Shedding light on the association between repetitive negative thinking and deficits in cognitive control – a meta-analysis

Ulrike Zetsche*[1], Paul-Christian Bürkner[2], Lars Schulze[1]

1 Freie Universität Berlin, Department of Clinical Psychology and Psychotherapy, Berlin, Germany

2 University of Münster, Department of Statistics, Faculty of Psychology, Münster, Germany

* Corresponding author. Ulrike Zetsche, Freie Universität Berlin, Department of Clinical Psychology and Psychotherapy, Habelschwerdter Allee 45, 14195 Berlin, Germany, phone: +49-30-838 55925; fax: +49-30-838 4 55925; u.zetsche@fu-berlin.de

Abstract

Individuals who experience recurrent negative thoughts are at elevated risk for mood and anxiety disorders. It is thus essential to understand why some individuals get stuck in recurrent negative thinking (RNT), whereas others are able to disengage eventually. Theoretical models propose that individuals high in recurrent negative thinking suffer from deficits in controlling the contents of working memory. Empirical findings, however, are inconclusive.

In this meta-analysis, we synthesize findings from 94 studies to examine the proposed association between RNT and deficits in cognitive control. We included numerous effect sizes not reported in the primary publications. Moderator analyses tested the influence of variables, such as stimuli valence, cognitive control function (e.g., shifting, discarding), or type of RNT (i.e., rumination or worry).

Results demonstrated an association between repetitive negative thinking and deficits in only one specific cognitive control function, namely difficulty discarding no longer relevant material from working memory ($r = -0.20$). This association remained significant after controlling for level of psychopathology. There was no substantial association between RNT and deficits in any other cognitive control function. All other moderators were not significant. We discuss limitations (e.g., primary sample sizes, reliability of paradigms) and highlight implications for future research and clinical interventions.

Keywords: Repetitive negative thinking, rumination, worry, cognitive control, inhibition, discarding

Most individuals with a mental disorder experience elevated levels of recurrent negative thoughts. Depressed individuals, for example, tend to ruminate on past failures or losses, whereas anxious individuals often worry about future events. Although the focus of such negative thoughts may differ between disorders, the *style* of thinking has been shown to be the same. It has been found to be recurrent, negative in valence, and difficult to control (Ehring & Watkins, 2008). Repetitive negative thinking (RNT), such as rumination or worry, has thus been considered a transdiagnostic process (Harvey, 2004).

In the past decades, research has identified various negative outcomes of RNT (Ehring & Watkins, 2008; Watkins, 2008). For example, dysphoric individuals induced to ruminate experienced increased depressed mood, difficulty in social problem solving, and biases in memory recall. Similarly, individuals induced to worry showed increases in both anxious and depressed mood (McLaughlin, Borkovec, & Sibrava, 2007). Furthermore, longitudinal studies have consistently demonstrated that higher levels of rumination predict higher levels of future depression, and ultimately the onset of future depressive episodes in initially non-depressed individuals (for a review, see Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Likewise, there is evidence that higher levels of worry predict higher anxiety levels even after controlling for initial anxiety levels. High trait worry has also been found to predict the onset and symptom level of posttraumatic stress disorder (Watkins, 2008).

Given this comprehensive evidence for the negative outcomes of RNT, it is important to ask why some people get caught in a spiral of recurrent negative thoughts, whereas others are able to disengage from these thoughts eventually. Several authors have proposed that deficits in cognitive control abilities may underlie the tendency to get stuck in recurrent negative thoughts (e.g., Joormann, 2010; Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Cognitive control processes help to continuously update and control the contents of working memory (WM). As such, they help to keep irrelevant information from entering working memory, to manipulate contents held in WM, and to expel no longer relevant information from WM. When individuals are in a negative mood, mood-congruent cognitions are activated in working memory (Siemer, 2005). Most individuals will eventually replace these negative contents with more pleasant cognitions in order to repair their mood (Joormann & Siemer, 2004). If cognitive control is impaired, however, individuals will have difficulty discarding negative cognitions from WM, resulting in prolonged RNT.

Indeed, several studies indicate an association between high levels of trait rumination and deficits in cognitive control (for reviews, see Whitmer & Gotlib, 2013; Yang, Cao, Shields, Teng, & Liu, 2017). Some studies also support an association between high trait worry and deficits in cognitive control (e.g., Fox, Dutton, Yates, Georgiou, & Mouchlianitis, 2015; Stout, Shackman, Johnson, & Larson, 2015). Other studies, however, have failed to find such associations (e.g., Aker, Harmer, & Landro, 2014; Goeleven, De Raedt, Baert, & Koster, 2006). Thus, the magnitude and pattern of the association between RNT and cognitive control deficits are still unclear.

