales provided a mean estimate of positive affect (Dutch equivalents of ‘energetic’, ‘satisfied’, and ‘happy’; 1 = not at all; 100 = very much), another three scales provided a mean estimate of negative affect (Dutch equivalents of ‘angry’, ‘tense’, and ‘depressed’).

Deployment and efficacy of emotion regulation in daily life. We explored the influence of CCT on emotion regulation in daily life using ESM (Larson & Csikszentmihalyi, 1983). During a period of seven days following training, participants received eight signals a day between 09:00 AM and 09:00 PM. In line with Moberly and Watkins (2008) we used a time-stratified strategy: each day was divided into eight intervals of 90 min, signals were sent at random moments within each of the eight intervals. A reminder signal was sent if no response was given within 15 min following the previous signal. Two consecutive signals were separated by at least 30 min. Using SurveySignal software (see Hofmann & Patel, 2015), each signal was delivered as a text message on the participants' smartphone, containing a link that directed the participant to an online survey that was created using LimeSurvey. Every signal, current affective state was assessed using the six VAS that were also used to check for effects of affect during the positive reappraisal procedure in lab context (energetic, satisfied, happy, angry, tense, depressed). Participants rated their affective state as experienced just before receiving the signal. Two different emotion regulation strategies were assessed ("Since the previous signal, to what extent were you …"), using two items to assess ruminative self-focus ("Focused on feelings", "Focused on problems"; Moberly & Watkins, 2008), and one item to assess positive appraisal ("Focused on a positive meaning"). The order of affect items and emotion regulation items was randomized per participant and signal. Participants responded by entering a score ranging from 1 (for affect items and emotion regulation items: not at all) to 100 (affect items: very much; emotion regulation items: almost all of the time). Ratings of emotion regulation always related to the period since the previous signal that was responded to, except for the very first signal of the ESM procedure, which related to the period since waking up.

Procedure

As illustrated in Figure 1, after giving informed consent participants completed self-report questionnaires (BDI-II-NL, RRS-NL-EXT, RPA-NL, CERQ, RS, PANAS), followed by a baseline assessment of cognitive control (dual n-back task; Time 1). Next, participants received instructions and a manual concerning the training procedure. Participants then performed 10 online training sessions over a period of 14 days, completing maximum one session a day. Depending on the subject number that was entered, participants either received the CCT or sham training. Participants then returned to the lab for a post-training assessment (Time 2) of mood (PANAS) and cognitive control (dual n-back task). Moreover, the ability of positive reappraisal of a previous negative event was examined during this session. Given that the assessment of ability to reappraise contains the recall of a negative autobiographical memory, participants were also instructed to recall a positive memory before ending the second lab session. Next, participants were registered in SurveySignal, received instructions concerning the ESM procedure, and a manual containing clear definitions of the items. One day following registration, daily fluctuations in affect and emotion regulation were assessed (eight signals a day between 09:00 AM and 09:00 PM) during a period of seven days. Upon completion of the experience sampling phase, participants were re-invited to the faculty for an oral and written debriefing as well as reimbursement.

Results

Group Characteristics

Eighty-three subjects participated to the baseline assessment of this study of which 61 adequately completed training (CCT: n = 29; sham: n = 32).[2] Descriptive information for both training groups can be found in Table 1. Both groups did not differ significantly at baseline concerning age (CCT: M = 21.59, SD = 2.87; sham: M = 21.19, SD = 2.07; $t(59) = 0.63$, p = .53) or gender distribution (male/female; CCT: 4/25; sham: 5/27; $\chi^2(1, n = 61) = 0.04$, p = .84). However, there were marginally significant baseline group differences in self-reported resilience levels ($t(59) = 1.92$, p = .06) and negative mood state ($t(45.68) = 1.74$, p = .09), both in favor of the sham group (see Table 1). Importantly, both groups did not differ concerning the amount of depressive symptomatology or self-reported use of adaptive and maladaptive emotion regulation strategies (all ts < 1.37). At the post-training lab assessment mood was re-assessed, allowing us to check for the influence of group differences in mood state on performance on the cognitive control assessment task (dual n-back). However, both groups did not differ in self-reported levels of positive affect or negative affect following training (all ts < 1.09). Analyses of the effects of training (Hypothesis 2 and 3) were based on the subsample of 61 participants that successfully completed training. As individual differences play an important role in cognitive task performance and the current study used unselected undergraduate students, we controlled for baseline levels of cognitive control when exploring transfer effects on the dual n-back task. Correlational analyses concerning baseline cognitive control and baseline self-reported emotion regulation (Hypothesis 1, $n = 75$) were based on the sample of 83 participants from which 8 outliers ($D > 4 / n$; Bollen & Jackman, 1990) were excluded based on Cook's *D* (calculated using the subscales of the emotion regulation self-report questionnaires).

