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Trait Rumination Moderates the Effect of Executive Control Training

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Abstract

The ability to regulate emotions during times of stress plays an important role in risk for psychopathology and resilient responding. Individual differences in executive control may critically affect this ability. Training executive control may therefore improve emotional adjustment to stressful events. The aims of the current study were to examine whether executive control training affects biological stress response and to investigate whether trait rumination moderates the training effect. Using a student sample (N = 69), two versions of the n-back task were administered, one with neutral and one with affective stimuli. The training groups were compared to a control condition on changes in salivary cortisol following a stress induction. Results indicate that trait rumination moderated the training effects. For participants low on trait rumination, condition assignment had no effect on cortisol reactivity. For participants high on trait rumination, however, the training compared to the control condition resulted in diminished cortisol reactivity. These results emphasize the importance of examining moderators when investigating the effects of executive control training.

Keywords: Executive control training; Rumination; Cortisol reactivity; Executive control; Working memory

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Introduction

When confronted with stressful life events, the ability to effectively regulate the ensuing affect varies greatly among individuals. Indeed, individual differences in stress recovery and emotion regulation are thought to be key factors in explaining risk for psychopathology versus resilient responding in the context of stressful life events (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Bonanno, Papa, Lalande, Westphal, & Coifman, 2004). Rumination has been identified as a particularly maladaptive response to stressful events and negative affect (for a review, see Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Susan Nolen-Hoeksema's groundbreaking research on the use of this emotion regulation strategy has demonstrated that people who are prone to ruminate are at significantly heightened risk for developing not only depression but also other internalizing and even some externalizing disorders. Rumination has been defined as a cognitive response to negative events characterized by a passive focus on one's negative internal state. Recent work on rumination has further demonstrated that deficits in executive control may underlie ruminative response tendencies emphasizing a close link between individual differences in cognitive processes and difficulties in emotion regulation (Davis & Nolen-Hoeksema, 2000).

Executive control is broadly defined as the set of cognitive processes employed to execute goal-directed behavior (Banich, 2009; Miller, 2000). The activation of mood-congruent material in working memory occurs with the experience of emotion. Emotion regulation, therefore, requires that individuals can exert control over the content of working memory in accordance with their goals. The idea that the ability to regulate emotion is reliant on such basic cognitive processes is supported by the finding that executive control and emotion regulation rely on the same neural systems (for a review, see Ochsner & Gross, 2005). De Lissnyder et al. (2012) provided additional support for this link by demonstrating that individuals with executive control deficits displayed increased levels of rumination following a stressful period of life. Together, the evidence suggests that executive control is associated with the ability to regulate emotions; however, it does not establish whether emotion regulation and executive control are causally linked.

This causal relation can be established, however, by experimentally manipulating executive control. For example, training on the n-back task, a measure of executive control which requires updating information in working memory,

has led to improvements in executive control (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). Some replications of the study by Jaeggi et al. (2008) produced null results; however, there is substantial support for the finding that executive control can be experimentally improved (for a review, see Morrison & Chein, 2011). Such studies, however, only examined executive control in the context of neutral material and did not investigate effects of this training in a context requiring emotion regulation.

Schweizer, Grahn, Hampshire, Mobbs, and Dalgleish, (2013) were the first to demonstrate that the ability to modulate an emotional response can be enhanced by improvements in executive control. These authors employed an executive control training task, which was completed daily for 20 days, to examine the hypothesized link between executive control and emotion regulation. During the training period, participants in the training condition completed an n-back task with stimuli consisting of faces expressing negative and neutral emotions. The control condition completed a placebo training task which required participants to match shapes. Following the training period, the two conditions were compared on emotion regulation ability by assessing change in self-reported negative emotion while watching neutral and distressing film clips. Results indicated that the ability to down-regulate negative emotion while viewing distressing film clips was improved in the training condition, compared to the control condition. Further, improvement in this emotion regulation ability was associated with increased recruitment of frontoparietal control regions. A central aim of the current study was to extend this work by examining whether biological measures of stress reactivity are affected by executive control training.