One factor constraining progress in this field is that important theoretical and methodological advances in the study of cognitive control have only partly been applied in clinical psychology research (Snyder, Miyake, & Hankin, 2015). Already decades ago, Teuber (1972) suggested that cognitive control is neither a unitary process, nor a set of independent functions. He used the term *unity-diversity* to reflect his observations that cognitive control deficits differ across individuals and yet share common features. The most well-known unity-diversity framework has been put forward by Miyake & Friedman (Friedman & Miyake, 2017; Miyake & Friedman, 2012). Using structural equation modeling, the authors have shown that individual differences in various cognitive control functions modeled as latent variables were intercorrelated by r = .42 - .63. Correlations could neither be constrained to zero (complete diversity), nor to one (complete unity) without worsening the model fit. This indicates that different cognitive control functions reflect different processes, but also have something in common. Today, there is wide agreement that cognitive control includes both, unity and diversity (for a review, see Friedman & Miyake, 2017). The specific sub-functions (diversity) proposed by different unity-diversity models, however, differ somewhat. In their bifactorial unity-diversity framework, Miyake and colleagues (2012; 2000) suggest a common cognitive control factor and two specific factors, namely *updating* and monitoring of working memory representations, and *shifting* between different task requirements or mental sets. In another article (Friedman & Miyake, 2004), the authors specify that the common factor can further be subdivided into a general *inhibition* factor and a factor labeled *resistance to proactive interference*. The inhibition factor is related to tasks assessing interference resolution and inhibition of dominant responses. *Resistance to proactive interference* reflects inhibition of formerly activated but no longer relevant information, i.e., the ability to discard no longer relevant information from working memory (hereafter referred to as *discarding*). This subfunction deserves special attention in the context of this meta-analysis: individuals getting stuck in recurrent negative thoughts seem to have particular problems discarding information (i.e., thoughts) that had been activated in memory but that is no longer relevant for the task at hand. It has thus been proposed that RNT may be associated primarily with problems in discarding no longer relevant material from working memory (Joormann & Vanderlind, 2014; Koster et al., 2011; Mogg & Bradley, 2005). This is in line with findings by Zetsche, D'Avanzato, and Joormann (2012), showing that rumination was related only to impairments in discarding no longer relevant material from working memory, but not to impairments in interference resolution.

Based on the above summarized theories and evidence, we will differentiate between different cognitive control functions when examining the link between RNT and cognitive control. Specifically, and in accordance with Miyake and Friedman (2004; 2000), we will differentiate between shifting, updating, discarding, and inhibition. As outlined above, we expect that RNT will primarily be associated with a diversity component, namely difficulty in discarding no longer relevant information from WM.

Another issue is the question of whether RNT is particularly associated with problems controlling the processing of *emotional* material in working memory. This appears likely given that RNT is characterized by its focus on emotionally negative content (e.g., Joormann, Levens, & Gotlib, 2011). Thus, we will also examine whether the association between RNT and cognitive control over emotional material is stronger than the association between RNT and cognitive control over neutral material.

It is unclear if different forms of RNT, such as rumination and worry, are related to the same impairments in cognitive control. Rumination is characterized by a focus on past experiences and has mostly been examined in the context of depression, whereas worry focuses on future events and has mostly been examined in relation to anxiety. Studies comparing rumination and worry, however, have concluded that these two processes share more similarities than differences (e.g., Watkins, Moulds, & Mackintosh, 2005). We thus hypothesize that the underlying cognitive control deficits are also the same.

Importantly, an observed association between RNT and cognitive control deficits might be due to higher levels of psychopathology in those individuals high in RNT. Depression, for example, has been shown to be associated with deficits in cognitive control (for a review, see Snyder, 2013). It is thus important to control for variance in cognitive control deficits that are due to high levels of psychopathology (i.e., depression or anxiety) when estimating the meta-analytic correlation between RNT and cognitive control.

The major aim of the present meta-analysis is to examine the magnitude and pattern of the association between RNT and deficits in cognitive control. We hypothesize that (a) RNT is specifically related to deficits in *discarding* no longer relevant information from working memory, that (b) RNT is mainly associated with deficits in controlling the processing of *emotional* (versus neutral) material, and that (c) rumination and worry are similarly related to cognitive control deficits. Because we expect that RNT is specifically related to deficits in discarding negative material from working memory, we also test the interaction between the cognitive control function (discarding versus others) and stimuli valence (emotional versus neutral). For each analysis, we examine whether the relation between RNT and cognitive control remains when controlling the influence of psychopathology (i.e., depression or anxiety, respectively) on cognitive control.

Methods

Search Strategy and Inclusion Criteria

The literature was searched for any studies assessing trait RNT (i.e., rumination or worry) and cognitive control functions within the same sample. The search was restricted to adult samples with an age range between 18 and 65 years (or an average age < 60 years if the range was unknown). Studies involving cognitive control trainings or prospective longitudinal designs were only included if baseline data was available. Studies examining the effect of experimentally induced state RNT on cognitive control were not included. We further excluded studies if the sample involved individuals with a diagnosis of schizophrenia, anorexia nervosa, autism spectrum disorder, or any neurological disease.

The literature search was conducted until 15th June 2017 in the databases Medline, PsychInfo, and Web of Science using the following search terms: ("Repetitive Negative Thinking" OR Worry OR Ruminat* OR Brooding) AND ("Executive Function" OR "Executive Control" OR "Cognitive Control" OR Inhibition OR Updating OR Switching OR “Interference control” OR "Attention* Control" OR “attention* disengagement” OR “thought suppression” OR “directed forgetting”). We searched for peer-reviewed articles and dissertations written in English or German. The reference lists of included articles were screened for further relevant studies. For a detailed flowchart of the search and selection process, please see Figure S1 in the supplements.

Data Extraction

All data were extracted by two independent persons (LS and UZ) and discussed in case of dissent. Note, that experimental tasks were considered eligible for inclusion if they have been associated with cognitive control processes in the literature. This was very evident for certain experimental paradigms, such as the modified Sternberg task (Joormann & Gotlib, 2008), the stop-signal task (Miyake et al., 2000), or task switching paradigms (Miyake et al., 2000). In less evident cases, we explicitly searched the literature to answer this question. For example, we only included dot probe tasks or other tasks typically used to assess selective attention if they used stimulus presentation times of 1000ms or above. Stimulus presentation times of 1000ms or above allow extensive elaborative processing and thus reflect difficulty disengaging from salient stimuli (Mogg & Bradley, 2005).