Cognitive Control and Emotion Regulation at Baseline: Cross-sectional Data

We explored the association between baseline levels of cognitive control and self-reported emotion regulation using Pearson's correlations ($n = 75$). As expected, this approach revealed significant associations and tendencies indicating that reduced cognitive control was related to the use of maladaptive emotion regulation strategies such as brooding (RRS Brooding: $r = -.27$, $p < .05$), rumination (CERQ Rumination: $r = -.25$, $p < .05$), self-blame (CERQ Self-Blame: $r = -.32$, $p < .01$), and catastrophizing (CERQ Catastrophizing: $r = -.24$, $p < .05$). Participants with reduced cognitive control also showed the tendency to respond to positive affect with dampening (RPA Dampening: $r = -.23$, $p = .052$). In contrast, better baseline cognitive control was positively related to – or showed a tendency towards – adaptive emotion regulation strategies such as acceptance (CERQ Acceptance: $r = .24$, $p < .05$), positive refocusing (CERQ Positive Refocusing: $r = .24$, $p < .05$), and putting into perspective (CERQ Putting Into Perspective: $r = .22$, $p = .063$; all other *r*s < .15). In sum, participants with higher levels of baseline cognitive control showed the tendency to report deploying more adaptive emotion regulation strategies in general (CERQ Compound Adaptive: $r = .22$, $p = .064$), whereas maladaptive emotion regulation in general was negatively related to cognitive control (CERQ Compound Maladaptive: $r = -.35$, $p < .01$).

Training Task Process Measures

In accordance with previous studies, median ISI scores per session were used to assess progress on the PASAT. The same approach was used for the sham training task. However, as both tasks differ, we performed two separate Repeated Measures ANOVA's to explore whether progress was made in both groups, as shown by a decrease in ISI over Time (10 sessions). As expected, both groups showed a significant increase in performance over time (CCT: $F(9, 20) = 38.49$, $p < .001$, $\eta_p^2 = .95$; sham: $F(9, 23) = 6.55$, $p < .001$, $\eta_p^2 = .72$; see Table 2 for mean ISI and accuracy rates).

Independent samples *t*-tests were used to explore group differences on process measures of training task experience (average VAS mood ratings and thought processes throughout and following training sessions; see Table 3). This approach revealed that participants from the CCT group showed the tendency to report higher levels of frustration following completion of a training session compared with participants from the active control condition, $t(49.27) = 1.86$, $p = .07$, $d = .46$, 95% CI [-0.55, 13.79]. Both groups did not differ concerning the other mood ratings, nor did they differ concerning the amount of experienced negative thoughts throughout training or experienced task competence (all *t*s < 1.26).

Effects of Training

Cognitive Control.

In line with previous work indicating the importance of taking into account individual differences in cognitive functioning when exploring cognitive transfer (Jaeggi, Buschkuehl, Shah, & Jonides, 2014; Whitlock, McLaughlin, & Allaire, 2012), our data suggests that baseline cognitive control performance forms an important predictor of increase in cognitive control following CCT ($\beta = -.54$, $p < .01$; Δ dual n-back = n-back post-training – n-back pre-training; a positive score is indicative for an increase in cognitive control following training).

This suggests that participants showing less cognitive control at baseline – as indicated by worse performance on the dual n-back task – benefit most from CCT. Accordingly, we explored effects of CCT on cognitive control levels using an univariate ANCOVA with post-training dual n-back score as dependent variable and Group (CCT vs. sham) as categorical independent variable, while controlling for baseline levels of cognitive control (covariate n-back pre-training). This approach revealed a significant effect of covariate baseline cognitive control ($F(1, 58) = 27.51$, $p < .001$, $\eta_p^2 = .32$) and a marginal significant effect of Group ($F(1, 58) = 3.52$, $p = .066$, $\eta_p^2 = .06$). Post-hoc paired samples *t*-tests indicate that both the CCT (Pre-training: $M = 0.71$, $SD = 0.49$; Post-training: $M = 1.04$, $SD = 0.49$; $t(28) = 3.39$, $p < .01$, $d = .63$, 95% CI [0.13, 0.54]) and sham group (Pre-training: $M = 0.62$, $SD = 0.58$; Post-training: $M = 0.79$, $SD = 0.55$; $t(31) = 2.05$, $p = .05$, $d = .36$, 95% CI [0.00, 0.33]) showed a significant increase in cognitive control over time. However, independent samples *t*-tests indicate that whereas both groups did not differ at baseline ($t(59) = 0.66$, $p = .51$, $d = .17$, 95% CI [-0.18, 0.37]), the CCT group showed a tendency to perform better following training ($t(59) = 1.94$, $p = .057$, $d = .48$, 95% CI [-0.01, 0.53]); see Figure 2).

Positive Reappraisal Ability.

