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Updating Positive and Negative Stimuli in Working Memory in Depression

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Difficulties in the ability to update stimuli in working memory (WM) may underlie the problems with regulating emotions that lead to the development and perpetuation of mood disorders such as depression. To examine the ability to update affective material in WM, the authors had diagnosed depressed and never-disordered control participants perform an emotion 2-back task in which participants were presented with a series of happy, sad, and neutral faces and were asked to indicate whether the current face had the same (match-set) or different (break-set or no-set) emotional expression as that presented 2 faces earlier. Participants also performed a 0-back task with the same emotional stimuli to serve as a control for perceptual processing. After transforming reaction times to control for baseline group differences, depressed and nondepressed participants exhibited biases in updating emotional content that reflects the tendency to keep negative information and positive information, respectively, active in WM. Compared with controls, depressed participants were both slower to disengage from sad stimuli and faster to disengage from happy facial expressions. In contrast, nondepressed controls took longer to disengage from happy stimuli than from neutral or sad stimuli. These group differences in reaction times may reflect both protective and maladaptive biases in WM that underlie the ability to effectively regulate negative affect.

Keywords: depression, working memory, *n*-back, emotion processing, emotion regulation

The ability to update and disengage from information in working memory (WM) is a critical component of cognition and emotion regulation. People continually process large amounts of information, and to solve problems, pursue goals, and regulate affect, they must be able to fluidly update the contents of WM to maintain only relevant information. WM, 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), has been studied extensively, as has the ability to update content in WM (Druzgal & D'Esposito, 2001; Y. Kessler & Meiran, 2006). Despite the fact that the contents of WM directly affect mood (Isen, 1984; Russell, 2003), the ability to update specifically emotional stimuli in WM has not been the focus of empirical study. Furthermore, difficulties in adaptively updating emotional content in WM may underlie the development and perpetuation of mood disorders such as major depressive disorder (MDD). For example, biases against keeping positive information active or toward maintaining negative content in WM may underlie the ease with which depressed individuals develop and propagate a negative mood.

MDD, among the most prevalent and burdensome of all psychiatric disorders (Gotlib & Hammen, 2009), is characterized by difficulties in both emotion regulation and cognitive functioning. Depressed individuals report pervasive negative thoughts and moods, problems with memory, and difficulty concentrating and planning (Paelecke-Habermann, Pohl, & Leplow, 2005; Rose & Ebmeier, 2006). To date, researchers attempting to identify and elucidate cognitive mechanisms that underlie the perpetuation of negative mood in depression have focused primarily on understanding how negative stimuli capture the attention and cognitive resources of depressed individuals (Gotlib et al., 2004; Kaplan et al., 2006). Although affective attention tasks have been helpful in understanding the perpetuation of negative affect in depression, it is unclear how depressed individuals process valenced information after it has captured their attention and entered WM.

During the performance of both high-level tasks, such as evaluating a credit card statement or writing a research paper, and of emotion regulation efforts, the contents of WM constantly change; new input from the environment needs to be stored and combined with previously stored information, and the products of manipulations performed on the stored information also need to be stored. Morris and Jones (1990) defined updating as "the act of modifying the current status of a representation of schema in memory to accommodate new input" (p. 112). This definition requires not only the replacement of current memory content by new material but also the modification of old information according to new input. Thus, although some parts of the old material in WM should stay intact, other parts should change. This modification of information as a function of new input may be particularly salient when emotional content is added to WM.

Valenced information encountered in the environment and processed in WM is elaborated, activating related representations from the environment and from long-term memory that may interact with and alter existing WM representations (Dudai, 2002). Furthermore, the length of time that a representation is active in