For the computation of effect sizes, we extracted the sample size and zero-order correlation coefficients between (a) measures of RNT and measures of cognitive control, (b) measures of RNT and psychopathology (i.e., depression or anxiety), and (c) measures of cognitive control and psychopathology. Some studies reported only means and standard deviations in cognitive control indices for individuals scoring high or low on measures of RNT. These data were extracted and transformed into correlation coefficients if no other data were provided.

We further examined three moderator variables of major interest: (A) *cognitive control function*: in line with Friedman and Miyake (Friedman & Miyake, 2004; Miyake et al., 2000), each cognitive control task was assigned to one of the following cognitive control functions: shifting, updating, inhibition (i.e., response inhibition or interference control), or resistance to proactive interference (i.e., discarding of no longer relevant information from working memory). Final classifications of individual paradigms to cognitive control functions can be found in Table 1. Classifications were based on previous factor analytic findings and categorizations (e.g., Miyake et al., 2000). (B) *stimuli valence (neutral versus emotional)*: stimuli were rated as neutral if they consisted of digits, letters, shapes, or neutral words or faces. Stimuli were rated as emotional, if they included negatively valenced images, faces, or words. Note that we did not extract cognitive control indices for only positive material. (C) *type of RNT (rumination versus worry)*. Rumination was mostly assessed by the Ruminative

Responses Scale of the Response Style Questionnaire (Nolen-Hoeksema & Morrow, 1991). This scale is comprised of two subscales assessing reflective pondering, considered a more adaptive form of rumination, and brooding, which has especially been linked to negative consequences (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). Given that some studies reported both, RRS total scores and RRS brooding scores, we examined whether the employed scale moderates the association between rumination and cognitive control.

We also examined the moderating influence of variables possibly confounding the relation between RNT and cognitive control. These were mean age, percent female participants, percent participants taking psychotropic medication (of those samples with known medication status), sample type (students versus other), and diagnostic status. Details on variable coding and a complete overview of all extracted information is provided in Table 6 in the supplements. For studies involving clinical and healthy samples, we extracted the data separated by diagnostic group if available.

If the relevant data or any other relevant information were not reported, we contacted the corresponding author for further information[1]. Thirty-six out of 84 contacted authors responded and provided additional data or information.

Statistical Analysis

For the present meta-analysis, zero-order correlations as well as semi-partial correlations controlling for depression or anxiety in cognitive control were computed. Note, that we computed semi-partial correlations between rumination and cognitive control controlled for depressive symptoms, and between worry and cognitive control controlled for anxiety symptoms. This was due to the very limited number of rumination studies assessing anxiety, or worry studies assessing depression, respectively. An interested reader will find the results of these subset analyses in Tables S4 and S5 in the supplements. Correlation coefficients were transformed into Fisher's *Z* values in order to stabilize variances and achieve more normally distributed outcomes (Fisher, 1921; Hedges & Olkin, 1983). Meta-analytic results were then transformed back to the correlation metric to ease their interpretation.

Because of varying sample characteristics and outcome measures, we expected heterogeneity between outcomes. Furthermore, many of the eligible studies included several measures of cognitive control; thus, outcomes were likely to be dependent. To account for these dependencies, multilevel meta-analyses were applied, which allow to estimate both the between-study variance τ^2 and the within-study variance σ^2 (Van den Noortgate, López-López, Marín-Martínez, & Sánchez-Meca, 2013). In order to investigate the impact of continuous as well as categorical study characteristics on effect sizes, we carried out moderator analyses through meta-regression analyses (Higgins, 2011). Continuous moderators were analyzed, if they were non-constant across studies. Categorical moderators were analyzed, if they had at least two levels and at least three studies assigned to each level.

A common problem in meta-analyses is publication bias, as research papers are more likely to be published when they report significant results (Lipsey & Wilson, 2001). To examine to what extent results are likely to be biased by a publication bias, we created funnel plots and applied the *trim and fill* method (Duval & Tweedie, 2000). In addition, we explored whether effect sizes differed dependent on whether or not effects were reported in the publications.

All analyses were conducted with the *System for Statistical Computation and Graphics R* (R Core Team, 2017), applying the R package *metafor* (Viechtbauer, 2010). Statistical tests were conducted at a 5% significance level and were one-tailed, when hypotheses were available. The full data sheet, syntax, and additional forest plots are available at https://osf.io/xrt8m/?view_only=f0d1deda6ba24d609f0c74a1b7885f28.

Results

Study Characteristics

In total, 94 studies were included, comprising of 109 independent samples with a total of 6698 participants. Across all studies, participants had a mean age of 25.32 years and 66% of participants were female. Primary sample sizes ranged from N = 16 to N = 315 with a median of N = 45. In total, we extracted k = 170 effect sizes. Seventy-five studies assessed rumination (k = 139 effect sizes) and 19 studies assessed worry (k = 31). Sixteen studies assessed discarding (k = 26), 15 studies assessed set shifting (k = 35), 13 studies assessed updating (k = 28), 31 studies assessed inhibition (k = 49), and 19 studies assessed other functions of cognitive control (k = 32). Finally, k = 90 effect sizes were related to cognitive control over emotional material, whereas k = 80 effect sizes were related to cognitive control over neutral material. Detailed study characteristics are depicted in Table 1 (see additional file).

Zero-order and Semi-partial Correlations

The estimated correlation between all measures of RNT and all measures of cognitive control was r = -0.11 (95% CI = [-0.15, -0.08]; see Table 2 for details, and the online supplements for the forest plot). Thus, individuals with high levels of repetitive negative thinking show worse cognitive control.

