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Sticky Thoughts: Depression and Rumination Are Associated With Difficulties Manipulating Emotional Material in Working Memory

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Abstract

Cognitive inflexibility may play an important role in rumination, a risk factor for the onset and maintenance of depressive episodes. In the study reported here, we assessed participants' ability to either reverse or maintain in working memory the order of three emotion or three neutral words. Differences (or *sorting costs*) between response latencies in backward trials, on which participants were asked to reverse the order of the words, and forward trials, on which participants were asked to remember the words in the order in which they were presented, were calculated. Compared with control participants, depressed participants had higher sorting costs, particularly when presented with negative words. It is important to note that rumination predicted sorting costs for negative words but not for positive or neutral words in the depressed group. These findings indicate that depression and rumination are associated with deficits in cognitive control.

Keywords

attention, depression, memory, cognitive processes

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Depression is associated with a tendency to respond to negative mood states and life events with ruminative thinking (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Recurrent, unintentional, and uncontrollable ruminative thoughts are not only a symptom of depression, but they have also been associated with vulnerability to the onset and recurrence of depressive episodes and with the maintenance of negative affect (Nolen-Hoeksema et al., 2008). Given these findings, it is critical that researchers gain a better understanding of the cognitive processes that may increase rumination. Ruminators tend to perseverate on recurring thoughts that revolve around a particular theme, most frequently related to the causes and implications of their depressive symptoms, and have trouble switching to a new train of thought. Indeed, the results of recent studies suggest that deficits in working memory (WM), a system that provides temporary access to a select set of representations in the service of current cognitive processes (Cowan, 1999; Miyake & Shah, 1999), underlie ruminative responses in depression (Davis & Nolen-Hoeksema, 2000; Joormann, 2010; Joormann & Gotlib, 2008).

WM reflects an individual's focus of attention because it holds the representations of which a person is aware at any given moment. Given the capacity limitation of this system, it is important that the contents of WM be updated efficiently and that information important to an ongoing task is kept accessible (e.g., Friedman & Miyake, 2004). It is also important, however, that people can flexibly manipulate the information that is accessible in WM to respond to changes in the environment and personal goals. Cognitive inflexibility may lead people to become stuck in a particular mind-set (Davis & Nolen-Hoeksema, 2000), which may lead to rumination and depression. Investigators have documented that depression and likely rumination involve difficulties both keeping irrelevant emotional information from entering WM (Goeleven, De Raedt, Baert, & Koster, 2006; Joormann, 2004, 2006) and removing previously relevant negative material from WM (Joormann & Gotlib, 2008). It is imperative, however, that research also examines individuals' ability to manipulate representations that are currently held in WM. When memories and external information enter WM, their position in WM is represented by associations that are formed between these items (Morris & Jones, 1990). To manipulate information in WM, the representations and the associations among them

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must be modified (Morris & Jones, 1990; Shimamura, 2000). In fact, the ability to not only maintain but also manipulate and update information in WM has been associated with individual differences in a range of cognitive processes (Barrouillet, Lépine, & Camos, 2008), including inhibitory control (Minamoto, Osaka, & Osaka, 2010), self-regulatory behavior (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008), and problem solving (De Smedt et al., 2009).

The study reported here was designed to test the hypothesis that depression and rumination are associated with a deficit in the manipulation of negatively valenced material in WM. We modified a WM manipulation task used in previous research (Crone, Wendelken, Donohue, & Bunge, 2006) to investigate participants' ability to manipulate emotional and neutral material in WM. This WM manipulation task distinguishes the ability to manipulate information in WM from the ability to maintain information in WM (Crone et al., 2006). We predicted, first, that compared with their nondepressed counterparts, depressed participants would exhibit deficits in their ability to manipulate negative material in WM, and, second, that difficulties manipulating negative material in WM would be related to individuals' tendency to ruminate.

Method

Participants

Fifty-three individuals participated in this study. Participants were solicited through advertisements posted within the community. Trained interviewers administered the Structured Clinical Interview for DSM-IV Axis I Disorders (First, Spitzer, Gibbon, & Williams, 1996); individuals were included in the depressed group ($n = 26$) if they met the criteria for major depressive disorder (MDD) in the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM–IV; American Psychiatric Association, 1994), and in the control group ($n = 27$) if they did not meet diagnostic criteria for any current or past Axis I disorder. Participants also completed the Beck Depression Inventory-II (BDI; Beck, Steer, & Brown, 1996), a 21-item self-report measure of the severity of depressive symptoms, and the Ruminative Responses Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003), which assesses how participants tend to respond to sad feelings and symptoms of dysphoria.