Importantly, studies show that there is great variability in performance on executive control tasks, such as the n-back, and that individuals vary in the degree to which they improve on these tasks (Jaeggi, Buschkuehl, Jonides, & Shah, 2011). Therefore, examining who may benefit from such training is an important next step. Individuals vulnerable to psychopathology who demonstrate executive control deficits as well as a maladaptive style of emotion regulation may be most likely to benefit from the effects of executive control training on emotional responding. As outlined above, the work by Susan Nolen-Hoeksema demonstrated that rumination is an important transdiagnostic marker of vulnerability to psychopathology. In addition, trait rumination is associated with maladaptive responses to stressors including increased levels of stress hormones following a laboratory stress induction (Zoccola & Dickerson, 2012) and trait rumination has also been associated with deficits in executive control (Bernblum & Mor, 2010; Joormann & Gotlib, 2008). Thus, trait rumination is ideally suited to investigate as a moderating factor in the effects of executive control training.

Consistent with previous research (Schweizer et al., 2013), the current study employed executive control training using a variation of the n-back task. Whereas Schweizer et al. (2013) included only one training condition, which contained affective stimuli, the current study included two training conditions, one using affective stimuli and one using neutral stimuli, which were compared to a control condition. The two training conditions were incorporated into the current study to explore whether the inclusion of affective stimuli plays a role in changing emotional responding following executive control training. A primary aim of this study was to extend the findings by Schweizer et al. (2013) by assessing the effect of training on changes in stress response following exposure to a stressor, measured by subjective ratings as well as salivary cortisol levels. We hypothesized that compared to participants in the control condition, participants in the training conditions would demonstrate a diminished cortisol stress response. We further examined whether the effect of training on stress response varies with individual differences in trait rumination. We hypothesized that rumination would moderate the relation between training and stress response. Specifically, we hypothesized that for individuals who tend to ruminate, training would result in an attenuated subjective and biological response, compared to participants in the control condition.

Method

Participants

Sixty-nine undergraduate students participated in this study in exchange for course credit. Participants were randomly assigned to one of three conditions: affective executive control training (affective EC training; n = 23), neutral executive control training (neutral EC training; n = 23), and affective control (n = 23).

Self-Report Measures

Ruminative Responses Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003).

The RRS is a 22-item scale that assesses the tendency to respond to stressful events and negative mood states with rumination. The RRS contains two subscales: brooding (RRS-B) and reflective pondering (RRS-R). All items are scored on a Likert-scale ranging from almost never (1) to almost always (4). Consistent with previous evaluations (Nolen-Hoeksema, Larson, & Grayson, 1999; Treynor et al., 2003), the RRS demonstrated good reliability in our sample (α = .94).

Beck Depression Inventory, Second Edition (BDI-II; Beck, Steer, & Brown, 1996).

The BDI-II is a 21-item self-report measure of depression severity. Participants rate each item on a scale ranging from 0 to 3. In our sample, the BDI-II demonstrated good reliability (α = .93), which is consistent with previous demonstrations of acceptable reliability and validity (Beck et al., 1996).

The Shipley Vocabulary Test (Shipley, 1940).

The Shipley is a 40-item measure of crystallized intelligence. For each item, participants are instructed to decide which of four words are most similar to a prompted word. The Shipley correlates with other measures of crystallized intelligence (r = 0.66; Matthews, Orzech, & Lassiter, 2011). Because intelligence is correlated with measures of the updating component of executive control (Friedman et al., 2006), the Shipley was included in this study to assess for differences in mean intelligence among conditions.

Anxiety ratings.

To assess stress response, participants' anxiety was measured before and after the stress induction using eleven-point Likert-scales, ranging from not at all (0) to very much (10). Ratings for *anxiety*, *nervousness*, and *tension* were combined to form a composite measure of anxiety (α = .71).

Cortisol Questionnaire.

Participants completed a questionnaire assessing various factors, including sleep duration, caffeine intake, nicotine use, and medication use, each of which may affect cortisol levels.

Training Tasks

Tasks.

The n-back task, which is a measure of the updating component of executive control (Chatham et al., 2011; Kirchner, 1958) was adapted for use in each of the three conditions. In each task, participants completed a series of trials consisting of a word presented for 2000 ms followed by a blank screen presented for 2000 ms. All participants completed a total of 19 blocks of 24 trials which resulted in a total of 456 trials. For each trial, participants were instructed to identify target trials, by pressing a key labeled with a red dot. In the affective EC training and neutral EC training tasks, target trials occurred when a word matched the word presented n trials previously. At the beginning of each block, a message appeared indicating whether n was equal to one, two, three, or four for the upcoming block of trials. A sample of affective EC training trials when n = 2 is presented in Figure 1. In the affective control condition, participants were informed at the beginning of each block that target trials were those that contained a certain word. Therefore, the affective control task relied little on participants' ability to update information in working memory. In each of the three tasks, half of all trials were target trials.