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WM directly affects the level of elaboration that that representation receives. A representation that is active in WM for a shorter time receives fewer processing resources, leading to less elaboration, weaker long-term memory representation, and decreased ability to recall related representations from long-term memory. Negative content that is being maintained in WM may also interact with other representations such that it becomes more negative, or more strongly interconnected, or conversely, less negative, or more weakly connected, when new positive content enters WM. Elaboration is also a hallmark component of both maladaptive rumination and adaptive mood repair. Maladaptive rumination is characterized by an inability to stop or reduce elaboration of negative material in WM (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). On the other hand, adaptive mood repair may involve, for example, the alleviation of a negative mood by thinking about positive material—the individual must not only activate and elaborate positive content in WM but must also break connections among negative representations by replacing the negative content with new positive content—all processes that depend on updating. In addition, there may be individual differences in the interaction of valence and updating processes that have downstream effects on emotion regulation abilities, resulting in vulnerability to rumination or resilience in response to trauma. Therefore, understanding how updating interacts with valence is critical; to date, however, there is little evidence of how valence interacts with updating. And although deficits in updating in WM have been reported in depressed individuals (Harvey et al., 2004; Matsuo et al., 2007), there is no research examining whether maladaptive updating processes may contribute to depression.

Existing research examining the processing of emotional stimuli in depressed participants and in resilient participants, might, however, elucidate how emotion might specifically affect updating processes in depressed individuals and in never-disordered individuals. For example, investigators examining behavioral responses to negative and positive stimuli have found that compared with nondepressed individuals, depressed persons attend selectively to negative stimuli (Gotlib et al., 2004; Kaplan et al., 2006), exhibit cognitive inflexibility when processing negative stimuli (Deveney & Deldin, 2006), and demonstrate an attenuated response to positive stimuli (Rottenberg, Gross, & Gotlib, 2005; Sloan, Strauss, Quirck, & Sajatovic, 1997). In addition, Joormann and Gotlib (2008) have demonstrated that depressed individuals have difficulty expelling irrelevant negative emotional content from WM, suggesting a depression-associated deficit in inhibiting negative material.

On the other hand, research examining the relation between the processing of emotional information and resilience has identified more adaptive emotion processing patterns. Resilience, the ability to recover from or cope with negative events by using positive emotions (Tugade, Fredrickson, & Barrett, 2004), is associated with greater psychological and physical well-being (Tugade et al., 2004) and lower incidence of anxiety and mood disorders (Southwick, Vythilingam, & Charney, 2005). Researchers examining the association of resilience and emotion processing have found that highly resilient people recruit positive emotions both to buffer depressive symptoms in times of potential trauma (Fredrickson, Tugade, Waugh, & Larkin, 2003) and to attenuate cardiovascular responses to stress (Tugade et al., 2004). Resilient people also tend to perceive neutral faces as happy (Arce et al., 2009), a bias that may underlie their ability to recruit positive emotions in times of stress and that may contribute to their never-disordered status.

The present study was designed in part to determine whether depressed individuals and never-disordered control individuals differ in affective updating. Depressed and nondepressed participants performed an emotion *n*-back task in which they had to indicate whether each face in a series of faces has the same or a different emotional expression as the expression on the face presented two trials before. The *n*-back stimuli were neutral, happy, and sad faces. Participants first performed a control 0-back task in which they indicated on each trial whether the current face had the same or a different facial expression as a target facial expression. Next, participants performed a 2-back task in which they compared the currently viewed facial expression with that presented two trials back, matching the two expressions into a conceptual set on same trials and breaking or determining the absence of a conceptual set on different trials. Reaction times (RTs) to the 0-back task represent the time it takes to perceptually perceive and categorize an emotional expression as it enters WM. Measuring perceptual processing via the 0-back is critical, as differences in how rapidly an emotional representation enters WM may underlie updating ability. In contrast, RTs on the 2-back task represent the time it takes to perceptually perceive and categorize an emotional expression as it enters WM and the time it takes to update the contents of WM and compare the current stimulus with that presented two trials earlier. Thus, 2-back trial responses and RTs serve as indicators of the ability to match and disconnect from emotional stimuli within WM. RTs to make a same judgment or a different judgment to each valence of stimuli (positive, neutral, negative) in each task (0-back, 2-back) were recorded, resulting in separate measurements of the time required to perceive and categorize emotional faces and the time required to update, link, and disengage from content in WM.