Demographic and clinical characteristics of the two groups of participants are presented in Table 1. The two groups differed significantly in age, $t(50) = 2.87$, $p < .05$, and education, $\chi^2(1, N = 53) = 5.63$, $p < .05$. As expected, the MDD participants obtained higher scores on the BDI than did control participants, $t(51) = 15.06$, $p < .01$, as well as higher RRS scores, $t(51) = 9.23$, $p < .01$.

Table 1. Demographic and Clinical Characteristics of Participants

Characteristic	Group: Depressed	Group: Control
Sex	8 males, 18 females	14 males, 13 females
Age (years)	46.73 (10.02)	38.42 (10.81)
College educated	46%	77%
Number of participants with a comorbid diagnosis	12	0
Mean depression score	29.92 (9.60)	1.30 (2.32)
Mean rumination score	2.69 (0.49)	1.47 (0.47)

Note: Standard deviations are presented in parentheses. Depression was measured with the Beck Depression Inventory-II (Beck, Steer, & Brown, 1996), and rumination was measured with the Ruminative Responses Scale (Treynor, Gonzalez, & Nolen-Hoeksema, 2003).

Stimuli

We selected 180 positive, 180 neutral, and 180 negative nouns from the Affective Norms of English Words list (Bradley & Lang, 1999), which provides arousal and valence ratings on a 9-point scale. We took care to ensure that the words in the three groups did not differ in length and that the positive and negative words did not differ in arousal ratings. The mean valence ratings were 7.39 ($SD = 0.62$) for the positive nouns, 2.66 ($SD = 0.62$) for the negative nouns, and 5.48 ($SD = 0.55$) for the neutral nouns.

WM manipulation task

On each trial, participants saw three words presented on a computer monitor. The words were presented one at a time for 1,000 ms each (a 750-ms fixation display preceded each word). After the presentation of the three words, a fixation display was presented for 750 ms. This was followed by a cue (either the word "Backward" or the word "Forward" presented for 750 ms) instructing participants either to remember the words in the order in which they were presented (forward) or to reverse the order and re-sort them in WM (backward). The cue was followed by a 3,000-ms delay period to allow participants to rehearse or re-sort the words. Finally, a probe word consisting of one of the three words was presented until the subject responded. Participants were instructed to press a key ("1," "2," or "3") to indicate as quickly and as accurately as possible whether the probe was the first, second, or third word (counting forward or backward, as appropriate) in the set they had been instructed to remember. Responses and response latencies were recorded.

The recognition probe was used to index *sorting costs* (i.e., differences between response latencies on the forward and the backward trials). Sorting costs reflect difficulties in manipulating material in WM independently of individual differences in pure maintenance (Crone et al., 2006). Six conditions were compared (three word valences in each of the three presentation orders; see Table 2). All three words within each trial were positive, negative, or neutral. Whether the first, second, or third word was the correct response was counterbalanced so that the probability of responding "1," "2," or "3" was equal across all six conditions. The experiment consisted of two blocks, with each condition presented 15 times in each block. The sequence of trials within blocks and the order of the blocks

Table 2. Response Latencies and Percentage of Correct Responses in the Two Groups

	Depressed group		Control group	
Sorting order and word valence	Response latency (ms)	Correct responses (%)	Response latency (ms)	Correct responses (%)
Forward				
Negative	1,314 (553)	95	1,086 (401)	94
Positive	1,280 (629)	95	1,023 (373)	95
Neutral	1,321 (643)	94	999 (351)	94
Backward				
Negative	1,871 (855)	87	1,227 (430)	89
Positive	1,702 (784)	91	1,130 (347)	87
Neutral	1,726 (861)	89	1,154 (361)	89

Note: Standard deviations are presented in parentheses. Participants were instructed to sort words either in the order in which they were presented (forward) or in the reverse order (backward).

were randomized. For each participant, a random sample of words was selected from the word lists without replacement.

Results

Correct responses

The mean percentage of correct responses in the different conditions are presented in Table 2. As expected, overall error rates were low. We conducted a repeated measures analysis of variance (ANOVA) to examine differences in the number of correct responses as a function of group, experimental condition, and valence.[1] This ANOVA did not yield significant main effects or interactions.