Participants were instructed to recall a negative autobiographical memory, which was rated on vividness. An independent *t*-test indicates that both groups did not differ in vividness of recalled negative memory (CCT: $M = 77.42$, $SD = 19.45$; sham: $M = 82.72$, $SD = 20.16$), $t(59) = 1.04$, $p = .30$, $d = .27$, 95% CI [-4.87, 15.47]. Participants were then instructed to reappraise and rate the ease of this process. In contrast to our hypothesis, both groups did not differ concerning experienced ease of positive reappraisal (CCT: $M = 57.10$, $SD = 23.90$; sham: $M = 53.49$, $SD = 27.26$), $t(59) = 0.55$, $p = .59$, $d = .14$, 95% CI [-9.59, 16.81]. The recalled negative autobiographical memory was rated preceding and following instructed reappraisal on the extent to which it was experienced as being negative, positive, and arousal eliciting. Three Mixed 2 (Time: pre-reappraisal vs. post-reappraisal) x 2 (Group: CCT vs. sham) ANOVA's revealed a main effect of Time for each of the three analyses, indicating that the negative autobiographical memory of the situation was rated as being less negative ($F(1, 59) = 92.44$, $p < .001$, $\eta_p^2 = .61$), more positive ($F(1, 59) = 86.70$, $p < .001$, $\eta_p^2 = .60$), and less arousal eliciting ($F(1, 59) = 75.01$, $p < .001$, $\eta_p^2 = .56$) following instructed positive reappraisal. However, in contrast to our expectations we did not find effects of Group or significant Time x Group interactions (all *F*s < 1.83; see Table 4 for descriptives).[3, 4]

Deployment and Efficacy of Emotion Regulation in Daily Life.

Participants responded to 87.73% of the daily assessments of affect and emotion regulation, with an average latency of 4 min 58 sec.[5] To examine *deployment* of rumination and positive appraisal in daily life in response to positive and negative affective states, we used a multilevel regression modeling approach. At level 1, we modeled how affect at time t-1 in individual j, denoted below as $X_{t-1,j}$, predicted the emotion regulation strategy (i.e., the extent to which participants engaged in rumination or positive appraisal since the previous signal) at time t in individual j, denoted as Y_{tj}:

$$Y_{tj} = \beta_{0j} + \beta_{1j} X_{t-1,j} + e_{ij}$$

To disentangle the within-subject effect from the between-subject effect, subject-centered predictors were used (Bolger & Laurenceau, 2013). At level 2, we modeled how the subject-specific intercept and slope were a function of training (CCT or sham) that participant j received:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} CCT_j + b_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} CCT_j + b_{1j}$$

A bivariate normal distribution was assumed for the random effects b_{0j} and b_{1j}, with an unstructured covariance, and a multivariate normal distribution for the residuals e_{ij} with an autoregressive AR(1) structure to account for the temporal correlation within an individual. Such multilevel model was fitted separately for every combination of affect (positive/negative) and emotion regulation strategy (rumination/positive appraisal). The estimated parameters of interest γ_{10} and γ_{11} are presented in Table 5. We found a significant positive association between negative affect and rumination (γ_{10} = 0.18, SE = 0.06, $p < .01$). That is, higher levels of negative affect within a subject reported at time t-1 were associated with higher rumination reported at time t. Similarly, we found a negative association between positive affect and rumination (γ_{10} = -0.13, SE = 0.03, p = .001): higher levels of positive affect within a subject reported at time t-1 were associated with lower rumination reported at time t. There was a marginal significant effect of Group for the negative association between positive affect and rumination ($\gamma11$ = 0.09, SE = 0.05, p = .06). For the sham training group lower levels of positive affect were related to a stronger engagement in subsequent ruminative thinking (β = -.13), whereas levels of positive affect were less predictive for rumination in the CCT condition (β = -.04). None of the other associations were significantly different between both training groups (all ps > .73).

Next, to examine the extent to which use of the emotion regulation strategy reported at time t-1 was associated with change in affect from time t-1 to time t (i.e., *efficacy*), we again used multilevel modeling. At level 1, we modeled how affect at time t (denoted as Y_{tj}) was predicted by using an emotion regulation strategy at time t-1 (denoted as $X_{t-1,j}$), while controlling for the affect at time t-1 (denoted as $Y_{t-1,j}$), i.e.:

$$Y_{tj} = \beta_{0j} + \beta_{1j} X_{t-1,j} + \beta_{2j} Y_{t-1,j} + e_{ij}$$

while at level 2 we again modeled those intercepts and slopes as a function of training:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\, CCT_j + b_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}\, CCT_j + b_{1j}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}\, CCT_j + b_{2j}$$

The estimated parameters of interest γ_{10} and γ_{11} are presented in Table 6. We found a significant positive association between rumination and negative affect ($\gamma_{10} = 0.22$, $SE = 0.03$, $p < .001$). That is, higher levels of rumination within a subject reported at time t-1 were associated with higher negative affect reported at time t, after controlling for negative affect at time t-1. Similarly, we found a negative association between positive appraisal and negative affect ($\gamma_{10} = -0.09$, $SE = 0.03$, $p < .01$), a negative association between rumination and positive affect ($\gamma_{10} = -0.17$, $SE = 0.04$, $p < .001$), and a positive association between positive appraisal and positive affect ($\gamma_{10} = 0.21$, $SE = 0.03$, $p < .001$); each time controlling for the affect reported at time t-1. None of these associations were significantly different between both training groups (all *p*s > .13).