Next, we computed semi-partial correlations to control for variance in cognitive control deficits that are due to high levels of psychopathology. As detailed above, we computed semi-partial correlations between rumination and cognitive control controlled for depressive symptoms, and between worry and cognitive control controlled for anxiety symptoms. The estimated semi-partial correlation between rumination and cognitive control controlling for depressive symptoms was r_{sp} = -0.04 (95% CI = [-0.07, -0.01]). The estimated correlation between rumination and depression was r = 0.50 (95% CI = [0.45, 0.55]), and the estimated correlation between depression and cognitive control was r = -0.04 (95% CI = [-0.07, -0.02]; see Table 2 for detailed statistics).

The estimated effect size for the semi-partial correlation between worry and cognitive control, controlling for anxiety symptoms was r_{sp} = -0.06 (95% CI = [-0.11, -0.01]). The estimated correlation between worry and anxiety was r = 0.53 (95% CI = [0.45, 0.61]), and the estimated correlation between anxiety and cognitive control was r = -0.03 (95% CI = [-0.07, 0.01]; see Table 2 for detailed statistics).

Moderator Analyses for Zero-order Correlations

In line with our hypothesis, the estimated correlation between RNT and discarding, r = -0.20 (95% CI = [-0.26, -0.13]), was significantly larger than the estimated correlation between RNT and any other cognitive control function (see Table 3). Stimuli valence (emotional versus neutral) and type of RNT (rumination versus worry) were no significant moderators (see Table 3). In addition, the interaction term between the moderators cognitive control function and stimuli valence was not significant, z = -0.01 (95% CI = [-0.17, 0.15]).

None of the other moderators, such as mean age, sex, intake of psychotropic medication, type of sample, diagnostic status, or RRS scale were significant on a 5%-level, (see Table S1 in the supplements for more details).

Table 2
Results for main analyses

Correlation	**# of samples**	**# of ES**	***z***	***p_z***	**95% CI_z**	***r***	**95% CI_r**	**τ Sample**	**τ Error**
RNT and Cognitive control	109	170	-0.11	< .0001	[-0.15, -0.08]	-0.11	[-0.15, -0.08]	0.12	0.02
Rumination and Cognitive control controlled for depressive symptoms[1]	60	104	-0.04	.009	[-0.07, -0.01]	-0.04	[-0.07, -0.01]	0.06	0.00
Worry and Cognitive control controlled for anxiety symptoms[1]	14	22	-0.06	.027	[-0.11,-0.01]	-0.06	[-0.11,-0.01]	0.00	0.04
Cognitive control and Depression	76	126	-0.04	.001	[-0.07, -0.02]	-0.04	[-0.07, -0.02]	0.04	0.04
Cognitive control and Anxiety	35	64	-0.03	.096	[-0.07, 0.01]	-0.03	[-0.07, 0.01]	0.05	0.00
Rumination and Depression[2]	64	64	0.55	< .0001	[0.49, 0.62]	0.50	[0.45, 0.55]	0.20	
Worry and Anxiety[2]	14	14	0.59	< .0001	[0.48, 0.71]	0.53	[0.45, 0.61]	0.17	

ES = effect sizes; RNT = repetitive negative thinking; 1 = semi-partial correlations: depressive or anxiety symptoms, respectively, are partialled out of cognitive control; 2 = no multi-level analyses because there were no samples including multiple effect sizes

Table 3

Main moderator analyses of zero-order correlation between RNT and CC

Moderator	Moderator levels	# of ES	z	p_z	95% CI_z	τ_{Sample}	τ_{Error}
CC functions	Discarding	26	-0.20	< .0001	[-0.27, -0.13]	0.12	0.02
	All other CC functions vs. discarding	**144**	**+0.10**	**.007**	**[0.03, 0.18]**		
Stimuli valence	Emotional	90	-0.11	< .0001	[-0.15, -0.06]	0.12	0.02
	Neutral vs. emotional	**80**	**-0.02**	**.554**	**[-0.07, 0.04]**		
RNT type	Rumination	139	-0.12	< .0001	[-0.15, -0.08]	0.13	0.02
	Worry vs. rumination	**31**	**+0.01**	**.817**	**[-0.07, 0.09]**		

Moderators are dummy coded. Rows in bold reflect estimates for the contrast (i.e. difference) of non-reference and reference group; all other rows reflect estimates for the reference group; ES = effect sizes; CC = cognitive control; RNT = repetitive negative thinking

Moderator Analyses for Semi-partial Correlations

Moderator analyses of semi-partial correlation between rumination and cognitive control, controlling for depression. In line with our hypothesis, the estimated semi-partial correlation between rumination and discarding controlled for depressive symptoms, r_{sp} = -0.11 (95% CI = [-0.19, -0.03]), was significantly larger than the effect size for the semi-partial correlation between rumination and any other cognitive control function (see Table 4). Contrary to our expectations, stimuli valence or the interaction between cognitive control function and stimuli valence were no significant moderators (see Table 4).

Again, none of the other moderators were significant on a 5%-level (see Table S2 in the supplements).

Semi-partial correlation between worry and cognitive control, controlling for anxiety. Contrary to our expectations, neither the kind of cognitive control function nor stimuli valence were significant moderators (see Table 4).

None of the other moderators were significant on a 5%-level (see Table S3 in the supplements).

