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Updating the Contents of Working Memory in Depression: Interference From Irrelevant Negative Material

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This study was designed to assess the effects of irrelevant emotional material on the ability to update the contents of working memory in depression. For each trial, participants were required to memorize 2 lists of emotional words and subsequently to ignore 1 of the lists. The impact of irrelevant emotional material on the ability to update the contents of working memory was indexed by response latencies on a recognition task in which the participants decided whether or not a probe was a member of the relevant list. The authors compared response latencies to probes from the irrelevant list to response latencies to novel probes of the same valence (intrusion effect). The results indicate that, compared to control participants in both neutral and sad mood states, depressed participants showed greater intrusion effects when presented with negative words. In an important finding, intrusion effects for negative words were correlated with self-reported rumination. These findings indicate that depression is associated with difficulties removing irrelevant negative material from working memory. Results also indicate that the increased interference from irrelevant negative material is associated with rumination.

Keywords: depression, working memory, cognition, emotion, attention

Recurrent and often unintentional and uncontrollable thoughts that involve negative, self-deprecating statements and pessimistic ideas about the self, the world, and the future are a hallmark of depressive episodes. Not only are these ruminative thoughts a debilitating symptom of depression but they have also been associated with vulnerability to the onset of depression, the recurrence of depressive episodes, and the maintenance of negative affect (Nolen-Hoeksema, 2000; Nolen-Hoeksema & Larson, 1999; Roberts, Gilboa, & Gotlib, 1998). It is critical, therefore, that we gain a better understanding of the underlying processes that increase the occurrence of ruminative thinking and, consequently, of the nature of the association between rumination and depression.

Investigators examining the interaction of cognition and emotion have proposed that the experience of negative mood is generally associated with, or consists in part of, the activation of mood-congruent representations in working memory (Isen, 1984; Siemer, 2005). Thus, negative mood has been found to be related to more frequent negative thoughts, to selective attention to negative stimuli, and to greater accessibility of negative memories (Blaney, 1986; Mathews & MacLeod, 2005; Rusting, 1998). This research has also demonstrated, however, that negative mood alone does not necessarily lead to prolonged rumination. Indeed, changes in cognition due to negative mood are usually transient, and mood-congruent cognitions are often quickly replaced by thoughts and memories that serve to regulate and repair the mood state (Erber & Erber, 1994; Parrott & Sabini, 1990; Rusting & DeHart, 2000). The critical question, therefore, is why, in response to negative mood, some people fail to regulate their mood and instead initiate a self-defeating cycle of increasingly negative ruminative thinking and intensifying negative affect. If changes in mood are, in fact, associated with activations of mood-congruent material in working memory, the ability to control the contents of working memory might play an important role in the development of rumination and, therefore, in recovery from negative mood.

Working memory is a limited-capacity system that provides temporary access to a select set of representations in the service of current cognitive processes (Cowan, 1999; Miyake & Shah, 1999). Thus, working memory reflects the focus of attention, holding those representations that a person is aware of at any given moment. Given the capacity limitation of this system, it is important that the contents of working memory be updated efficiently. It has been proposed that this task is controlled by executive processes and, more specifically, by inhibition (e.g., Friedman & Miyake, 2004; Hasher, Zacks, & May, 1999). Indeed, Hasher and Zacks (1988) posited that the efficient functioning of working memory depends on inhibitory processes that limit the access of information and update working memory by removing information that is no longer relevant. It is noteworthy, therefore, that several researchers have suggested that rumination and depression are associated with deficits in executive function, particularly in inhibition (Hertel, 1997; Joormann, 2005; Linville, 1996). Dysfunctions in updating the contents of working memory—more specifically an inability to appropriately expel negative cognitions and memories that were activated by a negative mood state from working memory as they become irrelevant—would lead to difficulties attending to and processing new information, result in rumination, and thereby make a depressive episode more likely.

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A small number of investigators have examined associations between interference from emotional material, depression, and rumination by using a modified negative priming task (Goeleven, De Raedt, Baert, & Koster, 2006; Joormann, 2004). In this task, participants are instructed to respond to a target stimulus while ignoring a simultaneously presented emotional stimulus that is clearly marked as to-be-ignored and irrelevant to the task; on the subsequent trial, the to-be-ignored emotional stimulus may become the target. Negative priming is operationalized as the differential delay between responding to a previously ignored stimulus and responding to a novel stimulus (Hasher et al., 1999; Tipper, 2001; Wentura, 1999). Joormann (2006) found that participants who scored high on a self-report measure of rumination exhibited reduced negative priming in response to emotional distractors, a finding that remained significant even after partialing out the level of depressive symptoms. Joormann (2004) demonstrated that dysphoric participants and participants with a history of depressive episodes also exhibited reduced negative priming in response to negative material that they were instructed to ignore. Finally, Goeleven et al. (2006) recently replicated these findings using a negative priming task with emotional faces. These investigators demonstrated that, compared to nondepressed controls, depressed participants showed reduced negative priming of sad facial expressions but intact negative priming of happy expressions. It is important to note, however, that negative priming tasks assess only one aspect of interference: the ability to control the access of relevant and irrelevant material to working memory. While these studies suggest that depression, and probably also rumination, involve difficulty in keeping irrelevant emotional information from entering working memory, no studies have examined whether depression and rumination are also associated with difficulty in removing previously relevant negative material from working memory. Difficulties inhibiting the processing of negative material that is no longer relevant might explain why people respond to negative mood states and negative life events with recurring, uncontrollable, and unintentional negative thoughts.