Discussion

Previous studies indicate the importance of cognitive control for emotion regulation processes. The aims of the current study were twofold: (1) we examined the relationship between cognitive control and self-reported emotion regulation cross-sectionally, and (2) we examined effects of CCT on reappraisal ability and emotion regulation processes in daily life (i.e., deployment and efficacy of rumination and positive appraisal) to further unravel the causal role of cognitive control in emotion regulation. Given the proposed role of adaptive emotion regulation in resilience and mental well-being, we set out to explore whether CCT holds potential in increasing resilience in a convenience sample.

First, the cross-sectional findings indicate a positive association between baseline cognitive control and adaptive emotion regulation strategies assessed using self-report questionnaires at baseline. Moreover, maladaptive emotion regulation strategies show a negative association with baseline cognitive control. These findings are in line with theoretical frameworks concerning the role of cognitive control in emotion regulation (Joormann & D'Avanzato, 2010; Joormann & Vanderlind, 2014), suggesting that impaired cognitive control does not merely increase the use of maladaptive emotion regulation strategies, but are also related to reduced resilience via decreased use of adaptive emotion regulation strategies. However, these cross-sectional findings do not allow to draw conclusions on the causal nature of this relation. Accordingly, a second aim of this study was to explore effects of a cognitive control manipulation – using CCT that has previously shown to be effective in reducing rumination and depressive symptomatology in at-risk undergraduates (e.g., Hoorelbeke, Koster, et al., 2015) and clinically depressed samples (e.g., Siegle et al., 2007) – on reappraisal ability in lab context and emotion regulation in daily life. For this purpose, effects of CCT were compared to an active control training.

Throughout 10 online training sessions both groups showed a significant increase in training task performance. Importantly, compared to the active control group, participants in the CCT group performed marginally significant better on the dual n-back task following training. This transfer effect indicates that CCT was successful in improving working memory functioning, but only when baseline characteristics in cognitive control ability were controlled for. It should be noted that specific sample characteristics in combination with the operationalization of our active control condition (an attention training) could have limited this transfer effect. That is, previous studies have typically explored effects of adaptive PASAT training in at-risk undergraduate students or clinically depressed patient samples. In contrast, the current study explored effects of CCT in an *unselected* undergraduate student sample in order to explore the potential of CCT in increasing predictors of resilience and mental well-being in general (i.e., adaptive emotion regulation). However, at-risk samples and patient samples are known to show lower levels of cognitive control compared to healthy populations (e.g., Beckwé, Deroost, Koster, De Lissnyder, & De Raedt, 2014; Joormann, 2004), and ceiling effects could pose a problem when demonstrating transfer to cognitive tasks in undergraduate student samples (Hoorelbeke, Koster, et al., 2015; Onraedt & Koster, 2014). Indeed, our findings suggest that it is important to take into account individual differences in baseline cognitive control when exploring transfer effects of CCT on cognitive tasks in an unselected student population. That is, lower baseline cognitive control was related to a stronger increase in cognitive control throughout CCT.

Although our findings suggest that CCT can be used to increase cognitive control in unselected undergraduate students, this did not affect adaptive emotion regulation processes. After training, groups did not differ in self-reported experienced ease of reappraising a negative autobiographical memory in a lab context, nor did CCT influence the effects of this instructed reappraisal exercise on emotional ratings of the situation. This finding might be due to demand effects, given that both groups were explicitly instructed to positively reappraise the situation. However, both groups also did not report differential effects of the reappraisal exercise on affective state. Second, on our daily life measures, deployment of positive appraisal predicted a general increase in positive affect and a reduction in negative affect, indicating the importance of adaptive emotion regulation strategies for mental well-being. However, both training groups did not significantly differ in the deployment and efficacy of positive appraisal in daily life. Thus, CCT targeting working memory functioning – at least in its current operationalization and this specific population – did not increase resilience and mental well-being via stimulating the deployment, ability and efficacy of positive (re-)appraisal.

In contrast to the null-findings for adaptive emotion regulation, CCT did exert a small effect on maladaptive emotion regulation in this population, which was observed at the level of deployment of rumination in response to reduced positive affect. That is, participants of the sham group showed a stronger tendency to respond with rumination to low levels of positive affect, whereas levels of positive affect were less predictive for future rumination in the CCT group. This seems to indicate that increasing cognitive control might serve to prevent further mood deterioration when experiencing lower levels of positive affect given that – in line with the Response Styles Theory of depression (Nolen-Hoeksema & Morrow, 1991) and previous ESM studies (e.g., Brans, Koval, Verduyn, Lim, & Kuppens, 2013) – our ESM efficacy measures indicate that rumination has detrimental effects on affect. That is, rumination predicts higher future levels of negative affect and reduced positive affect. This process might elucidate previous findings in at-risk undergraduate students showing a buffering effect of CCT compared to a sham training on positive and negative thought processes following a general decline in positive affect during a stress induction procedure (Hoorelbeke, Koster, et al., 2015). In this light, the latter could then have resulted in further increased negative affect in the sham condition compared to the CCT.