Table 4

Main moderator analyses of semi-partial correlations

Moderator	Moderator levels	# of ES	z	p_z	95% CI$_z$	τ Sample	τ Error
a) Semi-partial correlations between rumination and CC controlling for depression							
CC functions	Discarding	16	-0.11	.005	[-0.19, -0.03]	0.07	0.00
	All other CC functions vs. Discarding	**88**	**+0.08**	**.063**	**[-0.00, 0.15]**		
Stimuli valence	Emotional	65	-0.03	.101	[-0.07, 0.01]	0.06	0.00
	Neutral vs. emotional	**39**	**-0.03**	**.351**	**[-0.08, 0.03]**		
b) Semi-partial correlations between worry and CC controlling for anxiety							
CC functions	Discarding	1	-0.21	.028	[-0.40, -0.02]	0.00	0.02
	All other CC functions vs. Discarding	**21**	**+0.17**	**.101**	**[-0.03, 0.36]**		
Stimuli valence	Emotional	4	-0.07	.397	[-0.24, 0.10]	0.00	0.05
	Neutral vs. Emotional	**18**	**+0.02**	**.860**	**[-0.16, 0.20]**		

Moderators are dummy coded. Rows in bold reflect estimates for the contrast (i.e. difference) of non-reference and reference group; all other rows reflect estimates for the reference group; ES = effect sizes; CC = cognitive control; RNT = repetitive negative thinking

Publication Bias

As displayed in Figure 1, the funnel plot of the Fisher's z-transformed correlations between RNT and cognitive control appears relatively symmetric with the exception of a few small outlying studies on the left. The trim and fill method estimated four missing effect sizes on the right side (*SE* = 3.16), which provides little evidence for substantial publication bias in our analyses.

To examine a potential reporting bias, we examined whether effect sizes were influenced by whether or not the respective data were available in the publication or had been received via personal communication. Data availability was a significant moderator of both, the zero-order correlation between RNT and cognitive control, z = -0.12 (95% CI = [-0.18, -0.06]), and the semi-partial correlation between rumination and cognitive control controlling for depression, z = -0.06 (95% CI = [-0.12, -0.00]). Whereas the estimated correlation between RNT and cognitive control presented in publications was r = -0.16, 95% CI = [-0.20, -0.12], k = 83 (r_{sp} = -0.08, 95% CI = [-0.13, -0.03], k = 32), the respective correlation based on data received via personal communications was r = -0.05, 95% CI = [-0.09, -0.00], k = 87 (r_{sp} = -0.02, 95% CI = [-0.05, 0.02], k = 72). Data availability was no significant moderator of the semi-partial correlation between worry and cognitive control controlling for anxiety, z = 0.03 (95% CI = [-0.08, 0.14]).

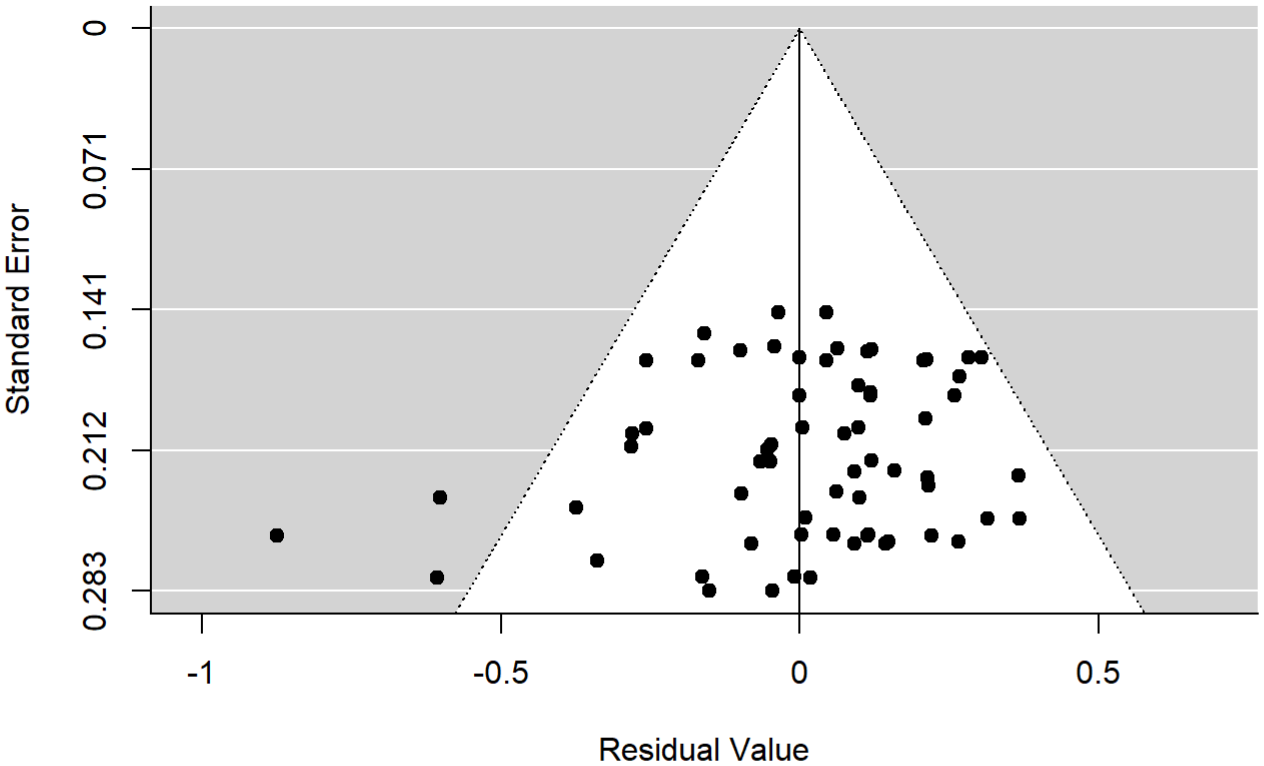

Figure 1

Funnel plot of Fisher's z-transformed correlations between repetitive negative thinking and cognitive control.