The present study was designed to test the formulation that depression and rumination are associated with a specific deficit in updating the contents of working memory that results in increased interference from irrelevant negative material. We posit that depression involves an inability to fully inhibit representations of previously relevant negative material. This inhibitory deficit leads to the prolonged activation of negative material in working memory, resulting in sustained negative affect and recurring negative thoughts. Thus, we propose that the inability to remove irrelevant negative information from working memory is related to the tendency to respond to negative mood and events with rumination. To test this hypothesis, we adapted a modified Sternberg task developed by Oberauer (2001, 2005a, 2005b) that combines a short-term recognition task with instructions to ignore a previously memorized list of words to assess interference from irrelevant positive and negative stimuli. In this task, two word lists are presented simultaneously. After the lists are memorized, a cue indicates which of the two lists is relevant for the recognition task on the next display, in which participants indicate whether the probe that is presented came from the relevant list; probes from the no-longer-relevant list must be rejected, as must new probes.

Oberauer (2001) and investigators who have used similar designs have found that participants take longer to reject probes from the no-longer-relevant list than they do new probes (Monsell, 1978; Neuman & DeSchepper, 1992). These studies also demonstrate that participants have an automatic tendency to endorse items from the irrelevant list, which must be overridden. Thus, Oberauer (2001, 2005a, 2005b) has suggested that the difference between reaction times to an intrusion probe (i.e., a probe from the irrelevant list) and reaction times to a new probe (i.e., a completely new word) reflects the strength of the residual activation of the contents of working memory that were declared to be no longer relevant and, therefore, assesses a person's ability to update the contents of working memory. Given the focus in the present study on depression and rumination, we varied the valence of stimuli in the relevant and the irrelevant lists. This design allows us to compare negative and positive intrusion probes to new words of the same valence in order to assess participants' ability to remove both negative and positive material from working memory. In addition, to test the proposition that difficulties in updating the contents of working memory are not due solely to a negative mood state, we examined interference from irrelevant material both in currently depressed participants and in control participants who were induced to feel sad. We predicted that, compared to their nondepressed counterparts (both exposed and not exposed to a sad mood induction), depressed participants would exhibit increased interference from irrelevant negative material, as reflected by increased decision latencies to negative words from lists that are no longer relevant (i.e., a greater intrusion effect). We also predicted that the ability to update the contents of working memory would be related to the tendency to ruminate.

Method

Overview

In this experiment we used a modified Sternberg task modeled after a task used by Oberauer (2001, 2005a, 2005b). Each trial in the experiment consisted of three separate displays: a learning display, a cue display, and a probe display. In the learning display, two lists of three words each were presented simultaneously. The words in one of the lists were presented in blue, and the words in the other list were presented in red. Words also differed in valence: Some of the words were positive, and others were negative. After the offset of the word lists, a cue was presented that informed participants which of the two word lists would be relevant for the recognition task that followed. The cue was either a red frame, which signaled that the red list would be relevant, or a blue frame, which signaled that the blue list would be relevant. Finally, in the probe display, a single black word appeared inside the red or blue frame, and participants were asked to indicate whether this word was from the relevant list. Participants were asked to respond as quickly and as accurately as possible by pressing the *1* key on the computer keyboard for "Yes" if the word came from the relevant list, or the *2* key for "No" if the word did not come from the relevant list. Participants' responses and the latency of their key presses were recorded.

Participants

Participants were recruited from two outpatient psychiatry clinics in a university teaching hospital, as well as through advertisements posted in numerous locations within the community (e.g., Internet bulletin boards, university kiosks, supermarkets). Participants' responses to a telephone interview provided initial selection information. This phone screen established that participants were fluent in English and were between 18 and 60 years of age. We excluded participants if they reported severe head trauma or learning disabilities, current or lifetime anxiety disorder, psychotic symptoms, bipolar disorder, or alcohol or substance abuse within the past 6 months. Eligible individuals were invited to come to the laboratory for a more extensive interview.

Trained interviewers administered the Structured Clinical Interview for the *DSM–IV* (SCID; First, Spitzer, Gibbon, & Williams, 1996) to eligible participants during their first session in the study. The SCID has demonstrated good reliability for the majority of the disorders covered in the interview (Skre, Onstad, Torgeresn, & Kringlen, 1991; Williams et al., 1992). All interviewers had extensive training in the use of the SCID, as well as previous experience in administering structured clinical interviews with psychiatric patients. In previous studies, our team of interviewers achieved excellent interrater reliability. The κ coefficients were .93 for the diagnosis of major depressive disorder (MDD) and .92 for the "nonpsychiatric control" diagnosis (i.e., the absence of current or lifetime psychiatric diagnoses). For the current study, two independent raters rated a randomly selected sample of 25% of the SCID tapes and achieved perfect agreement with the original interviewers. Although this represents excellent reliability, we should note that the interviewers used the "skip out" strategy of the SCID, which may have reduced the opportunities for the independent raters to disagree with the diagnoses (Gotlib et al., 2004).