In line with the literature, the effects observed in this study thus demonstrate that: (1) Cognitive control shows a positive association with adaptive emotion regulation and a negative association with maladaptive emotion regulation strategies, linking cognitive control impairments to increased vulnerability for depression and reduced resilience; (2) Cognitive control can be trained by performing an adaptive and engaging computer task as indicated by transfer to another measure of working memory functioning; (3) Inducing cognitive control lowers participants’ risk to respond with rumination when experiencing low levels of positive affect, which is in line with previous work in at-risk and MDD patient samples indicating that CCT shows potential as a preventive intervention for depression (Hoorelbeke, Koster, et al., 2015; Siegle et al., 2014); and (4) Overall effects were limited and did not show transfer to deployment, ability, or efficacy of adaptive emotion regulation.

The current findings of divergent effects of CCT on adaptive versus maladaptive emotion regulation could indicate that cognitive control plays a stronger role in maladaptive emotion regulation compared with adaptive emotion regulation. Cognitive control is crucial to efficient working memory functioning, where a lack of cognitive control places one at risk to persevere in habitual maladaptive strategies. However, it is possible that in absence of these habitual maladaptive processes, cognitive control plays a less determining role in adaptive emotion regulation in daily life. As a result, where cognitive control impairments have shown to disrupt healthy emotion regulation, it could be that in healthy functioning individuals stimulating cognitive control does not improve emotion regulation. This is in line with findings suggesting that difficulties with reappraisal are only present in severely depressed patients (e.g., Dillon & Pizzagalli, 2013) and may imply that CCT does not increase resilience or well-being through adaptive emotion regulation in samples that are not characterized by cognitive control deficits. Furthermore, context specific features may also influence the extent to which certain adaptive emotion regulation strategies rely on cognitive control processes (e.g., stressful situations). An alternative explanation is that, although increased working memory functioning may contribute to adaptive emotion regulation, a brief training period may not be sufficient to demonstrate immediate effects on deployment and efficacy of adaptive emotion regulation strategies in daily life. That is, in order to overcome habitual use of emotion regulation strategies (i.e., following years of reinforcement of deployment of emotion regulation strategies), more extensive training might be necessary, possibly combined with additional interventions targeting emotion regulation to stimulate cognitive change. Given the impact of psychopathology on cognitive development (e.g., Vijayakumar et al., in press), this might especially be the case in populations experiencing early onset of depressive symptoms.

Our study is the first to combine CCT with ESM, allowing to explore effects of CCT on emotion regulation processes in daily life, adding to the ecological validity of our findings. This combination offers an important advantage as it provides insights in the potential mechanisms underlying the relation between cognitive control, emotion regulation, and affect. Furthermore, to our knowledge this study is the first to explore effects of a multisession CCT targeting working memory functioning on adaptive as well as maladaptive emotion regulation strategies, extending previous findings. Related to adaptive emotion regulation processes, an important feature of this study is its aim to explore the effectiveness of CCT as an intervention to increase functioning and well-being in a general (student) population, whereas previous work has typically focused on emotional disfunctioning, either from a preventive (Hoorelbeke, Koster, et al., 2015) or a curative stance (e.g., Siegle et al., 2014).

However, several limitations should be noted. First, we experienced substantial drop-out. Although the excluded participants did not significantly differ from the included participants concerning our main variables of interest, small baseline group differences occurred for depressive symptomatology and catastrophizing, providing a potential source of sampling bias. Furthermore, given the importance of task engagement for training outcome (Siegle et al., 2014), future studies should invest in methods that might increase training retention (e.g., Hoorelbeke, Faelens, Behiels, & Koster, 2015). Second, positive reappraisal ability was assessed using a structured pen and paper procedure. This might have reduced the extent to which the reappraisal exercise placed demands on cognitive control processes. Furthermore, given that this study included healthy participants and the time to reappraise was not measured, we think the absence of a group difference could be attributed to a ceiling effect with all participants being able to reappraise. Third, we did not include a pre-training ESM period which does not allow to compare pre- and post-training differences in emotion regulation processes. Instead, we relied on emotion regulation questionnaires at baseline, indicating no significant group differences. Fourth, effects reported in this study are constricted to a seven-day period following training. Finally, sample size was limited and, given the exploratory nature of the paper, we did not consider any multiple testing corrections. This may have led to an increase in the number of false positives, but minimizes the risk of missing true effects. Nonetheless, careful interpretation of our findings is warranted, as this study represents a first step that should be replicated using larger samples.

Our study paves an interesting way forward. Future studies should go beyond exploring effects of experimental manipulations on self-report questionnaires or indicators of functioning in lab context. Moreover, future studies could extend the scope of the ESM protocol to other indicators of cognitive emotion regulation at item-level and rely on different outcome measures (other than efficacy and deployment) to assess effects of CCT on the process of emotion regulation. Furthermore, from both a positive psychological and preventive perspective, future studies should not limit their scope to merely exploring effects of interventions on indicators of disfunctioning given that fostering functioning could increase general well-being as well as show transdiagnostic preventive effects.