Discussion

In this meta-analysis, we examined the magnitude and pattern of the postulated association between repetitive negative thinking and deficits in cognitive control. The analysis encompassed a large number of samples including many unpublished effect sizes, and offers online access to the full datasheet and syntax. Results demonstrate that individuals with high levels of RNT do not suffer from general deficits in cognitive control, but rather from circumscribed difficulty in discarding no longer relevant material from working memory. These results support theoretical propositions that individuals with marked traits of RNT show specific trouble removing information from their working memory once it got in there (e.g., Joormann & Vanderlind, 2014; Koster et al., 2011). The association between RNT and deficits in discarding showed an effect of r = -.20. In addition, semi-partial correlations demonstrated that this association also holds when controlling for levels of depression or anxiety, respectively. On the other hand, correlations between RNT and deficits in all other cognitive control functions were negligible in magnitude.

Thus, the present results support current theories on the mechanisms underlying rumination, such as the impaired disengagement hypothesis by Koster and colleagues (2011). The authors postulate that “cued rumination” in response to life events is a normal phenomenon. According to the authors, ruminative thoughts only become pathological if they persist over time because they hinder adaptive strategies to regulate one’s mood. Koster and colleagues (2011) hypothesize that difficulty disengaging from negative material in working memory may underlie persistent ruminative thinking. Our results provide empirical evidence that this might be the case. This may have important clinical implications. If persistent rumination is actually due to deficits in discarding, mere verbal interventions to stop ruminative thoughts might not be sufficient to help patients in the long term. Instead, computer-based trainings to enhance the ability to discard irrelevant information from working memory might be an important add-on to common therapies. Recently, several research groups have designed computer based trainings to address various cognitive control functions (e.g., Cohen, Mor, & Henik, 2015; Hoorelbeke & Koster, 2017). Effects of these trainings on depressive rumination have been mixed (Mor & Daches, 2015). However, most of these trainings did not address discarding. The present results call for trainings specifically targeting difficulty in discarding. In this context, it has to be emphasized that the present results are exclusively based on cross-sectional data. It is thus not clear whether deficits in discarding cause higher levels of RNT, or vice versa. Intervention research could also clarify this question.

The present results further underscore that it is important to integrate insights from cognitive psychology into clinical research and distinguish between different cognitive control functions. Within the unity-diversity framework of cognitive control, our results suggest that RNT is rather associated with a diversity factor (discarding) than with the common cognitive control factor: the meta-analytic association between RNT and discarding is considerably larger than the associations between RNT and other cognitive control functions. Note, however, that tasks employed to assess discarding in the primary studies probably also include variance from the common factor. In general, this meta-analysis is not able to directly test the unity-diversity framework because the primary studies did not use a latent variable approach and thus did not differentiate between shared and specific variance in different cognitive control functions.

Remarkably, neither stimuli valence nor the interaction term of stimuli valence by cognitive control functions (discarding vs. all others) were significant moderators of the association between RNT and cognitive control. In other words, the present results indicate that the association between RNT and deficits in cognitive control is largely independent of stimuli valence. This is surprising given postulates that RNT, and particularly so rumination, is associated primarily with deficits in controlling negative material in working memory (Joormann & Gotlib, 2008; Joormann et al., 2011). Note, however, that we distinguished only between neutral and emotional stimuli. The latter category also involved emotionally mixed stimuli (i.e., mixed positive and negative stimuli), because several paradigms did not allow to clearly differentiate between strictly negative and emotionally mixed experimental conditions. It is thus unclear whether or not individuals high in RNT may experience selective difficulty discarding *negative* information from working memory.

The present results also show that rumination and worry are similarly related to deficits in cognitive control. Note that this study included more effect sizes related to rumination (N = 139), than related to worry (N = 31). Given the minimal difference in estimated effect sizes ($z = 0.01$), however, it is unlikely that a meaningful difference would emerge if more worry related effect sizes existed. Thus, results indicate that rumination and worry are related to the same underlying cognitive processes, although the content of ruminative or worrisome thoughts differs. This adds to findings showing that rumination and worry share more commonalities than differences and ultimately supports the notion that RNT is a transdiagnostic process (Ehring & Watkins, 2008; McEvoy, Watson, Watkins, & Nathan, 2013). The central feature of this transdiagnostic process is the *style* of thinking, which has been characterized to be recurrent and difficult to control (Ehring & Watkins, 2008). The findings of this meta-analysis might indicate that difficulty in discarding no longer relevant information from working memory might be the mechanism underlying this recurrent and uncontrollable style of thinking. The present results, however, do not allow any causal interpretation. Further research is needed to clarify this potentially causal relationship. In this context, questionnaires assessing the style of thinking specific to RNT (e.g., Ehring et al., 2011; McEvoy, Mahoney, & Moulds, 2010) may be more promising than disorder specific questionnaires of RNT, which focus on the non-shared variance between worry and rumination, namely the content.

There are some issues that need further attention. Some readers may have noticed that the estimated correlation between measures of psychopathology (depression, anxiety) and cognitive control deficits (r = -.04 for depression, and r = -.03 for anxiety) in this meta-analysis are very low. This may be because the present study mostly summarized correlation coefficients between measures of psychopathology and cognitive control *within* diagnostic groups, resulting in limited variance in both variables. Thus, the present correlation coefficients underestimate the real association between these variables. Comparing clinically depressed and healthy individuals in cognitive control measures results in much larger effect sizes (d = 0.4 - 0.6; Snyder, 2013).