Participants were included in the depressed group if they met the MDD criteria of the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994). The never-disordered control group consisted of individuals with no current diagnosis and no history of any Axis I disorder. Participants were scheduled for a second session of "computer tasks," usually within 2 weeks after the interview. Sixty-three individuals (23 diagnosed with MDD and 40 never-disordered controls) participated in this study. The control participants were randomly assigned either to receive (CTL-SAD; $N = 19$) or not to receive (CTL; $n = 21$) a sad mood induction.

Questionnaires

Participants completed the Beck Depression Inventory—II (BDI; Beck, Steer, & Brown, 1996), a 21-item, self-report measure of the severity of depressive symptoms. The acceptable reliability and validity of the BDI has been well documented (Beck, Steer, & Garbin, 1988). We also administered the 22-item Ruminative Response Scale (RRS) of the Response Style Questionnaire (Nolen-Hoeksema & Morrow, 1991) to examine how participants tend to respond to sad feelings and symptoms of dysphoria. The RRS assesses responses to dysphoric mood that are focused on the self (*think about all your shortcomings, failings, faults, mistakes*), on symptoms (*think about how hard it is to concentrate*), or on possible consequences and causes of moods (*analyze recent events to try to understand why you are depressed*) using a 4-point scale (*almost never* to *almost always*). In addition, the RRS assesses behavioral responses to sad moods (*go someplace alone to think about your feelings*). Previous studies using this measure have shown good test–retest reliability and acceptable convergent and predictive validity (Nolen-Hoeksema & Morrow, 1991; Nolen-Hoeksema, Parker, & Larsen, 1994; Treynor, Gonzales, & Nolen-Hoeksema, 2003). Treynor et al. (2003) recently suggested that the RRS is composed of two subscales that reflect adaptive and maladaptive components of rumination. Treynor et al. have interpreted the five-item Reflective Pondering subscales as assessing "a purposeful turning inward to engage in cognitive problem solving to alleviate one's depressive symptoms," and the five-item Brooding subscale as assessing "a passive comparison of one's current situation with some unachieved standard" (p. 256). Given that Treynor et al. have reported that these subscales differentially predict concurrent and future depression, we included the Reflective Pondering and Brooding subscales in this study. Both subscales have been found to have acceptable internal consistencies and retest reliabilities (Treynor et al., 2003).

Mood Induction

Before participating in the task, half of the control participants were instructed to listen to sad music and try to imagine unpleasant times in their life that made them unhappy. The participants were asked to experience as intensely as possible the feelings of the music and their memories, and to listen to the tape for 3 min. The effectiveness of the mood manipulation was assessed with a visual analogue scale administered before and after the mood induction. Participants rated their mood state on a 10-point bipolar scale anchored with -5 (*very sad*) and $+5$ (*very happy*).

Stimuli

Words from the Affective Norms of English Words (Bradley & Lang, 1999), which lists valence and arousal ratings for over 1,000 English adjectives, verbs, and nouns on 9-point scales, were used as stimuli. Nouns with a rating of 4 or less were examined for possible inclusion in the negative valence condition, and nouns with a rating of 6 or more were examined for inclusion in the positive valence condition. We selected words from these lists, taking care to ensure that the positive and negative words did not differ in arousal ratings or word length. The final set of 208 positive nouns had an average valence rating of $M = 7.28$ ($SD = 0.64$) and an arousal rating of $M = 5.49$ ($SD = 0.95$), while the final set of 208 negative nouns had an average valence rating of $M = 2.83$ ($SD = 0.72$) and an average arousal rating of $M = 5.42$ ($SD = 0.85$). Positive and negative words in the two conditions did not differ on the arousal dimension or in average word length, both $ts(414) < 1$, *ns*.

Design and Procedure

We compared three different groups of participants (MDD, CTL, CTL-SAD groups). Our task consisted of eight different conditions (see Table 1): we varied the valence of the words in the relevant list (positive or negative) and the probe type (relevant probes [i.e., words from the relevant list]; intrusion probes [i.e., words from the irrelevant list]; new positive probes; and new negative probes). Each condition was presented four times in each block, and each run was composed of three blocks. In the critical trials, the red and the blue list included either only positive words

Table 1
Experimental Conditions, Response Latencies, and Percentage of Correct Responses

				MDD			CTL			CTL-SAD		
Cond	Relevant	Irrelevant	Probe	*M*	*SD*	%	*M*	*SD*	%	*M*	*SD*	%
1	Positive	Negative	Relevant	1,135	194	93	1,106	236	95	1,097	372	96
2	Positive	Negative	Intrusion	1,493	186	86	1,308	318	94	1,155	344	86
3	Positive	Negative	New positive	1,062	225	97	1,056	251	99	1,012	321	98
4	Positive	Negative	New negative	1,040	207	99	1,027	275	100	986	308	99
5	Negative	Positive	Relevant	1,181	187	89	1,124	194	96	1,113	340	95
6	Negative	Positive	Intrusion	1,389	185	86	1,387	336	94	1,283	311	86
7	Negative	Positive	New positive	1,060	264	99	1,016	223	100	988	331	98
8	Negative	Positive	New negative	1,098	221	98	1,020	201	99	1,001	307	97

Note. Cond = condition; MDD = participants diagnosed with major depressive disorder; CTL = control group; CTL-SAD = control group with sad mood induction.

or only negative words, and the two lists always differed in valence. In addition to these critical trials, we included eight trials in each block in which positive and negative words were mixed within the red or blue lists to discourage participants from using the valence of the lists as a cue when responding to the probes and to be able to assess the use of this strategy.[1] Thus, we presented 120 trials, which were preceded by five practice trials. For each participant, a random sample of words was selected from the word lists without replacement. Thus, words were never repeated within a block but could be presented up to three times within the experiment. All possible combinations of color assignment to the positive or negative list and the presentation of the blue and red lists in the upper or lower part of the screen were presented equally often within each block. The sequence of trials within blocks and the order of the blocks were randomized.