Summary

The current study explored the role of cognitive control in adaptive and maladaptive emotion regulation, testing the effectiveness of cognitive control training (CCT) in increasing resilience in a general student population. Using experience sampling method, effects of a multisession CCT on adaptive and maladaptive emotion regulation were compared with an active control condition. Baseline cognitive control showed a positive association with self-reported use of adaptive emotion regulation strategies and a negative association with maladaptive emotion regulation strategies. Although CCT showed transfer to working memory functioning, we did not find transfer effects to a lab assessment of positive reappraisal ability, nor to deployment or efficacy of positive appraisal in daily life. Therefore, in contrast to previous studies in at-risk or clinical populations, CCT did not increase resilience in an unselected student population. Concerning maladaptive emotion regulation, we found a buffering effect of training on deployment of rumination in response to low levels of positive affect.

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Table 1

Group characteristics as a function of training condition

	Training condition			
	Cognitive control (*n* = 29)		Sham (*n* = 32)	
	M	*SD*	*M*	*SD*
Depressive symptomatology	8.28	5.79	7.41	6.14
RRS trait rumination	42.41	10.92	42.00	12.74
Brooding	10.17	2.99	9.75	3.45
Reflection	8.59	3.20	8.97	3.81
RPA Self-focus	8.48	2.50	9.37	2.60
RPA Dampening	12.10	4.25	11.16	3.30
RPA Emotion focus	13.62	2.14	13.56	2.50
CERQ Self-blame	10.90	2.99	10.25	2.90
CERQ Acceptance	12.45	3.88	12.84	3.06
CERQ Rumination	12.03	4.21	12.12	4.23
CERQ Positive refocusing	10.14	4.02	10.06	3.55
CERQ Refocus on planning	13.38	3.06	14.41	2.92
CERQ Positive reappraisal	11.86	3.65	12.59	3.31
CERQ Putting into perspective	13.00	4.46	12.66	3.48
CERQ Catastrophizing	6.86	2.77	6.78	2.81
CERQ Blaming others	6.66	2.07	7.06	2.35
Resilience	75.59	8.27	79.59	8.01
Positive affect (baseline)	32.38	5.98	32.38	6.49
Negative affect (baseline)	16.14	5.39	14.13	3.32

Positive affect (post-training)	31.14	5.57	30.06	5.16
Negative affect (post-training)	14.79	4.33	13.72	3.37

Note: RRS = Ruminative Response Scale, RPA = Response to Positive Affect Scale, CERQ = Cognitive Emotion Regulation Questionnaire

Table 2

Training session mean median ISI and accuracy rates as a function of training condition

	Training condition					
	Cognitive control (*n* = 29)			Sham (*n* = 32)		
	M ISI (ms)	*SD ISI*	*M % correct*	*M ISI (ms)*	*SD ISI*	*M % correct*
Session 1	2034	321	55.03	653	154	62.25
Session 2	1631	269	56.83	594	129	61.84
Session 3	1428	299	57.38	563	136	62.47
Session 4	1310	232	58.38	534	123	62.75
Session 5	1207	227	58.62	522	118	63.19
Session 6	1162	241	59.14	508	140	62.75
Session 7	1100	258	59.28	515	137	62.75
Session 8	1048	242	59.28	513	152	62.56
Session 9	1010	244	59.52	516	137	62.97
Session 10	1000	245	60.24	494	122	62.50

Note: ISI = InterStimulus Interval

Table 3

Process measures of training task experience

	Training condition			
	Cognitive control (*n* = 29)		Sham (*n* = 32)	
	M	*SD*	*M*	*SD*
During a training session				
Negative thoughts	39.87	17.39	34.33	18.60
Stressed	60.03	9.83	56.55	15.26
Competence	40.77	10.84	44.41	14.20
Following a training session				
Tense	53.98	12.36	49.94	14.51
Energetic	37.62	12.74	40.22	11.38
Frustrated	57.21	9.66	50.59	17.45
Sad	29.98	18.46	24.56	15.36
Happy	47.29	14.99	49.60	9.73

Table 4

Visual analogue scale ratings throughout the reappraisal procedure

	Training condition			
	Cognitive control (*n* = 29)		Sham (*n* = 32)	
	M	*SD*	*M*	*SD*
Mood ratings				
Positive affect 1	57.05	17.89	52.96	16.95
Negative affect 1	21.70	17.39	19.96	13.96
Positive affect 2	41.91	18.65	37.80	20.14
Negative affect 2	35.97	21.82	35.68	18.43
Positive affect 3	52.12	18.40	52.85	17.39
Negative affect 3	25.85	20.87	22.86	16.95
Situation ratings				
Negativity 1	77.02	18.88	77.49	15.08
Positivity 1	12.50	13.36	17.22	18.50
Arousal 1	75.33	22.33	66.89	27.44
Negativity 2	49.67	24.14	47.78	23.27
Positivity 2	44.10	24.71	44.53	24.68
Arousal 2	51.76	24.88	43.90	27.70