Second, this meta-analysis included different types of paradigms assessing discarding of no longer relevant information from WM. It is not clear whether some of these tasks are more adequate measures of discarding than others in terms of reliability, purity, and sensitivity. There was heterogeneity between samples in this meta-analysis that could not fully be explained by the tested moderators. Low reliability of experimental paradigms is an important factor that could cause such heterogeneity. To date, there have been few attempts to estimate the reliability of paradigms assessing cognitive control. Kowalczyk and Grange (2017) tested the split-half reliability of the n-2 repetition cost index (i.e., backward inhibition) in three paradigms. They concluded that the index is not a reliable measure of inhibition. Koster and colleagues (2013), on the other hand, demonstrated that the switch cost index of the Internal Switching Task shows good split-half and test-retest reliability. Thus, some paradigms included in this meta-analysis seem to show good reliability, whereas others do not. Disconcertingly, for most included paradigms reliability is unknown.

In addition to the question of reliability, the issue of task purity is also an important one. Paradigms assessing cognitive control functions are no pure measures of cognitive control because they always require additional abilities specific to each task. Such task-specific variance as well as error variance can be quite large. Both, low reliability and task impurity can result in an underestimation of real effect sizes or in false null-findings. Thus, the present null-findings regarding the association between RNT and any cognitive control functions other than discarding might also be due to low reliability or high task impurity of the paradigms employed in the primary studies. In this context, Snyder and colleagues (2015) point out that traditional neuropsychological tasks, such as the Trail-making task or the Wisconsin Card Sorting Test, were designed to detect severe neuropsychological impairments. These tasks are, however, not sensitive enough to measure inter-individual differences in specific cognitive control functions. Nevertheless, they are still employed in research. According to Miyake and colleagues (Friedman & Miyake, 2004; Snyder et al., 2015), a solution to the reliability and impurity problem is to employ multiple tasks assessing the same function and to use latent variable analysis. Latent variable analysis extracts the common variance among several paradigms assessing the same process and thus eliminates measurement error and task-specific variance. Latent variable analysis, however, requires large sample sizes, which is not always practicable in clinical research. An alternative, somewhat less optimal solution would thus be to use mean z-scores across paradigms.

Another important topic in this field is statistical power in the primary studies. The median sample size of included studies was N = 45. It is noteworthy that a sample size of N = 153 is needed to detect a one-sided correlation of $r = .20$ (80% power, $\alpha = .05$), such as the one found between RNT and discarding in this meta-analysis. Small primary sample sizes may also contribute to unexplained heterogeneity in the data, because correlation coefficients tend to be unstable in small samples (Schönbrodt & Perugini, 2013). The recruitment of big sample sizes is not always practical in clinical psychology research. A solution for this problem may lie in open data repositories to aggregate primary data from multiple sites, or in concerted effort to assess data across many labs (e.g., The Psychological Science Accelerator; Many Labs Project).

Finally, the present results indicate a reporting bias. Specifically, effect sizes reported in publications were significantly larger than effect sizes received via personal communication. Given that this meta-analysis included a large number of unpublished effect sizes, a publication bias was not reflected in the forest plots. Solutions to this problem have been comprehensively discussed in recent years (e.g., Chambers, 2013; Nosek et al., 2015).

To summarize, the present results demonstrate that individuals with high levels of RNT do not suffer from general deficits in cognitive control, but rather from circumscribed difficulty in discarding no longer relevant material from working memory. Computer based trainings to improve cognitive control should thus specifically address the ability to discard irrelevant information from working memory. Future studies will benefit from employing multiple tasks assessing the same cognitive control function and using latent variable analysis to alleviate the reliability and task impurity problems.

References

Aker, M., Harmer, C., & Landro, N. I. (2014). More rumination and less effective emotion regulation in previously depressed women with preserved executive functions. *Bmc Psychiatry, 14*.

Chambers, C. D. (2013). Registered reports: a new publishing initiative at Cortex. *Cortex, 49*(3), 609-610.

Cohen, N., Mor, N., & Henik, A. (2015). Linking executive control and emotional response: A training procedure to reduce rumination. *Clinical Psychological Science, 3*(1), 15-25.

Ehring, T., & Watkins, E. R. (2008). Repetitive negative thinking as a transdiagnostic process. *International Journal of Cognitive Therapy, 1*(3), 192-205.

Ehring, T., Zetsche, U., Weidacker, K., Wahl, K., Schonfeld, S., & Ehlers, A. (2011). The Perseverative Thinking Questionnaire (PTQ): Validation of a content-independent measure of repetitive negative thinking. *Journal of Behavior Therapy and Experimental Psychiatry, 42*(2), 225-232.

Fox, E., Dutton, K., Yates, A., Georgiou, G. A., & Mouchlianitis, E. (2015). Attentional control and suppressing negative thought intrusions in pathological worry. *Clinical Psychological Science, 3*(4), 593-606.

Friedman, N. P., & Miyake, A. (2004). The Relations Among Inhibition and Interference Control Functions: A Latent-Variable Analysis. *Journal of Experimental Psychology: General, 133*(1), 101-135.

Friedman, N. P., & Miyake, A. (2017). Unity and diversity of executive functions: Individual differences as a window on cognitive structure. *Cortex, 86*, 186-204.

Goeleven, E., De Raedt, R., Baert, S., & Koster, E. H. (2006). Deficient inhibition of emotional information in depression. *J Affect Disord, 93*(1-3), 149-157.

Harvey, A. G. (2004). *Cognitive behavioural processes across psychological disorders: A transdiagnostic approach to research and treatment*: Oxford University Press, USA.