Given previous findings of depression-associated difficulties in the processing of emotional stimuli, we predicted that depressed participants would match and integrate in to WM sad stimuli more quickly and happy stimuli more slowly, compared both with neutral stimuli and with never-disordered controls. Given their greater resilience, we predicted that never-disordered individuals would exhibit the opposite pattern, matching and integrating happy stimuli more quickly and sad stimuli more slowly, compared both with neutral stimuli and with depressed participants. Finally, on trials that require participants to disconnect from an emotional category, we predicted that compared with nondepressed controls, depressed individuals would break sets of sad stimuli more slowly and happy stimuli more quickly than they would neutral stimuli; we predicted further that never-disordered individuals would exhibit the opposite pattern of results. In sum, therefore, we predicted that depressed and never-disordered participants would demonstrate valence-specific biases in the ease with which they update emotional stimuli.

Method

Participants

Fifty-eight individuals, 29 diagnosed with current MDD (20 women, 9 men) and 29 never-disordered control participants (16

women, 13 men), participated in this study.[1] Participants were solicited 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. Individuals were excluded if they were not fluent in English, were not between 18 years and 60 years of age, and reported severe head trauma, learning disabilities, psychotic symptoms, bipolar disorder, or alcohol or substance abuse within the past 6 months. Eligible persons were invited to come to the laboratory for a more extensive diagnostic interview. Participants were then scheduled for a second session within 2 weeks after the interview, during which they completed the emotion *n*-back task.

Trained interviewers administered the *Structured Clinical Interview for the DSM–IV* (*SCID*; First, Spitzer, Gibbon, & Williams, 1996) to these individuals 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, Torgersen, & Kringlen, 1991; Williams et al., 1992). All interviewers had extensive training in the use of the *SCID*, with interrater reliability kappa coefficients of .93 for the MDD diagnosis and .92 for the never-disordered diagnosis (i.e., the absence of current or lifetime psychiatric diagnoses). Participants were included in the depressed group if they met the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; *DSM–IV*; American Psychiatric Association, 1994) criteria for current MDD and were included in the nondepressed group if they had no current or past Axis I disorder. All participants completed the Beck Depression Inventory–II (BDI-II; Beck, Steer, & Brown, 1996), a 21-item, self-report measure of the severity of depressive symptoms.

Stimuli

A total of 138 digital gray scale images of faces from the NimStim Face Set (Tottenham et al., 2009) were used as stimuli. The set of 138 faces comprised 46 sad faces, 46 happy faces, and 46 neutral or calm faces from 23 different actors (12 female, 11 male). Half of the facial expressions of each emotion featured an open mouth, and the other half featured a closed mouth. Each emotional expression of each actor was presented approximately four times during the experiment. Each of the blocks of trials (see below) contained either only male or only female emotional faces. Face gender was counterbalanced across blocks: in the 0-back task segment, participants viewed two blocks of female faces and one block of male faces, or vice versa; in the 2-back task segment, all participants viewed three blocks of female faces and three blocks of male faces.

Task Design

The experiment was divided into a 0-back task segment and a 2-back task segment. All participants performed the 0-back task first, followed immediately by the 2-back task. The experimental procedure was similar for each segment, and instructions were given to participants both orally and in writing. In both tasks, participants viewed emotional faces presented one at a time for 2 s, with an intertrial interval of 2.5 s. Response and response latency were recorded for each trial.

0-back task. The 0-back task, modeled after that used by Harvey et al. (2005) and Ladouceur et al. (2005), consisted of 129 trials separated into three blocks of 43 trials, as well as an additional eight practice trials that were not scored. Participants were presented with an expression label (happy, sad, or neutral) and a sample face displaying that expression. The target emotional expression differed across blocks: One block was sad, one block was happy, and one block was neutral. Following the presentation of the target label and expression for each block, the trials began. Participants pressed a key labeled *Same* if the facial expression was the same as that of the target expression or a key labeled *Diff* if the facial expression was different from the target face (Figure 1A). The presentation order of the three blocks of 0-back trials was random.

2-back task. The 2-back task consisted of 330 trials separated into 6 blocks of 55 trials, as well as an additional 10 practice trials that were not scored. Participants were asked to indicate whether the emotional expression of the currently presented face was the same as, or different from, the facial expression presented two faces earlier. Participants pressed a key labeled *Same* if the facial expression was the same as the expression presented two faces before or a key labeled *Diff* if the facial expression was different from the expression presented two faces earlier. For each block of trials, for the first two faces presented, participants were told to view the faces without pressing a key; from the third face on, participants were told to respond with the keys *Same* or *Diff* to each face presented, resulting in 53 usable trials per block. Participants were also told that because of the difficulty of the task, they might lose their place in the sequence of trials and forget which face(s) had been presented in the preceding trial(s). Participants were instructed, if this occurred, to start over—to view the current face and the next face—and then from the third face on begin responding *Same* or *Diff* once again.