Table 5

Deployment of rumination and appraisal in response to positive and negative affect

	γ_{10} *[95% CI]*	*SE*	*t*	γ_{11} *[95% CI]*	*SE*	*t*
NA → Rumination	0.18 [0.07,0.29]	0.06	3.23**	-0.03 [-0.18,0.13]	0.09	-0.35
NA → Appraisal	0.05 [-0.07,0.17]	0.06	0.90	0.03 [-0.14,0.19]	0.09	0.30
PA → Rumination	-0.13 [-0.19,-0.06]	0.03	-3.97***	0.09 [-0.01,0.18]	0.05	1.86
PA → Appraisal	0.07 [-0.03,0.17]	0.05	1.40	-0.02 [-0.16,0.13]	0.07	-0.22

Note 1: NA = negative affect, PA = positive affect

Note 2: * = $p < .05$, ** = $p < .01$, and *** = $p < .001$

Table 6

Efficacy of rumination and appraisal

	γ_{10} *[95% CI]*	*SE*	*t*	γ_{11} *[95% CI]*	*SE*	*t*
Rumination → NA	0.22 [0.15,0.28]	0.03	6.41***	0.07 [-0.02,0.17]	0.05	1.50
Appraisal → NA	-0.09 [-0.14,-0.03]	0.03	-3.03**	-0.05 [-0.13,0.03]	0.05	1.14
Rumination → PA	-0.17 [-0.24,-0.09]	0.04	-4.59***	-0.02 [-0.13,0.08]	0.05	-0.39
Appraisal → PA	0.21 [0.15,0.27]	0.03	6.88***	0.01 [-0.08,0.10]	0.04	0.82

Note 1: NA = negative affect, PA = positive affect

Note 2: * = $p < .05$, ** = $p < .01$, and *** = $p < .001$

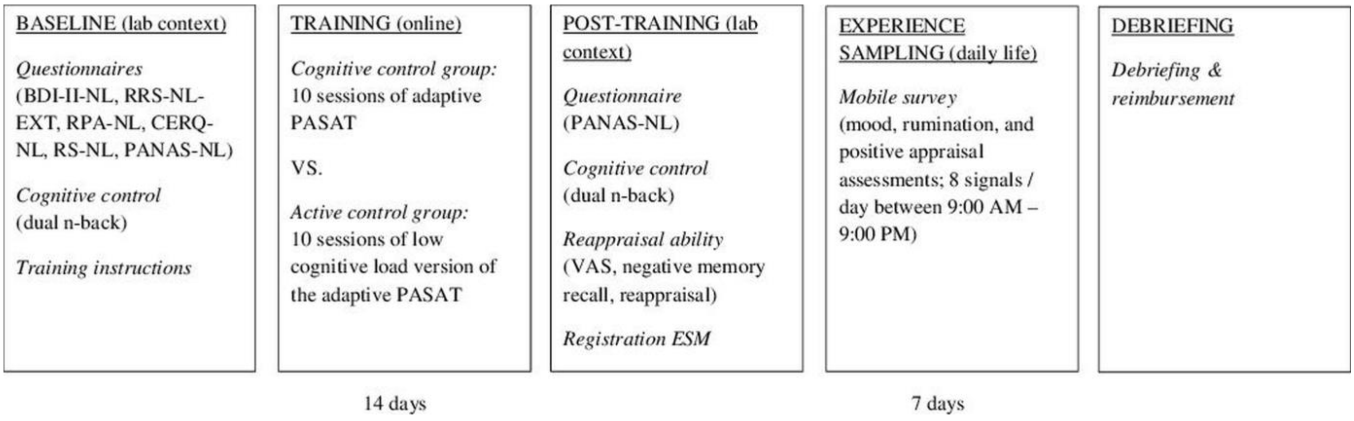

Figure 1. Procedure

Note: BDI = Beck Depression Inventory, RRS = Ruminative Response Scale, RPA = Response to Positive Affect Scale, CERQ = Cognitive Emotion Regulation Questionnaire, PANAS = Positive and Negative Affect Schedule, PASAT = Paced Auditory Serial Addition Task, VAS = visual analogue scale, ESM = Experience Sampling Method