Each of the trials began with the presentation of a fixation cross for 500 ms, followed by the simultaneous presentation of six words arranged in two rows of three words each (*learning display*). The words in one row were presented in blue, and the words in the other row were presented in red. The participants were instructed to read the words and to memorize them. The presentation time for this display was 7.8 s (1.3 s $\times$ number of words in the display). Next, a blank screen was presented for 800 ms, followed by the frame for 1 s (*cue display*). The frame was either blue or red to indicate which of the two lists just presented would be relevant for making the upcoming probe decision. Finally, the probe was presented in black in the frame in the center of the screen and remained on the screen until the participants made their response (*probe display*).

Participants were tested individually within 2 weeks after their initial diagnostic interview. Half of the control participants (selected randomly) were administered a mood assessment, followed by a sad mood induction, followed by another mood assessment. Participants were told that the experiment was designed to assess memory and learning. After responding to practice trials to familiarize themselves with the procedure and the stimuli, participants were presented with the 120 trials in three blocks with short breaks between the blocks. The entire task took about 30 min. Finally, participants completed the questionnaires described above.

Results

Participant Characteristics

Demographic and clinical characteristics of the three groups of participants are presented in Table 2. As is evident from the table, the three groups did not differ significantly in age, $F(2, 60) < 1$, or education, $\chi^2(2) < 1$, *ns*. As expected, the groups did differ in their BDI scores, $F(2, 60) = 63.63$, $p < .01$; the MDD group had significantly higher BDI scores than did the CTL and the CTL-SAD participants, both *p*s $< .05$. In addition, MDD participants reported a greater tendency to respond to negative life events and negative mood states with rumination, as indicated by their elevated RRS scores, $F(2, 60) = 21.12$, $p < .01$, compared to the CTL and the CTL-SAD participants. Two participants in the MDD group reported comorbid disorders: 1 participant was diagnosed with comorbid dysthymia and 1 with comorbid dysthymia and binge eating disorder. Finally, the analysis of the pre–post induction sad mood ratings indicated that the mood induction was successful in the CTL-SAD group, $t(18) = 9.60$, $p < .01$.

Correct Responses

Oberauer (2001, 2005a, 2005b) found low overall error rates using a similar modified Sternberg task; consequently, we did not expect to find valence or group differences in error rates in the present study. The mean percentages of correct responses in the different conditions are presented in Table 1. As expected, overall error rates were low (MDD, 6.6%; CTL, 2.8%; CTL-SAD, 5%). We conducted mixed effects analyses of variance (ANOVAs) to examine differences in the number of correct responses as a function of group and experimental condition. We conducted a two-way ANOVA (Group [MDD, CTL, CTL-SAD] $\times$ Probe Valence [positive, negative]) to examine group differences in

[1] We included control trials in which we presented lists that included both positive and negative words (mixed lists) to evaluate the use of valence as a strategy to make decisions about the probes. If participants remember the valence of the lists instead of the words, their performance should decrease in the mixed lists trials. Overall, however, response accuracy for the mixed list trials was well above 90% and did not differ among groups, $F(2, 60) < 2$, *ns*.

Table 2
Characteristics of Participants

Variables	Group MDD	CTL	CTL-SAD
N (N female)	23 (16)	21 (14)	19 (12)
Age	35.45_a (10.83)	35.52_a (12.49)	33.42_a (8.90)
College education (%)	69	66	78
Participants with comorbid diagnosis	2	0	0
Beck Depression Inventory	27.48_a (11.48)	1.19_b (1.99)	1.25_b (2.05)
Rumination Scale	51.63_a (13.23)	31.54_b (6.76)	30.26_b (6.95)
Reflective pondering	11.01_a (3.17)	9.25_a (3.69)	8.18_a (2.07)
Brooding	12.12_a (4.47)	6.86_b (1.77)	7.18_b (2.01)

Note. In last seven rows, standard deviations are shown in parentheses. Means with the same subscript are not significantly different at $p < .05$. MDD = patients diagnosed with major depressive disorder; CTL = control group; CTL-SAD = control group with sad mood induction.

correctly identifying relevant words. This ANOVA, which compared the correct responses of participants in three groups to probes from the relevant list (Conditions 1 and 5; see Table 1), yielded only a significant main effect for group, $F(2, 60) = 3.56$, $p < .05$; neither the main effect for probe valence nor the interaction of group and probe valence was significant, both Fs < 1. Follow-up tests indicated that the MDD participants had significantly fewer correct responses to relevant probes than did either the CTL participants, $t(42) = 2.20$, $p < .05$, or the CTL-SAD participants, $t(40) = 2.12$, $p < .05$, who did not differ significantly from each other, $t(38) < 1$, *ns*. We also conducted a three-way ANOVA (Group [MDD, CTL, CTL-SAD] × Probe Valence [positive, negative] × Condition [irrelevant, control]) comparing correct responses to intrusion probes (i.e., probes from the irrelevant list; Conditions 2 and 6 in Table 1) to responses to new probes of the same valence (Conditions 4 and 7 in Table 1). This analysis yielded only a significant main effect for condition, $F(1, 60) = 51.14$, $p < .01$. Overall, participants made fewer errors when evaluating a new probe than an intrusion probe. No other significant main effects or interactions with valence or group were obtained. In sum, therefore, while depressed participants made more errors in the relevant trials, there was no difference between depressed and control participants in the intrusion trials.