Trial types. By presenting emotional stimuli and asking participants to respond based on the facial expressions of the stimuli, we modified the traditional *n*-back task to be an emotional category monitoring task that assesses the ability to continually update emotion representations in WM. On each trial, participants must perceptually process the presented facial expression, add that stimulus to their maintained set of stimuli, discard the facial expression presented three trials earlier, compare the current facial expression with the one presented two trials earlier, and then respond. What differs across trials are the valence of the incoming and outgoing stimuli and the cognitive processes involved in comparing the current facial expression with that presented two trials earlier, resulting in four trial types: match-set trials, break-set trials, perseveration-set trials, and no-set trials. In match-set or *same* response trials, the currently presented facial expression is the same as that presented two trials earlier, requiring participants to identify the two expressions as members of the same category (see Figure 1B).

Trials requiring a *different* response involve a different set of cognitive processes. There are three types of *different* response trials: break-set trials, perseveration-set trials and no-set trials. A break-set trial is a trial that immediately follows a match-set trial:

[1] Including gender in the 0-back and 2-back accuracy and RT analyses did not change any of the findings reported in this article.

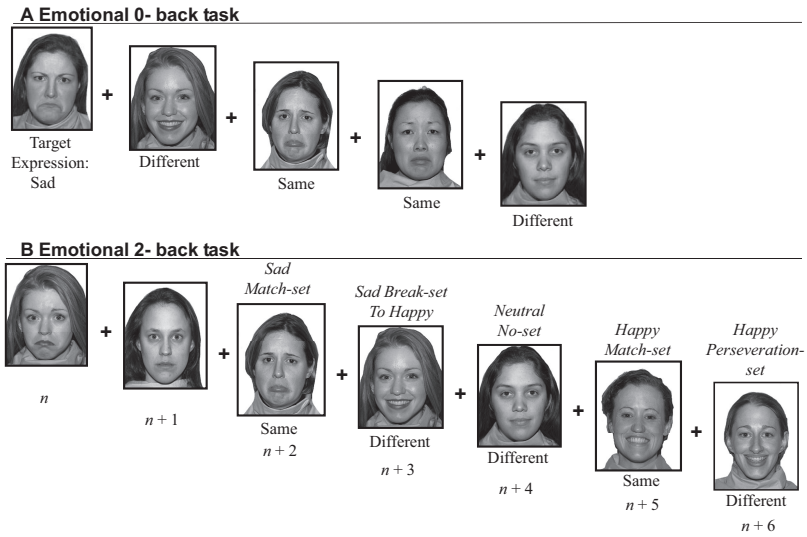

Figure 1. Examples of 0-back and 2-back emotion task trial types with correct responses. From "The NimStim Set of Facial Expressions: Judgments From Untrained Research Participants," by N. Tottenham, J. Tanaka, A. C. Leon, T. McCarry, M. Nurse, T. A. Hare, D. J. Marcus, A. Westerlund, B. J. Casey, and C. A. Nelson, 2009, *Psychiatry Research, 168.* Copyright 2009 by N. Tottenham, J. Tanaka, A. C. Leon, T. McCarry, M. Nurse, T. A. Hare, D. J. Marcus, A. Westerlund, B. J. Casey, and C. A. Nelson. Development of the MacBrain Face Stimulus Set was overseen by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at tott0006@tc.umn.edu for more information concerning the stimulus set. A: Sample target expression and emotion 0-back task trials with correct responses. B: Sample of each emotion 2-back trial type with correct response.