The affective EC training and neutral EC training tasks were designed to train the updating component of executive control. To achieve this, each task was adaptive, such that it became more or less difficult based on the performance of the participant. This type of task ensured that all participants had the potential to improve regardless of their initial ability (Dahlin, Bäckman, Neely, & Nyberg, 2009). Participants were not informed that the

task was adaptive, but were informed that the number for *n* would change throughout the task. All participants started on a block with *n* equal to one. After the first block, the number for *n* was determined by the performance on the previous block. Participants advanced to the next level (*n + 1*) when 95% or more of their responses were correct. Participants moved to a new block on the same level (*n*) if between 75% and 95% of their responses on the previous block were correct. Participants moved to a lower level (*n - 1*) when 75% or less of the responses were correct. An assessment of training task performance was obtained by recording the level (*n*) for each block of trials.

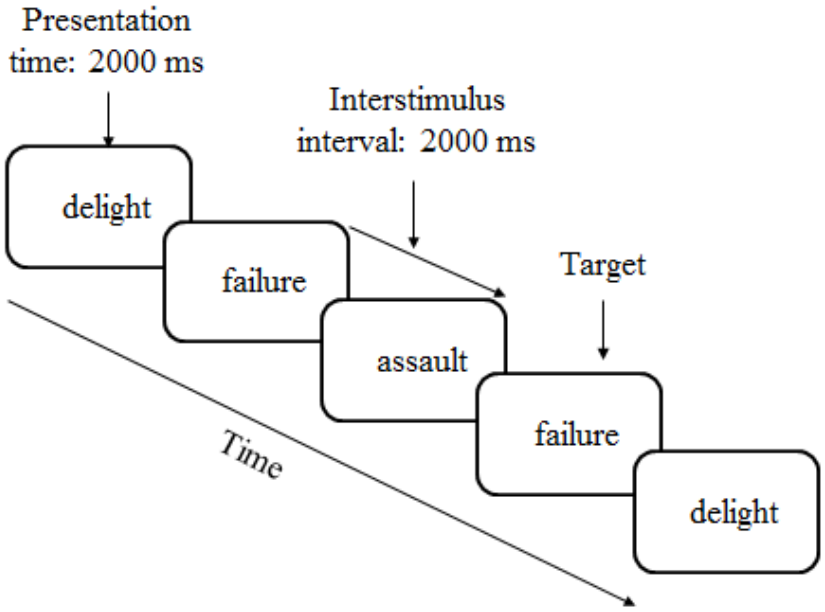

Figure 1: Series of trials from n = 2 block of the affective EC training task. In this task, words were presented one at a time in the center of the screen and participants were instructed to identify target trials. Target trials in an n = 2 block are those that match the word presented two trials previously. In this example, the 4th trial is a target.

Stimuli.

The words presented in the affective EC training task and affective control tasks were identical and were selected from the Affective Norms of English Words list (Bradley & Lang, 1999). Twenty-four positive and twenty-four negative words between four and eight characters were selected based on their valence and arousal ratings. The mean arousal rating and word length for the positive and negative words did not differ. The mean valence rating was 8.19 (*SD* = 0.21) for the positive words and 1.82 (*SD* = 0.22) for the negative words.

The words presented in the neutral EC training task were neutral words selected from the Affective Norms of English Words list (Bradley & Lang, 1999). Forty-eight neutral words between four and eight characters were selected based on their valence and arousal ratings. The mean valence rating of the neutral words was 5.24 (*SD* = 0.16) and the mean arousal rating was 3.79 (*SD* = 0.50).

Stress Induction

A modified version of the Trier Social Stress Test (TSST; Kirschbaum, Pirke, & Hellhammer, 1993) was used to induce stress. The TSST is a frequently used laboratory stress induction which induces social-evaluative threat. The TSST reliably produces a subjective as well as physiological stress response (Kirschbaum et al., 1993). Similar to other variations of the TSST (Gotlib, Joormann, Minor, & Hallmayer, 2008; Yoon & Joormann, 2012), our stress induction consisted of a speech and a working memory task completed in front of one experimenter. Participants were told that both tasks measure aspects of their intelligence. Participants were also told that the speech would be videotaped so that their performance could be rated by other students. Participants were asked to spend three minutes preparing a speech arguing for their position on the death penalty and were prompted to fill a five minute

period with their speech. For the working memory task, participants counted out loud backwards from 2083 to 0 in increments of 13. Each time a mistake was made, the experimenter prompted participants to start from the beginning.