Decision Latencies to Relevant Probes

For all conditions (relevant and irrelevant 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 (fewer than 5% of all reaction times). No group differences in the number of outlying latencies were obtained, $F(2, 60) < 1$. Mean decision latencies for participants in the three groups in the different experimental conditions are presented in Table 1. We had no specific predictions for group or valence differences in response to the relevant probe words and, in fact, a two-way ANOVA (Group [MDD, CTL, CTL-SAD] × Probe Valence [positive, negative]) conducted on the decision latencies in response to probes from the relevant lists (Conditions 1 and 5 in Table 1) yielded no significant main effects or interactions, all Fs < 1.[2]

Decision Latencies to Intrusion Probes (Intrusion Effects)

Our main hypotheses involve decision latencies to the intrusion probes.[3] First, we predicted a significant three-way interaction of group, valence, and condition. We expected that depressed participants would show increased interference from irrelevant negative words and, therefore, that MDD participants would be significantly slower than controls to decide whether negative intrusion probes came from the relevant list; no group differences were expected for decisions about new probes of the same valence. We tested this prediction by analyzing the decision latencies in the irrelevant condition with a three-way mixed-effects ANOVA (Group [MDD, CTL, CTL-SAD] × Probe Valence [positive, negative] × Condition [irrelevant, new]) (Conditions 2, 6 vs. 4, 6 in Table 1). This analysis yielded a significant main effect for condition, $F(1, 60) = 124.99$, $p < .01$, which was qualified by the predicted significant three-way interaction of group, valence, and condition, $F(2, 60) = 5.03$, $p < .01$. Because our hypothesis posits an interaction of group and condition only for negative intrusion probes, we conducted follow-up tests separately for positive and negative probes. For positive probes we obtained a significant main effect for condition, $F(1, 60) = 92.80$, $p < .01$; no other main effects or interactions were significant, all Fs < 2, *ns*. For the negative probes, however, we obtained significant main effects for group, $F(2, 60) = 3.38$, $p < .05$, and for condition, $F(1, 60) = 86.65$, $p < .01$, which were qualified by the predicted significant interaction of group and condition, $F(2, 60) = 6.61$, $p < .01$. Mean decision latencies for the interaction are presented in Figure 1. While no group differences were obtained for decision latencies to the new negative probes, all ts < 1, *ns*, MDD participants took significantly longer to decide whether a negative intrusion probe

[2] We did not compare decision latencies to new probes in the relevant condition to relevant probes. Whereas the former require a "no" response, the relevant probes require a "yes" response; these conditions, therefore, cannot meaningfully be compared.

[3] We calculated internal consistency scores for the intrusion effects to investigate the reliability of our reaction-time data. Cronbach's alpha for the intrusion score for negative words was .91.

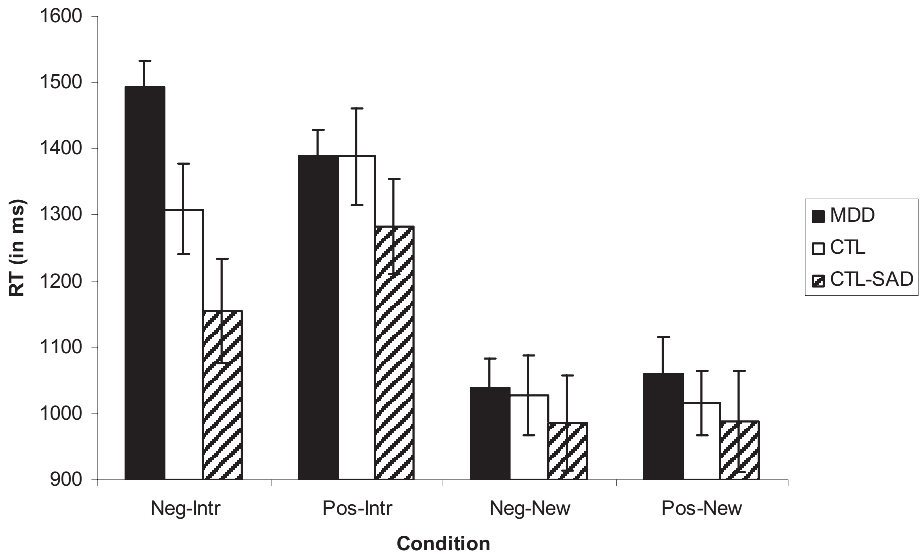

Figure 1. Mean decision latencies for negative intrusion probes (Neg-Intr), positive intrusion probes (Pos-Intr), new negative probes (Neg-New), and new positive probes (Pos-New) in participants with major depressive disorder (MDD), control participants (CTL), and control participants with a sad mood induction (CTL-SAD). Error bars represent one standard error. RT = response time.

was relevant than did the CTL participants in a neutral mood state, $t(42) = 2.37$, $p < .05$, and the CTL-SAD participants, $t(40) = 4.06$, $p < .01$, who did not differ significantly from each other, $t(38) = 1.47$, *ns*.