The facial expression presented three trials earlier, which must be discarded, was one expression in a matched pair. Therefore, to respond to break-set trials, participants must break a set that they endorsed in the preceding trial. Thus, break-set trials assess participants' ability to disconnect two paired-valenced stimuli and disengage from the first face to remove it from WM. Perseveration-set trials are similar to break-set trial in that they must follow a match-set trial. In perseveration set trials, however, the current face, the stimulus to be added to WM, is the same valence as the face presented three trials earlier, the stimulus that must be removed from WM. To respond to perseveration-set trials, participants must break a set that they endorsed in the preceding trial. However, the valence of the incoming and outgoing stimuli is the same; therefore, to respond correctly, the participant must not perseverate on the preceding matched set. No-set trials, in contrast, do not follow a match-set trial. On no-set trials, participants do not need to break a set of previously paired facial expressions to respond; instead, participants need simply to determine that no set exists and respond accordingly. Therefore, no-set trials assess participants' ability to integrate a valenced stimulus into WM and assess its relatedness to existing stimuli being held in WM.

As an example of how the four trial types relate to each other in a sequence, consider the following sequence of seven presented faces (see Figure 1B): sad (n), neutral ($n + 1$), sad ($n + 2$), happy ($n + 3$), neutral ($n + 4$), happy ($n + 5$), and happy ($n + 6$). Participants passively view and remember the faces presented in trials n and $n + 1$. Trial $n + 2$ is a sad match-set trial requiring a *same* response. Trial $n + 3$ is a break-set trial; the correct *different* response to the currently presented happy face requires participants to break the sad category set endorsed in the previous match-set trial by disengaging and removing the sad face n from WM. Trial $n + 4$ is a no-set trial; the current neutral face needs to be added to WM and compared against the expression presented two trials earlier, but no previously endorsed happy or sad set needs to be broken to do so. Trial $n + 5$ is a happy match-set trial; the current expression is the same as that presented in trial $n + 3$, so a *same* response is required. Finally, trial $n + 6$ is a happy perseveration-set trial; the correct *different* response to the current happy face requires the participant to break the happy category set endorsed in the previous match-set trial and remove the expression $n + 3$ from WM. However, the valence of the incoming and outgoing content is the same.

Because of the critical cognitive process required, we categorized break-set trials according to the emotional expression of the set that participant must break to respond rather than by the facial expression of the current trial to which participants are responding; this categorization yielded neutral, happy, and sad break-set trials. Calculating RTs for break-set trials, therefore, required that *different* response RTs be averaged across specific trial types. The sad break-set RT, for example, is the mean RT to respond *different* to a trial in which a happy or neutral face is presented following a sad match-set trial. In contrast, match-set, perseveration-set, and no-set trials were categorized based on the current facial expression to which participants were responding.

Statistical analysis. RTs and responses were recorded for each trial, and a mean RT and accuracy rate was calculated for correct trials for each trial type in the 0-back and 2-back tasks. Although investigators have often used accuracy as the dependent

variable in *n*-back tasks, RT has also been frequently analyzed as the primary dependent variable (e.g., Druzgal & D'Esposito, 2001; Kensinger & Corkin, 2003; Y. Kessler & Meiran, 2006) in between-groups comparisons (Ladouceur et al., 2005; Paramenter, Shucard, & Shucard, 2007; Paramenter, Shucard, Benedict, & Shucard, 2006). In the present study, based on our goal of measuring the duration that a representation is in WM receiving processing resources, our primary dependent variable is RT. We did, however, also analyze accuracy rates for each trial type. Outlier trials, identified as those with RTs greater than 2.5 standard deviations from the mean, were excluded from the analyses (Howell, 2002).[2] Depressed and nondepressed participants did not differ with respect to the number of excluded trials, $t(56) = 0.83$, $p > .1$ In addition to RT and accuracy rates, response rates (i.e., the number of no-response trials) were recorded and calculated separately for the 0-back and 2-back segments. A three-way (group [depressed, nondepressed] repeated over emotion [happy, neutral, sad] repeated over response [*same*, *different*]) analysis of variance (ANOVA) was used to examine accuracy and response rates in the 0-back task. Accuracy and response rates for the 2-back task segment were examined by conducting separate two-way (group repeated over emotion) ANOVAs for match-set, break-set, perseveration-set, and no-set trials.