To assess the physiological response to the stressor, salivary cortisol samples were assayed in duplicate. Samples were collected using salivette swabs (Sarstedt, Numbrecht, Germany) and were kept frozen at −20 °C. After all samples were collected, they were shipped to the lab of Clemens Kirschbaum in Dresden, Germany for analysis. Samples were centrifuged at 3000 rpm for 5 minutes to yield a clear supernatant of low viscosity, of which 50 µL were removed for cortisol analysis. A commercially available immunoassay with chemiluminescence detection with a lower detection limit of 0.43 nmol/L was used.

Procedure

Before giving consent, participants were told that the study's purpose was to investigate information processing and its relation to different behaviors and thought patterns. The specific purpose and hypotheses of the study were not given to participants. After consenting to participate, an online survey consisting of the RRS, BDI-II, Shipley Vocabulary Test, and demographic questions was administered to all participants. Next, based on condition assignment, participants completed one task, either the affective EC training task, neutral EC training task, or the affective control task. At the beginning of each task, participants were instructed how to identify target trials and completed a set of practice trials to ensure that they understood the task. Participants in each of the training conditions were not aware that they were completing a training task or informed that task difficulty changed based on performance. Instead, participants were told that the number for *n* may change throughout the task. The length of each of the three tasks was approximately 35 minutes.

After completing the training task, the pre-stressor measure of anxiety was obtained. Participants then completed the stress induction, which consisted of three minutes preparing for the speech, five minutes giving the speech, and five minutes completing the working memory task. Immediately following the completion of the stress induction, the post-stressor measure of anxiety and baseline cortisol sample was obtained. A response to a stressor is evident in salivary cortisol levels 21 to 40 minutes after the onset of the stressor (Dickerson & Kemeny, 2004); thus, our baseline sample was timed to reflect the participant's physiological state prior to the stress induction. Participants were then told that the hard part of the experiment was over and they would be able to relax for the remainder of the experiment. The post-stressor cortisol sample was obtained ten minutes after the completion of the stress induction.

Results

Preliminary Analyses

Data Screening.

Data were screened for missing values and outliers. One participant was removed from analyses because self-report data was missing. Another participant was identified as a potential outlier because cortisol levels were above 60 nmol/L. According to data collected from the Cortisol Questionnaire, this participant had not slept the night before the experiment. As sleep deprivation may affect cortisol levels (Leproult, Copinschi, Buxton, & Van Cauter, 1997), this participant's cortisol data was unlikely to reflect a typical stress response and this participant was removed from all analyses.

Group Characteristics.

Demographic and clinical information for all participants retained for analyses are presented by condition in Table 1. Participants in study conditions did not differ in terms of age, gender, or race/ethnicity. Additionally, participants in study conditions did not differ in intelligence measured by the Shipley Vocabulary Test, trait rumination measured by the RRS and its subscales (Treynor et al., 2003), or depression symptoms measured by the BDI-II (Beck et al., 1996). Finally, we verified through self-report on the Cortisol Questionnaire that participants did not

differ on factors that may affect cortisol levels. Study conditions did not differ in number of participants who drank caffeine the day of the session, number of participants who smoked a cigarette the day of the session, number of participants who take daily medications, mean participant sleep duration on the prior night, or scheduled session time. Cortisol Questionnaire data are presented by condition in Table 1.

Table 1: Demographic and clinical characteristics of participants.