Following Oberauer (2001), to examine this finding further, we calculated intrusion effects (decision latencies to intrusion probes minus decision latencies to new probes of the same valence), which are presented in Figure 2. No group differences were found in intrusion effects when comparing responses to positive material, all *t*s < 1, *ns*. As predicted, however, MDD participants had significantly higher intrusion effects when responding to negative material than did both the CTL participants, $t(42) = 2.60$, $p < .01$, $d = 0.78$, and the CTL-SAD participants, $t(40) = 3.38$, $p < .01$, $d = 1.03$, who did not differ from each other, $t(38) < 2$, *ns*.

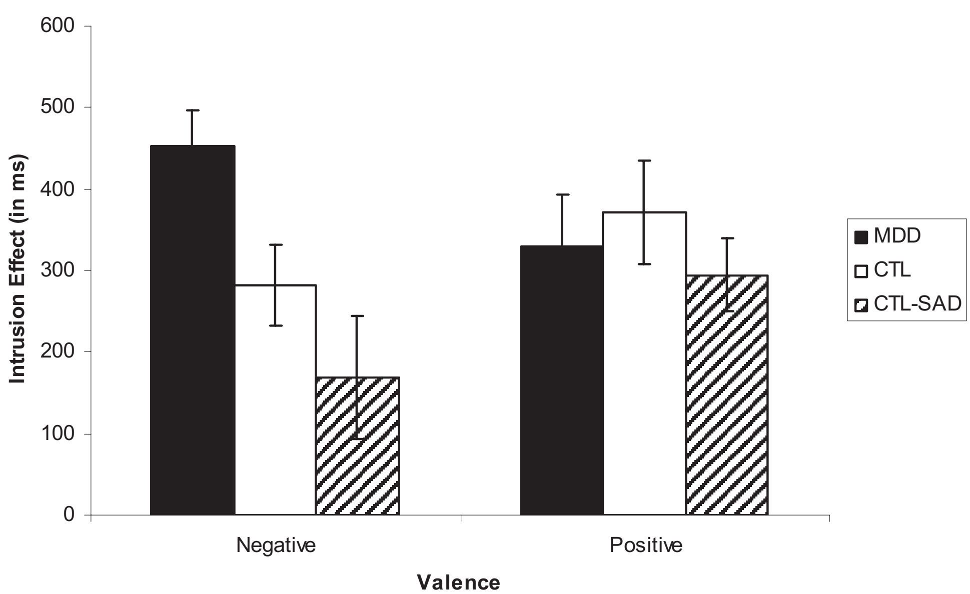

Figure 2. Mean intrusion effects for negative and positive material (response time to intrusion probes minus response time to new probes) in participants diagnosed with major depressive disorder (MDD), control participants (CTL), and participants with a sad mood induction (CTL-SAD) as a function of valence of facial expression. Error bars represent one standard error.

Table 3
Correlations and Regression Analysis of Intrusion Effects, BDI scores, and Rumination

Measures	Intrusion		Regression analysis		
	Negative	Positive	DV:RRS	β	ΔR^2
Group: MDD (N = 23)					
Intrusion Positive	.46*		Step 1:	BDI: .71*	.50*
BDI	.25	.03	Step 2:	BDI: .62*	.11*
RRS	.49*	.16		Intrusion negative: .34*	
Reflection	.50*	.16			
Brooding	.48*	.34			
Group: CTL (N = 40)					
Intrusion Positive	.46*				
BDI	.17	.23			
RRS	.23	.19			
Reflection	.21	.29			
Brooding	.26	.03			

Note. DV = dependent variable; RRS = Rumination Scale; MDD = major depressive disorder; CTL = control; Intrusion = intrusion effect in the Modified Sternberg Task; BDI = Beck Depression Inventory.
* $p < .05$.

Intrusion Effects and Rumination

Our second main hypothesis was that the interference from irrelevant negative material would be related to individual differences in rumination. We expected, therefore, that the intrusion effect for negative material would be significantly correlated with individual differences in rumination. We computed correlations between intrusion effects for positive and negative material in the modified Sternberg task and self-reported depressive symptomatology and rumination within the groups of MDD and CTL participants.[4] Table 3 presents the results of this analysis. Significant correlations between intrusion effects and rumination were found only in the MDD group, not in the CTL group. Given the high correlation of BDI and rumination scores within the MDD group (r = .71), we conducted a hierarchical linear regression analysis in which we predicted individual differences in rumination by entering BDI scores in Step 1 and intrusion effects for negative material in Step 2. In this regression model, both BDI scores and intrusion effects for negative material were significant predictors of individual differences in rumination in the MDD group and together explained 61% of the variance in rumination scores.

Discussion

Depression is associated with a tendency to respond to negative mood states and negative life events with ruminative thinking (Nolen-Hoeksema, 2000; Nolen-Hoeksema & Morrow, 1991). Moreover, numerous studies have demonstrated that rumination is linked to a heightened vulnerability for the onset and maintenance of depressive episodes (Lyubomirsky & Nolen-Hoeksema, 1993, 1995; Nolen-Hoeksema, 1991; Nolen-Hoeksema, Morrow, & Fredrickson, 1993). Despite this growing body of research, however, it is still unclear why some people are especially prone to ruminate while others find it relatively easy to reorient and recover from sad mood states. Previous research has reported that rumination is related to memory deficits and memory biases (Hertel, 1998; Lyubomirsky, Caldwell, & Nolen-Hoeksema, 1998). In the present study, we used a modified Sternberg task to test the hypotheses that depressed individuals experience difficulty updating the contents of working memory (more specifically, that they experience interference from irrelevant negative material), and that this difficulty is associated with rumination and might, therefore, be an important mechanism by which depression and rumination are related.