RTs to respond *same* to emotional faces on the 0-back task represent the time it takes to perceptually perceive and categorize an emotional expression as it enters WM. RTs on the 2-back task, in contrast, represent the time it takes to perceptually perceive and categorize an emotional expression as it enters WM and the time it takes to update the contents of WM and compare the current stimulus with that presented two trials earlier. Evidence from studies of RT, however, suggests that having groups with slower RTs often produces a larger experimental effect (Faust, Balota, Spieler, & Ferraro, 1999). It has consistently been demonstrated that depressed participants exhibit slow RTs, typically attributed to the psychomotor retardation that characterizes this disorder (Sobin & Sackeim, 1997). To avoid spurious findings due to depressed individuals' slower RTs, we converted all trial type RTs to *z*-scores, as suggested by Faust et al. (1999). Trial type RTs were converted to *z*-scores by subtracting each individual's trial type RT mean from his and/or her overall RT mean and dividing by the standard deviation of the trial type mean. To separate the time required to perceive and categorize emotional faces from the time required to update and link content in WM, separate *z*-score transformations were conducted on the 0-back and 2-back RTs. Then, a three-way (group [depressed, nondepressed] repeated over emotion [happy, neutral, sad] repeated over response [*same*, *different*]) ANOVA was conducted on 0-back RT *z*-scores. Finally, to examine the more complex updating and linking processes required in the emotion 2-back task, separate two-way (group [depressed, nondepressed] repeated over emotion [happy, neutral, sad]) ANOVAs were conducted on match-set, break-set, perseveration-set, and no-set condition *z*-scores.

Results

Participant Characteristics

Depressed and nondepressed participants did not differ significantly in age ($M = 42$, $SD = 11$; $M = 37$, $SD = 12$, respectively), $t(56) = 1.43$, or education ($M = 14.5$, $SD = 2.5$; $M = 15.5$, $SD = 2$, respectively), $t(56) = 1.38$, ps $> .05$; as expected, depressed participants obtained significantly higher scores on the BDI than did nondepressed participants ($M = 30$, $SD = 7$; $M = 1.5$, $SD = 2.5$, respectively), $t(56) = 23.6$, $p < .001$. Finally, 11 of the 29 MDD participants were diagnosed with at least one comorbid disorder: 7 participants were diagnosed with social phobia, 3 were diagnosed with panic disorder, 3 were diagnosed with post traumatic stress disorder, 1 was diagnosed with obsessive compulsive disorder, and 1 was diagnosed with generalized anxiety disorder.[3]

We present the results in two sections. In the first section, we present the results of the accuracy and response rates analysis conducted on the 0-back and the 2-back match-set, break-set, perseveration-set, and no-set trials. In the second section, we present the results of the reaction-time analysis conducted on the 0-back and the 2-back match-set, break-set, perseveration-set, and no-set trials.

Accuracy and Response Rates

0-back. Accuracy and response rates for each trial are reported in Table 1. The three-way ANOVA conducted on 0-back accuracy rates yielded significant main effects of emotion, $F(2, 112) = 14.7$, $p < .001$, $\eta^2 = .22$, and response, $F(1, 56) = 12.25$, $p < .001$, $\eta^2 = .19$; no other effects were significant. Follow-up tests indicated that the main effect of emotion was due to participants exhibiting lower accuracy rates for identifying neutral expressions than for identifying happy, $t(57) = 4.64$, $p < .01$, and sad, $t(57) = 2.93$, $p < .01$, expressions and lower accuracy rates for identifying sad facial expressions than for identifying happy facial expressions, $t(57) = 3.24$, $p < .01$. The main effect of response was due to significantly lower accuracy rates for *same* responses than for *different* responses, $t(57) = 3.49$, $p < .01$. The three-way ANOVA conducted on 0-back response rates yielded significant main effects of emotion, $F(2, 112) = 4.1$, $p < .05$, $\eta^2 = .07$, response, $F(1, 56) = 56.05$, $p < .001$, $\eta^2 = .52$, and group, $F(1, 56) = 4.41$, $p < .05$, $\eta^2 = .078$; no other effects were significant. Follow-up tests indicated that the main effect of emotion was due to participants responding to fewer sad trials than happy trials, $t(57) = 3.14$, $p < .01$. The main effect of response was due to significantly more absent responses on *same* trials than on *different* trials, $t(57) = 7.58$, $p < .01$. Finally, the main effect of group was due to depressed participants responding on significantly fewer trials than did nondepressed participants, $t(56) = 2.22$, $p < .05$.