	Affective EC Training	Neutral EC Training	Affective Control
Age	19.48 (1.37)	19.00 (1.35)	19.30 (1.49)
Gender (*n*)			
Male	12	15	14
Female	9	8	9
Race/Ethnicity (*n*)			
Caucasian	12	11	17
Hispanic/Latino	3	8	3
African American	3	0	2
Asian	2	2	0
American Indian / Alaska Native	0	0	1
Other	1	2	0
Shipley	30.40 (3.33)	29.92 (4.28)	32.19 (4.54)
RRS	41.95 (13.75)	37.17 (9.42)	40.52 (16.35)
RRS-B	9.24 (3.63)	8.43 (2.43)	9.35 (4.10)
RRS-R	9.29 (3.29)	8.57 (3.42)	9.26 (3.95)
BDI-II	11.19 (9.51)	6.61 (5.44)	8.30 (9.54)
Sleep Duration	7.18 (1.75)	6.54 (2.02)	6.59 (1.86)
Participants who had caffeine (*n*)	4	6	5
Participants who smoke (*n*)	1	1	0
Participants who take daily medications (*n*)	5	4	5
Scheduled session time (*n*)			
9:00am	3	5	5
12:00pm	6	7	7
3:00pm	6	7	7
6:00pm	6	4	4

Note. Standard deviations are in parentheses; Shipley = Shipley Vocabulary Test; RRS = Ruminative Responses Scale; RRS-B = Ruminative Responses Scale – Brooding Subscale; RRS-R = Ruminative Responses Scale-Reflective Pondering Subscale; BDI-II = Beck Depression Inventory, 2nd Edition; Cortisol is listed in nmol/L; Sleep duration is listed in hours.

Evaluation of training tasks.

Performance on the executive control training tasks, quantified by mean n-back level (e.g., 1, 2, 3, or 4) on each block, was evaluated. Because the training tasks were adaptive and participants started on a block of 1-back, the first 3 blocks did not reflect participants' ability and were eliminated from this analysis. Of the remaining sixteen blocks, the first eight were compared to the second eight to assess change in performance. See Table 2 for descriptive statistics. Across both training conditions, performance on the second half was significantly greater than performance on the first half, $F(1,42) = 13.99$, $p < .001$, partial $\eta^2 = .25$. Participants in the training conditions did not differ in mean training task performance, $F(1,42) = .01$, $p = .91$, partial $\eta^2 = .00$, or in change in training task performance from the first half to second half of the task $F(1,42) = .00$, $p = .99$, partial $\eta^2 = .00$. The analyses indicate that training on each task occurred and the training conditions did not differ in training task performance.

Table 2: Descriptive statistics, including means (standard deviations) of training task performance by training condition.

	Affective EC Training	Neutral EC Training	Both Training Conditions
Mean n-back level: 1st half	2.56 (.59)	2.58 (.67)	2.57 (.63)
Mean n-back level: 2nd half	2.86 (.65)	2.88 (.78)	2.87 (.72)
Mean n-back level: overall	2.71 (.59)	2.73 (.66)	2.72 (.62)

Note. Training task performance is measured by mean n-back level achieved.

Evaluation of stress induction.

Ratings of self-reported anxiety and cortisol levels were analyzed to determine whether the stress induction elicited a stress response. See Table 3 for descriptive statistics. Across all conditions, post-stressor anxiety was significantly greater than pre-stressor anxiety, $F(1,64) = 4.62$, $p < .05$, partial $\eta^2 = .07$. There was not a significant difference in mean anxiety rating between conditions, $F(2,64) = .08$, $p = .92$, partial $\eta^2 = .00$, nor was there a significant condition by time interaction, $F(2,64) = 1.32$, $p = .27$, partial $\eta^2 = .04$. An analysis of cortisol revealed similar patterns[1]. Across all conditions, post-stressor cortisol was significantly greater than baseline cortisol, $F(1,64) = 8.98$, $p < .01$, partial $\eta^2 = .12$. Conditions did not significantly differ in mean cortisol level, $F(2,64) = .73$, $p = .48$, partial $\eta^2 = .02$, and there was not a significant condition by time interaction, $F(2,64) = 1.97$, $p = .15$, partial $\eta^2 = .06$. Together, the analyses revealed that the stress induction elicited a subjective and physiological stress response and the response did not differ among participants in the three conditions.

Table 3: Descriptive statistics, including means (standard deviations) of stress response by condition.

Self-Reported Anxiety	Affective EC Training	Neutral EC Training	Affective Control	All Participants
Pre-stressor Anxiety	1.62 (1.58)	1.55 (1.76)	1.06 (1.49)	1.40 (1.61)
Post-Stressor Anxiety	1.84 (2.24)	1.77 (1.61)	2.02 (2.00)	1.88 (1.93)
Salivary Cortisol	**Affective EC Training**	**Neutral EC Training**	**Affective Control**	**All Participants**
Baseline Cortisol	9.53 (5.22)	8.76 (6.03)	10.16 (6.92)	9.48 (6.05)
Post-Stressor Cortisol	10.86 (6.35)	9.07 (6.71)	12.67 (10.74)	10.87 (8.24)

Note. Cortisol values are nmol/L.