As predicted, the results of this study indicate that participants diagnosed with major depression exhibit increased interference from irrelevant negative material when updating the contents of working memory. Specifically, compared to never-depressed controls, depressed individuals demonstrated greater decision latencies to an intrusion probe (i.e., a probe from the irrelevant list) than to a new probe (i.e., a completely new word), reflecting the strength of the residual activation of the contents of working memory that were declared to be no longer relevant (see Oberauer, 2001, 2005a, 2005b). An important finding is that this pattern was not found for positive material. To examine whether these difficulties were due simply to elevated levels of sad mood, we compared the performance of depressed participants to that of never-depressed participants who completed the task after receiving a sad mood induction. We find it important that the depressed participants exhibited greater interference from irrelevant negative material than did the control participants who were in a sad mood, indicating that a negative mood state alone is not sufficient to explain this effect. We also found that interference from negative irrelevant words was correlated with self-reported rumination. This relation with rumination was limited to the MDD group and remained significant even after partialing out the level of depressive symptomatology: the higher the participants' scores on a self-report measure of rumination, the more difficulty they exhib-

[4] The correlations within the control group without the mood induction did not differ from the correlations within the control group with the negative mood induction. Therefore, we collapsed across the control groups.

ited in removing task-irrelevant negative material from working memory. In sum, therefore, the present findings suggest that depression and rumination are associated with impairments in updating the contents of working memory—specifically, with difficulties in removing irrelevant negative material from working memory.

This study adds to a small but growing literature linking depression and rumination with difficulties in inhibiting negative material. As we noted earlier, investigators have recently used a negative affective priming task to examine inhibition of emotional stimuli in depression. Although the results of these studies indicate that depression and a lifetime diagnosis of depressive episodes are related to increased interference in the processing of negative material (Goeleven et al., 2006; Joormann, 2004), it is important to recognize that the negative priming task and the modified Sternberg task differ in the degree to which stimuli are processed. In the negative priming task, participants are instructed to completely ignore the stimuli that are irrelevant to their response, to not process them at all. In contrast, in the Sternberg task, participants are instructed first to memorize all of the words in two lists, and then to ignore or forget one of the lists. Thus, while the negative priming design assesses individual differences in controlling the access of irrelevant material to working memory, the modified Sternberg task assesses individual differences in removing irrelevant material from working memory. Certainly, these two mechanisms are not mutually exclusive; indeed, they may contribute additively to rumination and depression. If a negative mood state is associated with the activation of mood-congruent material in working memory, the ability to restrict access to working memory could be closely related to the initial response to the mood-inducing situation, whereas the ability to update the contents of working memory may be associated more strongly with recovery from the mood state.

These findings are also consistent with a small number of studies that have used a "directed forgetting" task to examine individual differences in instructed forgetting (e.g., Korfine & Hooley, 2000; Tolin, Hamlin, & Foa, 2002). Of these, only one has examined intentional forgetting by participants diagnosed with MDD. Power, Dalgleish, Claudio, Tata, and Kentish (2000) used a directed forgetting paradigm in which, halfway through the learning phase, depressed and nondepressed participants were instructed to forget the words they had learned so far. When participants were tested on their final recall for words from both halves of the list, only the depressed participants showed better memory for the to-be-forgotten negative than for the to-be-forgotten positive words in the first half of the list. We find it interesting, however, that Power et al. found this effect only in one of their three studies, in which participants were asked to make self-reference judgments about the words. One significant difference between our study and Power et al.'s investigation is that we did not have participants encode the stimuli self-referentially; future research would do well to assess the effects of this procedure more explicitly.

Although investigators have suggested that a deficit in executive functioning and, in particular, in inhibition plays an important role in rumination (Hertel, 1997; Linville, 1996), the current study is among the first to demonstrate such an association empirically. Because previous studies assessed executive functions while participants were processing neutral stimuli, they do not address the important question of why rumination typically involves negatively valenced material. For example, Davis and Nolen-Hoeksema (2000) used the Wisconsin Card Sorting Task and found that, compared to nonruminators, ruminators made more perseverative errors, regardless of their level of depressive symptomatology. Watkins and Brown (2002) induced rumination in depressed participants and demonstrated that, compared both to depressed participants in a distraction group and to nondepressed participants in a rumination group, these participants showed stereotyped counting responses in a random number generating task, reflecting their difficulty inhibiting prepotent responses. In contrast to these results, Goeleven et al. (2006) found that self-reported level of rumination was not related to differences in negative priming in response to sad faces. Goeleven et al. suggested that this finding might be due to the use of facial expressions, underscoring the potentially important association between rumination and semantic material, such as that found in the present study. In addition, however, it is possible that rumination is related more closely to difficulties expelling negative material from working memory than to difficulties controlling access of negative material to working memory, a formulation that should be examined more explicitly in future research.