Decision latencies following probes

We restricted our analyses of decision latencies to trials on which participants made correct responses. To eliminate outliers, we treated decision latencies that exceeded 3 s as missing values (less than 5% of all reaction times). There was no group difference in the number of outlying latencies. Mean response latencies for MDD and control participants in the different experimental conditions are presented in Table 2. We conducted an ANOVA on response latencies, with group as the between-subjects factor and condition (backward, forward) and word valence (neutral, positive, negative) as within-subjects factors. This analysis yielded a significant main effect of valence, $F(2, 102) = 16.78$, $p < .01$, $\eta_p^2 = .25$, a significant main effect of condition, $F(1, 51) = 56.74$, $p < .01$, $\eta_p^2 = .53$, and a significant main effect of group, $F(1, 51) = 8.40$, $p < .01$, $\eta_p^2 = .14$, as well as significant interactions of group and condition, $F(1, 51) = 17.04$, $p < .01$, $\eta_p^2 = .25$, and condition and valence, $F(2, 102) = 5.28$, $p < .01$, $\eta_p^2 = .09$. These effects were qualified, however, by the predicted three-way interaction of group, condition, and valence, $F(2, 102) = 4.45$, $p < .02$, $\eta_p^2 = .08$.[2] To examine this interaction further, we computed sorting costs for each participant by subtracting response latencies in the forward trials from response latencies in the backward trials. Figure 1 shows the mean sorting costs for the three word valences in each group.

Analyses of sorting costs

Our main hypotheses involved group differences in sorting costs. Specifically, we predicted that MDD and control participants would differ in sorting costs for positive, negative, and neutral stimuli. We tested this prediction by conducting a repeated measures ANOVA on sorting costs. This analysis yielded significant main effects for both group, $F(1, 51) = 17.04$, $\eta_p^2 = .25$, and valence, $F(2, 102) = 5.28$, $p < .01$, $\eta_p^2 = .09$. These main effects were qualified, however, by the predicted significant interaction of group and valence, $F(2, 102) = 4.45$, $p < .05$, $\eta_p^2 = .08$.[3] Follow-up tests indicated that MDD and control participants differed in sorting costs for positive words, $t(51) = 3.79$, $p < .01$, $d = 1.04$, negative words, $t(51) = 4.61$, $p < .01$, $d = 1.27$, and neutral words, $t(51) = 3.03$, $p < .01$, $d = 0.83$. Follow-up tests within the control group yielded no significant differences between sorting costs for positive versus neutral words, $t(26) = 1.42$, $p = .17$, positive versus negative words,

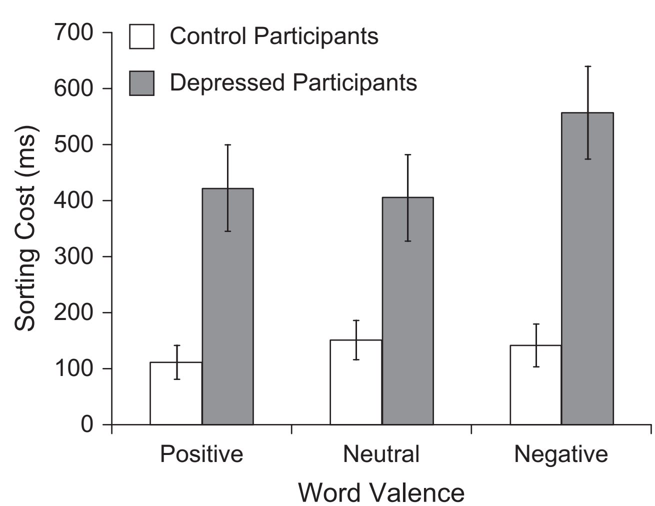

Fig. 1. Mean sorting cost as a function of word valence for control and depressed participants. Sorting costs were calculated by subtracting response latencies on trials in which participants were instructed to remember words in the order in which they were presented from response latencies on trials in which participants were instructed to remember words in the reverse order. Error bars show 1 *SEM*.

$t(26) < 1$, or neutral versus negative words, $t(26) < 1$. In contrast, within the MDD group, participants had significantly higher sorting costs for negative words than for positive words, $t(25) = 2.95$, $p < .01$, and neutral words, $t(25) = 3.72$, $p < .01$; there was no difference in sorting costs for positive versus neutral words, $t(25) < 1$.