Moderating Role of Rumination

A hierarchical linear regression was conducted to determine whether ruminative tendencies, measured by the RRS, moderated the relation between training and change in self-reported anxiety. Our measure of change in self-reported anxiety was obtained by subtracting the pre-stressor value from the post-stressor value (see Table 4). Since there were no significant differences in training task performance or cortisol levels between the two training conditions, participants in the training conditions were combined[2]. Condition was dummy coded with the control condition as the reference group. Because the relation between rumination and depression is well established (Nolen-Hoeksema et al., 1999; Nolen-Hoeksema et al., 2008) and BDI-II was significantly correlated with RRS in our sample ($r = .70$), we included BDI-II in the following analyses to control for current depression symptoms. Scores on the RRS[3] and BDI-II were centered. RRS, BDI-II, and condition assignment were entered in step one and the RRS by condition interaction term was entered in step two (Baron & Kenny, 1986). The model was not significantly improved by including the interaction term, $F_{change}(1,62) = .74$, $p = .39$, $R^2_{change} = .01$, indicating that trait rumination did not moderate the relation between training and self-reported anxiety.

To determine whether ruminative tendencies moderated the relation between training and cortisol reactivity, a second hierarchical linear regression was conducted. Our measure of cortisol reactivity was obtained by

[1] Using log transformed cortisol variables yielded the same pattern of results.
[2] Not collapsing the training conditions for the moderation analyses yielded the same pattern of results.
[3] Using the Brooding or Reflective Pondering subscales of the RRS in the moderation analyses yielded the same pattern of results.

subtracting the baseline value from the post-stressor value (see Table 4). As in the previously described analysis, participants in the training conditions were combined[2]. Condition was dummy coded with the control condition as the reference group and BDI-II was included to control for current depression symptoms. Scores on the RRS[3] and BDI-II were centered. RRS, BDI-II, and condition assignment were entered in step one and the RRS by condition interaction term was entered in step two (Baron & Kenny, 1986). The regression analysis indicated that the model was significantly improved by including the interaction term in the model, F_{change} (1,62) = 11.93, $p < .001$, R^2_{change} = .13 (see Table 5). To probe the significant interaction, simple slopes were examined according to recommendations by Holmbeck (2002). For participants in the control condition, the simple slope was obtained from the regression analysis described above, whereas the simple slope for the training condition was obtained by making the training condition the reference group in the dummy coded condition variable, computing a new interaction term, and running a new regression analysis. For participants in the control condition, RRS significantly predicted cortisol reactivity, β = .78, $t(62) = 4.32$, $p < .001$. For participants in the combined training condition, RRS did not significantly predict cortisol reactivity, β = .07, $t(62) = .38$, $p = .70$.

Table 4: Zero-order correlations for variables included in regression analyses and descriptive statistics for variables by condition.

Variable	**RRS**	**BDI-II**	**Cortisol Reactivity**	**Change in Self-Reported Anxiety**
BDI-II (*r*)	.70**	--	--	--
Cortisol Reactivty (*r*)	.42**	.28*	--	--
Change in Self-Reported Anxiety (*r*)	.09	−.11	.12	--
Condition	**RRS**	**BDI-II**	**Cortisol Reactivity**	**Change in Self-Reported Anxiety**
Combined Training Condition *M* (*SD*)	39.45 (11.80)	8.80 (7.91)	.80 (2.37)	.22 (1.51)
Affective Control Condition *M* (*SD*)	40.52 (16.35)	8.30 (9.54)	2.52 (5.57)	.96 (2.18)

Note. RRS = Ruminative Responses Scale; BDI-II = Beck Depression Inventory, 2nd Edition; Cortisol is listed in nmol/L; * p < .05, ** p < .01.

Table 5: Hierarchical regression predicting cortisol reactivity with BDI-II, RRS, condition, and condition by RRS interaction.