This study provides a critical first step in investigating the relations among working memory, rumination, and depression. Given the cross-sectional design of this study, formulations concerning underlying mechanisms and consequences are necessarily speculative. Although investigators have demonstrated that rumination is not simply a symptom of depression but also predicts the onset of depressive episodes (Just & Alloy, 1997; Nolen-Hoeksema, 2000), the specific role that individual differences in the ability to update the contents of working memory may play in this association is unclear. Longitudinal studies are needed to assess this ability prior to the onset of rumination and/or depression in order to provide clear evidence that these impairments underlie rumination and thereby increase the risk for the onset and maintenance of depressive episodes. Preliminary evidence for this proposition comes from studies that have shown that inhibitory dysfunctions are not only correlates of depression, but can also be found in individuals who have recovered from a depressive episode (Goeleven et al., 2006; Joormann, 2004). In this context, it is also important to note that we found no evidence in the current study of increased interference from negative material in control participants in a negative mood state. We also found no significant correlation between interference and rumination in the control group, which is likely due to the restricted range in both the interference and the rumination measure in this group. Future studies should include additional rumination measures and, ideally, should compare self-reported rumination and experimental rumination manipulations. We also found that interference from negative material was associated with individual differences in both the brooding and the reflection components of rumination. This is surprising given that other studies have reported that cognitive biases in depression are related only to the maladaptive brooding component (Joormann, Dkane, & Gotlib, 2006). Although future studies are needed to clarify this finding, it is possible that deficits in updating working memory are related to a higher frequency of intrusive thoughts in general rather than being confined to maladaptive rumination.

It is unclear whether an induced negative mood state can be compared to the negative mood that is associated with chronic depression. Consequently, it is possible that the obtained differences between the MDD participants and CTL participants who experienced a negative mood induction are due to differences in the intensity of their negative mood. Because the CTL participants in a negative mood state did not differ significantly from the CTL participants without a mood induction (and actually showed a trend toward weaker intrusion effects for negative material), while the MDD participants showed significantly stronger intrusion effects than did both groups of control participants, this is unlikely to be a viable explanation for the obtained results. It is possible, however, that the relation between mood and interference from negative material in working memory is nonlinear (e.g., interference effects are found only at very high levels of negative affect).

Although a comprehensive discussion of the following issue is beyond the scope of this article, we should point out that the concept of inhibition has been criticized in research on attention and memory (e.g., Friedman & Miyake, 2004; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Thus, the construct validity of several measures that have been proposed to assess inhibition has been questioned (Friedman & Miyake, 2004). Specifically, research on the negative priming task has led investigators to propose a number of alternative mechanisms that could underlie the observed effects. Indeed, MacLeod et al. (2003) argued that many results that are interpreted in terms of inhibitory processes can be explained without reference to this concept. One possible alternative explanation for the present results is that there is differential initial activation of positive and negative material in the depressed group in the absence of group differences in the strength of inhibition. While we cannot rule out these alternative explanations, we should note that we are able to compare responses to relevant and irrelevant probes within the same task. If negative material were differentially activated in the MDD and CTL groups, we would expect the depressed group to be faster to respond to negative material in the relevant trials, that is, when judging that a presented negative probe indeed came from the relevant list. We did not find any evidence for such an activation effect in our data. While there might be other explanations for the lack of group differences in the relevant trials, this pattern of findings suggests that the concept of differential activation is not a complete explanation for the present findings. Still, we cannot rule out differences in other mechanisms that might underlie our findings, such as source monitoring (e.g., Johnson & Raye, 1981; Mandler, 1980) or other memory processes. Clearly, future studies are needed to investigate whether inhibition, or any of these alternative mechanisms, provides the best explanation of the observed effects. We believe, however, that our finding of increased response latencies to negative intrusion probes in the MDD group, which are correlated with self-reported rumination, represents an important finding even if the precise underlying mechanisms remain open to debate. These findings could provide insights into cognitive deficits in depression such as concentration difficulties and memory impairment. Indeed, several investigators have suggested that the source of general cognitive deficits in depression is a competition between attempts to direct attention to the task at hand and away from distractive and intrusive effects of negative thoughts and memories (Christopher & MacDonald, 2005; Hertel, 1998). In addition, the observed relation between the intrusion effect and self-reported rumination suggests that these problems in updating the contents of working memory might underlie the sustained processing of negative material that is seen in ruminative responses and has been found to predict both the onset and the maintenance of depression (e.g., Nolen-Hoeksema, 2000).

Other potential alternative explanations of the obtained results involve the concept of generalized deficits in depression (Chapman & Chapman, 1973, 1978). That is, it is possible that MDD participants are characterized by general memory impairments, a general slowing in response times, or reduced confidence in their judgments. In this context, it is important to note that in the condition in which the MDD participants exhibited the slowest response times (negative intrusion probes), the CTL participants were faster to respond than they were to positive intrusion trials, indicating that this was not the most difficult condition overall.

In sum, while additional studies are needed to investigate the role of inhibition in depression and its associated mechanisms, the present study is important in beginning to elucidate the nature of the relationship between rumination, removal of irrelevant negative material from working memory, and depression. Because the experience of negative mood states and negative life events is associated with the activation of mood-congruent cognitions in working memory, the ability to control the contents of working memory could be crucial in understanding and differentiating people who recover easily from negative affect from those who initiate a vicious cycle of increasingly negative ruminative thinking and deepening sad mood. Investigating individual differences in executive functions and, specifically, in the control of the contents of working memory, has the potential to provide important insights into the maintenance of negative affect and vulnerability to experience depressive episodes.

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