Sorting costs and rumination

Our second hypothesis was that sorting costs for negative words would be significantly correlated with rumination. Given the high correlation between BDI and RRS scores ($r = .52$), we conducted a hierarchical linear regression analysis, in which we predicted sorting costs for negative words from RRS scores, controlling for BDI scores and sorting costs for positive and neutral words. In the full sample, we also included group and the interaction of group and RRS scores, as well as the interaction of group and BDI scores. The predictors explained 81% of the variance in sorting costs for negative material, but neither BDI nor RRS scores was a significant predictor. The interaction of group and RRS scores, however, was a significant predictor of sorting costs for negative words ($\beta = 1.28$, $p < .02$). When examining only the control group, this regression was not significant. In contrast, in the MDD group, the regression explained 83% of the variance in sorting costs for negative words: Both RRS scores ($\beta = 0.27$, $p < .05$) and sorting costs for neutral words ($\beta = 0.55$, $p < .01$) were significant and unique predictors of sorting costs for negative words in the MDD group.[4]

Discussion

A growing body of research has linked depression with a tendency to ruminate in response to negative affect (Nolen-Hoeksema et al., 2008). Moreover, numerous studies have demonstrated that rumination is associated with a heightened vulnerability to experiencing depressive episodes (Lyubomirsky & Nolen-Hoeksema, 1993; Nolen-Hoeksema, Parker, & Larson, 1994). Despite this research, however, it is still unclear why some people are prone to ruminate while others find it relatively easy to reorient and recover. One reason may be that ruminators become stuck on recurrent thoughts that revolve around a specific theme and have difficulty flexibly switching to a new train of thought; such perseveration may reflect difficulties manipulating information in WM.

As we predicted, MDD participants in our study found it difficult to manipulate information in WM. Moreover, although MDD compared with control participants were characterized by higher sorting costs in general, these costs were greatest when the material was negatively valenced. Indeed, whereas control participants did not demonstrate differential sorting costs for positive, neutral, and negative words, MDD participants exhibited significantly greater sorting costs for negative than for positive or neutral words. These findings extend previous research on WM function in depression by demonstrating that MDD is associated not only with difficulties keeping irrelevant negative material from entering WM and discarding previously relevant material from WM, but also with difficulty manipulating negative material in WM.

It is important to note that the backward conditions were more difficult than the forward conditions. Although this may make it difficult to attribute our findings to WM manipulation, other studies that have examined the effect of WM load and task difficulty in depression have not reported that increasing load or difficulty results in a valence-specific deficit in MDD subjects (e.g., Levens & Gotlib, 2010). Therefore, we are confident that our manipulation effects, which are restricted to negative valence, reflect differences in WM manipulation that are not fully explained by task difficulty.

We also found that difficulties in the manipulation of negative words, but not of neutral or positive words, were associated with increases in self-reported rumination in the MDD participants. These results add to findings of previous studies documenting an association between rumination and cognitive inflexibility (Altamirano, Miyake, & Whitmer, 2010; Whitmer & Banich, 2007), and between rumination and both the intrusion of irrelevant material into WM and the ability to discard irrelevant material from WM (Joormann & Gotlib, 2008). In the study reported here, self-reported rumination was related to cognitive inflexibility specifically in the manipulation of negative material, but only in individuals diagnosed with MDD. Most studies investigating rumination and cognitive flexibility have used neutral material (e.g., Altamirano et al., 2010; Whitmer & Banich, 2007) with unselected or dysphoric samples, not people diagnosed with MDD. This is the first study to assess these constructs with valenced stimuli in clinically depressed individuals, for whom the salience of negative material is likely greater than it is for unselected participants. Therefore, it is likely that discrepancies between the current findings and the results of other studies are due to differences in both participant samples and stimuli.

Given the cross-sectional design of our study, formulations concerning underlying mechanisms of rumination are necessarily speculative. Investigating individual differences in executive functioning in WM has the potential to yield important insights concerning the maintenance of negative affect and vulnerability to experiencing depressive episodes. Difficulties manipulating material in WM may affect people's ability to regulate negative affect by impairing the formation of new associations within WM. For example, down-regulating an emotional response requires that existing associations be reorganized to alter the meaning of a stimulus or event, whereas reappraisal requires that new associations be formed between accessible negative content and novel positive content. Examining people's ability to manipulate the contents of WM promises to be critical in identifying individuals who recover easily from negative affect and differentiating them from individuals who tend to get stuck in a vicious cycle of increasingly negative ruminative thinking and deepening sad mood.

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Sara M. Levens is now at the University of Pittsburgh.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Notes

1. Including age and level of education as covariates did not alter the findings.
2. Including age and level of education as covariates did not alter the three-way interaction, $F(2, 94) = 3.95$, $p < .02$, $\eta_p^2 = .08$.
3. Including age and level of education as covariates did not alter the two-way interaction, $F(2, 94) = 3.95$, $p < .02$, $\eta_p^2 = .08$.
4. Using the Brooding and Reflection subscales of the RRS did not yield significant findings in any analysis.

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