Match set. Accuracy and response rates for each trial type are reported in Table 2. The two-way ANOVA conducted on match-set trial accuracy rates yielded a significant effect only for emotion, $F(2, 112) = 48.43$, $p < .001$, $\eta^2 = .46$. Accuracy rates for sad

[2] We defined outlier trials as those with RTs greater than 2.5 *SD*s from the mean primarily to eliminate accidental premature responses (i.e., RTs under 200 ms). Using a more conservative criterion of 3.5 *SD*s did not change our findings. In addition, there was no difference in the total number of trials excluded for each person between the depressed ($M = 10.4$, $SD = 2.5$) and nondepressed ($M = 11.2$, $SD = 2.3$) groups, $p > .1$.

[3] Depressed participants with and without a comorbid disorder did not differ in any of the analyses comparing 0-back and 2-back accuracy, RTs, and z-scores.

Table 1
0-Back Trial Mean Reaction Times, Accuracy Rates, and Response Rates for Depressed and Nondepressed Participants

	Nondepressed				Depressed			
	RT				RT			
Facial expression	*M*	*SD*	Acc %	RR %	*M*	*SD*	Acc %	RR %
Happy								
Same	710	92	95	94	750	161	97	94
Different	719	97	97	98	780	151	97	96%
Neutral								
Same	813	99	76	96	935	160	80	92
Different	774	118	83	98	891	208	87	95
Sad								
Same	794	98	87	94	914	222	90	90
Different	854	169	92	97	940	155	93	96

Note. Reaction times are presented in milliseconds. Accuracy is presented as percentage correct. Response rates are presented as percentage of trials on which a response was made. Same = Same facial expression as target; Different = Different facial expression than target; RT = reaction time; Acc = accuracy rate; RR = response rate.

match-set trials were significantly lower than were rates for both neutral, $t(57) = 5.8$, $p < .01$, and happy, $t(57) = 7.2$, $p < .01$, match-set trials, which did not differ significantly from each other, $t(57) = 0.36$, $p > .05$. The two-way ANOVA conducted on match-set trial response rates also yielded a significant effect of emotion, $F(2, 112) = 48.43$, $p < .001$, $\eta^2 = .46$, as well as a main effect of group, $F(1, 56) = 4.41$, $p < .05$, $\eta^2 = .078$. The main effect of emotion is due to a higher response rates to happy match-set trials than to neutral match-set trials, $t(57) = 3.05$, $p < .01$, or sad match-set trials, $t(57) = 2.65$, $p < .01$, whereas the main effect of group is due to lower response rates for depressed participants than for nondepressed participants, $t(56) = 2.13$, $p < .05$.

Break set. The ANOVA conducted on break-set trial accuracy rates yielded only a main effect of emotion, $F(2, 112) = 4.54$, $p < .05$, $\eta^2 = .12$, which, like the match-set trials, was due to slightly but significantly lower accuracy rates for sad break-set trials than for neutral break-set trials, $t(57) = 2.71$, $p < .05$. The ANOVA conducted on break-set trial response rates revealed a main effect of group, $F(1, 56) = 5.5$, $p < .05$, $\eta^2 = .09$, which was due to

Table 2
2-Back Trial Mean Reaction Times, Accuracy Rates, and Response Rates For Depressed and Nondepressed Participants

	Nondepressed				Depressed			
	RT				RT			
Set	*M*	*SD*	Acc %	RR %	*M*	*SD*	Acc %	RR %
Happy match set	948	154	89	97	1,156	222	89	93
Neutral match set	1,117	167	90	96	1,292	209	86	90
Sad match set	1,127	199	75	95	1,302	241	76	91
Happy break set to								
Neutral	1,266	240	90	97	1,272	238	89	91
Sad	1,131	173	94	96	1,209	287	92	89
Combined	1,199	189	92	96	1,241	253	90	90
Neutral break set								
To happy	1,094	235	91	96	1,261	277	90	90
To sad	1,142	227	94	96	1,262	247	93	90
Combined	1,118	205	93	96	1,261	232	91	90
Sad break set								
To neutral	1,147	195	88	97	1,405	320	86	91
To happy	1,099	191	92	95	1,344	280	90	90
Combined	1,123	181	90	96	1,374	288	88	91
Happy perseveration set	1,278	276	84	97	1,417	201	87	90
Neutral perseveration set	1,286	303	82	93	1,460	252	87	87
Sad perseveration set	1,263	235	84	96	1,441	205	90	86
Happy no set	1,119	201	87	95	1,251	202	89	90
Neutral no set	1,193	223	84	94	1,296	212	80	90
Sad no set	1,190	230	85	96	1,228	197	86	88