Variable	***B***	***SE***	**β**	***t***	***p***
Step 1					
BDI-II	.00	.07	.01	.05	.96
RRS	.12	.05	.41	2.60	.01
Condition	-1.60	.90	-.20	-1.78	.08
Step 2					
BDI-II	-.01	.07	-.01	-.10	.93
RRS	.22	.05	.78	4.32	.00
Condition	-1.55	.83	-.20	-1.87	.07
Condition X RRS	-.20	.06	-.51	-3.45	.001
Model	***R²***	***F***	***df***	***p***	
Step 1	.22	5.74	3,63	.002	
Step 2	.34	8.03	4,62	.000	

Note. RRS = Ruminative Responses Scale; BDI-II = Beck Depression Inventory, 2nd Edition; BDI-II and RRS were centered; Condition was dummy coded (training condition = 1 and control condition = 0).

Additional analyses were conducted by regressing cortisol reactivity on condition at 1 SD above and below the centered mean RRS score to further evaluate the nature of the interaction (Holmbeck, 2002). At one standard deviation below the mean RRS score, participants in the training condition did not significantly differ from participants in the control condition in cortisol reactivity, β = .15, $t(62) = 1.02$, $p = .31$. At one standard deviation

above the mean RRS score, participants in the training condition had significantly lower cortisol reactivity compared to participants in the control condition, β = −.53, *t*(62) = −3.77, *p* < .001 (Figure 2).

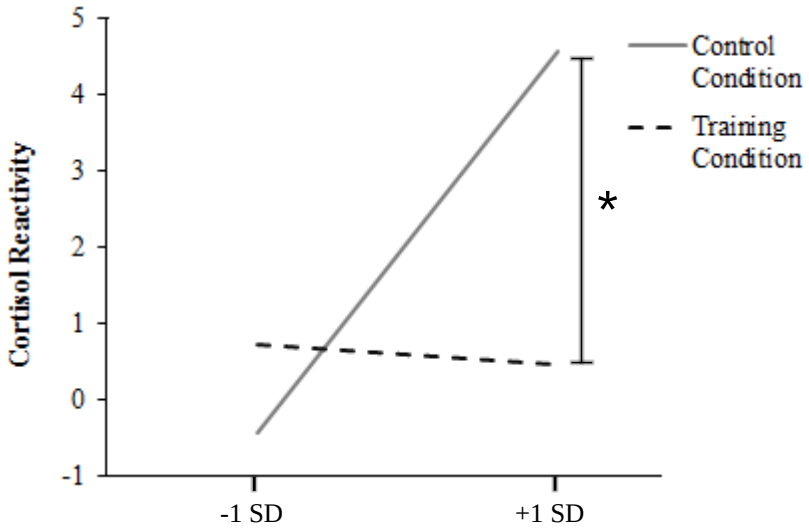

*Figure 2: Ruminative Responses Scale (RRS) score moderates the effect of condition assignment on cortisol reactivity. At one standard deviation below the mean RRS score, condition did not predict cortisol reactivity. At one standard deviation above then mean RRS score, participants in the combined training condition had significantly lower cortisol reactivity than participants in the control condition. * = p < .001.*

Discussion

The goal of the current study was to assess the effect of executive control training on stress reactivity following exposure to a laboratory stressor. Importantly, the current study examined whether trait rumination moderated the effect of the training. In line with our predictions, trait rumination was found to moderate the relation between training condition and cortisol reactivity. Probing of the interaction indicated that for participants low on trait rumination, condition assignment had no effect on cortisol reactivity. For participants with high ruminative tendencies, however, a significantly lower cortisol response was measured in participants who completed the training compared to participants who completed the control task.

Our results are consistent with the proposition that executive control is associated with biological stress responding. Because the ability to regulate emotions is important for resilient responding to stressors (e.g., Bonanno et al., 2004), it is plausible that our training effect occurred through improved emotion regulation ability. Although we did not directly investigate the potential mediating role of emotion regulation in the effect of the training, this study took the first step in establishing that training affects an objective measure of stress response. Our results open the door for future studies examining potential mediators in the relation between executive control training and stress response.