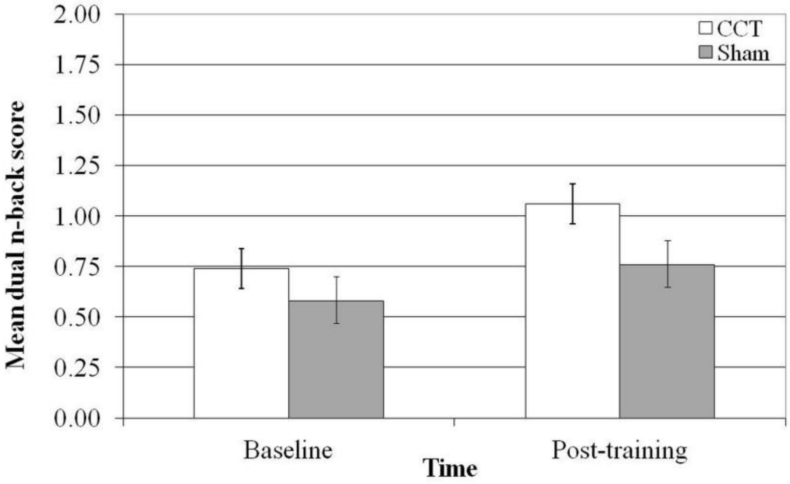

Figure 2. Increase in cognitive control (*M* & *SE*).

Note: CCT = cognitive control training

Footnotes

(1) Emotions have been conceptualized to mainly differ from mood states concerning duration, the presence of a specific object that precedes the onset of an emotion, and related to these objects, the extent to which they give rise to a response tendency (Gross, 1998). However, the way emotion regulation has typically been studied using ESM does not allow to differentiate between emotion and mood as it provides no information concerning the object and duration of a certain affective state. As a result, when it pertains to ESM-measures, we refer to 'affective states' rather than 'emotions'.

(2) Excluded participants did not differ from included participants concerning our variables of interest at baseline (cognitive control, depressive rumination / brooding, and positive reappraisal; *t*s < 1.36). However, excluded participants did report higher baseline levels of depressive symptomatology ($p < .05$; excluded participants: *M* = 11.45, *SD* = 5.88; included participants: *M* = 7.82, *SD* = 5.94), which was accompanied by increased catastrophizing ($p < .05$; excluded participants: *M* = 8.59, *SD* = 3.47; included participants: *M* = 6.82, *SD* = 2.77) and a tendency to report more dampening of positive affect ($p = .054$; excluded participants: *M* = 13.50, *SD* = 4.19; included participants: *M* = 11.61, *SD* = 3.78). Although the current study sought out to explore effects of CCT in healthy / unselected undergraduate students, this finding indicates that future studies targeting (sub)clinically depressed populations and other risk groups should take into account population specific threats for training retention in order to avoid sampling bias (e.g., adding a daily reminder signal and psycho-education; Hoorelbeke, Faelens, et al., 2015).

(3) Participants rated mood preceding (VAS1) and following (VAS2) the recall of a negative autobiographical memory, as well as following positive reappraisal (VAS3; see Table 4 for descriptives). Effects of recalling a negative autobiographical memory on positive

and negative affect were assessed using two 2 (Time: VAS1 vs. VAS2) x 2 (Group: CCT vs. sham) Mixed ANOVA's. Following the recall of a negative autobiographical memory, both groups showed a decrease in positive affect as shown by a main effect of Time ($F(1, 59) = 52.57$, $p < .001$, $\eta_p^2 = .47$; all other *F*s < 0.93). For ratings of negative affect, a Mixed ANOVA revealed a general increase in negative affect ($F(1, 59) = 43.58$, $p < .001$, $\eta_p^2 = .43$; all other *F*s < 0.11). Similarly, we used two 2 (Time: VAS2 vs. VAS3) x 2 (Group CCT vs. sham) Mixed ANOVA's to assess effects of positive reappraisal of a negative memory on positive and negative affect. This revealed a general increase in positive affect following reappraisal ($F(1, 59) = 63.64$, $p < .001$, $\eta_p^2 = .52$; all other *F*s < 2.34) as well as a general decrease in negative affect ($F(1, 59) = 41.50$, $p < .001$, $\eta_p^2 = .41$; all other *F*s < 0.58).

(4) Controlling for changes in positive (Δ positive affect during recall = positive affect VAS1 – positive affect VAS 2; Δ positive affect during reappraisal = positive affect VAS2 – positive affect VAS 3; a positive score is indicative for a decrease in positive affect) and negative affect (Δ negative affect during recall = negative affect VAS1 – negative affect VAS 2; Δ negative affect during reappraisal = negative affect VAS2 – negative affect VAS3; a negative score is indicative for an increase in negative affect) following recall of the negative memory did not influence these null-findings, neither did controlling for vividness of the negative autobiographical memory.

(5) Participants from the CCT group ($n = 29$) responded to 87% of the SurveySignal messages via their smartphones. In total, 86% of all sent signals were followed by completion of the questionnaire within the specified time-frame for the CCT condition. Participants of the active control condition ($n = 32$) showed similar response- and questionnaire completion rates: they responded to 88% of the signals, providing all necessary data in most of the cases (87%). On average, participants of the active control condition provided a response 4 min 51 sec (*SD* = 1 min 52 sec) after the text message was sent, whereas this was 5 min 14 sec (*SD* =

1 min 25 sec) for the CCT condition. Importantly, both groups did not significantly differ concerning mean response time as indicated by an independent samples *t*-test, $t(57.18) = 0.93$, $p = .35$.