Hoorelbeke, K., & Koster, E. H. (2017). Internet-delivered cognitive control training as a preventive intervention for remitted depressed patients: Evidence from a double-blind randomized controlled trial study. *Journal of consulting and clinical psychology, 85*(2), 135.

Joormann, J. (2010). Cognitive inhibition and emotion regulation in depression. *Current Directions in Psychological Science, 19*(3), 161-166.

Joormann, J., & Gotlib, I. H. (2008). Updating the contents of working memory in depression: Interference from irrelevant negative material. *Journal of Abnormal Psychology, 117*(1), 182-192.

Joormann, J., Levens, S. M., & Gotlib, I. H. (2011). Sticky Thoughts: Depression and Rumination Are Associated With Difficulties Manipulating Emotional Material in Working Memory. *Psychological Science, 22*(8), 979-983.

Joormann, J., & Siemer, M. (2004). Memory Accessibility, Mood Regulation, and Dysphoria: Difficulties in Repairing Sad Mood With Happy Memories? *Journal of Abnormal Psychology, 113*(2), 179-188.

Joormann, J., & Vanderlind, W. M. (2014). Emotion regulation in depression: The role of biased cognition and reduced cognitive control. *Clinical Psychological Science, 2*(4), 402-421.

Koster, E. H. W., De Lissnyder, E., & De Raedt, R. (2013). Rumination is characterized by valence-specific impairments in switching of attention. *Acta Psychologica, 144*(3), 563-570.

Koster, E. H. W., De Lissnyder, E., Derakshan, N., & De Raedt, R. (2011). Understanding depressive rumination from a cognitive science perspective: The impaired disengagement hypothesis. *Clinical Psychology Review, 31*(1), 138-145.

Kowalczyk, A. W., & Grange, J. A. (2017). Inhibition in task switching: The reliability of the n-2 repetition cost. *Quarterly Journal of Experimental Psychology, 70*(12), 2419-2433.

McEvoy, P. M., Mahoney, A. E., & Moulds, M. L. (2010). Are worry, rumination, and post-event processing one and the same?: Development of the Repetitive Thinking Questionnaire. *Journal of anxiety disorders, 24*(5), 509-519.

McEvoy, P. M., Watson, H., Watkins, E. R., & Nathan, P. (2013). The relationship between worry, rumination, and comorbidity: Evidence for repetitive negative thinking as a transdiagnostic construct. *Journal of Affective Disorders, 151*(1), 313-320.

McLaughlin, K. A., Borkovec, T. D., & Sibrava, N. J. (2007). The effects of worry and rumination on affect states and cognitive activity. *Behavior Therapy, 38*(1), 23-38.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current directions in psychological science, 21*(1), 8-14.

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

Mogg, K., & Bradley, B. P. (2005). Attentional bias in generalized anxiety disorder versus depressive disorder. *Cognitive Therapy and Research, 29*(1), 29-45.

Mor, N., & Daches, S. (2015). Ruminative thinking: lessons learned from cognitive training. *Clinical Psychological Science, 3*(4), 574-592.

Nolen-Hoeksema, S., & Morrow, J. (1991). A prospective study of depression and posttraumatic stress symptoms after a natural disaster: The 1989 Loma Prieta earthquake. *Journal of Personality and Social Psychology, 61*(1), 115-121.

Nolen-Hoeksema, S., Wisco, B. E., & Lyubomirsky, S. (2008). Rethinking rumination. *Perspectives on Psychological Science, 3*(5), 400-424.

Nosek, B. A., Alter, G., Banks, G. C., Borsboom, D., Bowman, S., Breckler, S., et al. (2015). Promoting an open research culture. *Science, 348*(6242), 1422-1425.

Schönbrodt, F. D., & Perugini, M. (2013). At what sample size do correlations stabilize? *Journal of Research in Personality, 47*(5), 609-612.

Siemer, M. (2005). Mood-congruent cognitions constitute mood experience. *Emotion, 5*(3), 296-308.

Snyder, H. R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive function: A meta-analysis and review. *Psychological Bulletin, 139*(1), 81-132.

Snyder, H. R., Miyake, A., & Hankin, B. L. (2015). Advancing understanding of executive function impairments and psychopathology: bridging the gap between clinical and cognitive approaches. *Frontiers in psychology, 6*.

Stout, D. M., Shackman, A. J., Johnson, J. S., & Larson, C. L. (2015). Worry is associated with impaired gating of threat from working memory. *Emotion, 15*(1), 6-11.

Teuber, H.-L. (1972). Unity and Diversity of Frontal Lobe Functions. *Acta Neurobiol. Exp, 32*, 615-656.

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

Watkins, E. R. (2008). Constructive and unconstructive repetitive thought. *Psychological Bulletin, 134*(2), 163-206.

Watkins, E. R., Moulds, M., & Mackintosh, B. (2005). Comparisons between rumination and worry in a non-clinical population. *Behaviour Research and Therapy, 43*(12), 1577-1585.

Whitmer, A. J., & Gotlib, I. H. (2013). An attentional scope model of rumination. *Psychological Bulletin, 139*(5), 1036.

Yang, Y., Cao, S., Shields, G. S., Teng, Z., & Liu, Y. (2017). The relationships between rumination and core executive functions: A meta-analysis. *Depression and Anxiety, 34*(1), 37-50.

Zetsche, U., D'Avanzato, C., & Joormann, J. (2012). Depression and rumination: Relation to components of inhibition. *Cognition & Emotion, 26*(4), 758-767.

Footnotes

1 We also contacted all authors of included studies and asked whether they have studies examining the relation between RNT and cognitive control, which have not been published. We did not receive any unpublished datasets.