As expected, we found that trait rumination moderated the effects of the training on cortisol reactivity. Identifying a significant moderating effect is in line with research demonstrating that individual differences exist in the extent to which training is beneficial (Jaeggi et al., 2011). Further, the finding that participants high on trait rumination displayed an attenuated cortisol response following training is consistent with previous research demonstrating that individuals high on trait rumination benefitted from training aimed at changing basic cognitive processes (Arditte & Joormann, 2014). As trait rumination is associated with executive control deficits (Bernblum & Mor, 2010; Joormann & Gotlib, 2008) and increased cortisol reactivity (Zoccola & Dickerson, 2012), it is possible that rumination moderated the effects of executive control training simply because individuals who ruminate have more to gain from executive control training than other individuals. This possibility is particularly exciting because it suggests that improving executive control through training may affect not only healthy individuals, but may actually benefit individuals in need of such training. Thus, as future research continues to explore the role of executive control in emotional responding, the effect of such potential moderating factors must be considered.

Although results of the moderation analysis on cortisol reactivity was in line with our expectations, we did not see executive control training effects across the entire sample, which is inconsistent with the results of Schweizer et al. (2013). The discrepant results between the two studies, however, may be explained by a crucial variation in study design. Our training period consisted of a single training session and their procedure included 20 days of training. Previous research demonstrates a dose-dependent relation between training duration and training effects such that a longer training duration leads to a greater training effect (Jaeggi et al., 2008). Consequently, the duration of our study's training period may have been long enough to produce effects only for those with the most to gain in terms of executive control and cortisol reactivity (i.e., participants high in trait rumination). It is possible that implementing a longer training period in our study may have led to a training effect observable across the entire sample. An important next step for future research is replicate our study using a longer training period to determine whether the effects of executive control training are observable across the full sample.

Whereas rumination moderated the effect of training on cortisol reactivity, it did not moderate the effect of training on self-reported anxiety. In addition, cortisol reactivity was not correlated with change in self-reported anxiety. This divergence between subjective and physiological measures of stress response is consistent with previous findings (Brooks & Robles, 2009; Yim, Quas, Cahill, & Hayakawa, 2010) and emphasizes the importance of examining more than one measure of stress response.

It is also worth noting that although we included two training groups in our study design, one exposed to neutral stimuli and one exposed to affective stimuli, we found that individuals in the two training groups performed similarly on their trained tasks and importantly, they did not differ in cortisol reactivity. This runs counter to the assertion that for executive control training to transfer to emotional responding, the stimuli in the training task must be affective in nature (Schweizer et al., 2013). Schweizer et al. (2013) proposed that executive control training should include an integration of affective and cognitive systems in order to produce effects on emotional responding. Given this discrepancy, future research should explore whether the nature of the stimuli used in executive control training tasks are important for producing effects on emotional responding.

This study has a number of limitations that should be considered. First, our sample consisted only of students; therefore, replication in a non-student sample will be important to establish generalizability of our findings. Second, as mentioned previously, our study contained only one training session. Whereas we found an association between training group and stress reactivity, this study should be replicated using a longer training period to determine whether the effects remain significant only for individuals who ruminate or whether this finding will extend to the entire sample. Additionally, the timing and number of our cortisol samples are limitations of the current study. Ideally, our baseline cortisol sample would have been collected after a rest period. Instead, our baseline sample reflected the period when participants were completing the training or control task. Although this may have impacted the baseline sample, it is important to note that participants in the three conditions did not differ in baseline cortisol levels, indicating that one task was not more stressful than the others. It is also possible that our post-stressor cortisol sample did not capture the average peak cortisol response; however, across all conditions, we captured an increase in cortisol following the stressor indicating that we were able to measure cortisol reactivity. Further, our study design would have benefitted from inclusion of pre- and post- training measures of executive control to verify that training led to an improvement not only in the trained task, but also general executive control. This would allow for a more definitive conclusion that the difference in cortisol reactivity between conditions was due to improved executive control in the training condition. Finally, we believe that the effect of executive control training on cortisol reactivity may occur through changes in emotion regulation ability; however, we did not include an assessment of this in our study design. Thus, an important next step would be to investigate whether emotion regulation ability mediates the effect of executive control training on cortisol reactivity.

Despite limitations of the current study, our results advance our understanding of the basic cognitive processes which impact our ability to respond to stressful events. Furthermore, our finding that individuals high on trait rumination benefitted from just one training session has potential implications for clinical interventions. Rumination predicts the onset of depression and is also thought to contribute to anxiety, eating disorders, and substance abuse (for a review, see Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Thus, our findings may pave the way for future research to establish whether individuals with a tendency to ruminate can be trained to change how they respond to stressful events and, importantly, whether this change may deter the onset of such disorders.

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