Note. Reaction times are presented in milliseconds. Accuracy is presented as percentage correct. Response rates are presented as percentage of trials on which a response was made. RT = reaction time; Acc = accuracy rate; RR = response rate.

lower response rates by depressed participants than by nondepressed participants, $t(56) = 2.34$, $p < .05$.

Perseveration set. The ANOVA conducted on perseveration-set trial accuracy rates yielded only a main effect of emotion, $F(2, 112) = 3.87$, $p < .05$, $\eta^2 = .065$, which reflected significantly lower accuracy rates for neutral perseveration-set trials than for sad perseveration-set trials, $t(57) = 3.12$, $p < .01$. The ANOVA conducted on response rates for perseveration-set trials yielded a main effect of emotion, $F(2, 112) = 6.7$, $p < .05$, $\eta^2 = .11$, which was due to higher response rates to happy perseveration-set trials than to neutral perseveration-set trials, $t(57) = 3.3$, $p < .01$, or sad perseveration-set trials, $t(57) = 2.5$, $p < .05$, and a main effect of group, $F(1, 56) = 6.7$, $p < .01$, $\eta^2 = .11$, which was due to lower response rates for depressed participants than for nondepressed participants, $t(56) = 2.6$, $p < .05$.

No set. The ANOVA conducted on no-set trial accuracy rates also yielded only a main effect of emotion, $F(2, 112) = 8.24$, $p < .001$, $\eta^2 = .13$, which was due to significantly lower accuracy rates for neutral no-set trials than for happy no-set trials, $t(57) = 3.78$, $p < .01$, or sad no-set trials, $t(57) = 2.41$, $p < .05$. Finally, the ANOVAs conducted on response rates for no-set trials yielded only main effect of group, $F(1, 56) = 4.9$, $p < .05$, $\eta^2 = .08$, which was due to lower response rates by depressed participants than by nondepressed participants, $t(56) = 2.2$, $p < .05$. In sum, depressed and nondepressed participants did not differ in their accuracy on the 0-back and 2-back tasks; they did, however, respond on significantly fewer trials than did nondepressed participants.[4]

RT Analysis

0-back. RT means and standard deviations for each group for each emotion on the 0-back task are presented in Table 1, and *z*-scores are presented graphically in Figure 2. The three-way ANOVA conducted on *z*-scores yielded a significant main effect of emotion, $F(2, 112) = 60.87$, $p < .001$, $\eta^2 = .52$, which was qualified by a significant interaction of emotion and response, $F(2, 112) = 9.33$, $p < .001$, $\eta^2 = .14$. The interaction of emotion and response reflected that fact that whereas neutral *same* RTs were significantly slower than were neutral *different* RTs, $t(57) = 2.81$, $p < .01$, sad *same* RTs were significantly faster than were sad *different* RTs, $t(57) = 2.85$, $p < .01$; happy *same* and *different* RTs did not differ significantly from each other, $t(57) = 0.5$, $p > .01$.

Match set. Mean RTs and standard deviations for the match-set trials are presented in Table 2, and *z*-scores are presented graphically in Figure 3. The two-way ANOVA conducted on these *z*-scores yielded significant main effects of emotion, $F(2, 112) = 4.037$, $p < .05$, $\eta^2 = .067$, and group, $F(1, 56) = 4.68$, $p < .05$, $\eta^2 = .077$. The main effect of emotion was due to significantly faster happy match-set RTs than neutral match-set RTs, $t(57) = 9.6$, $p < .001$, or sad match-set RTs, $t(57) = 10.2$, $p < .001$. The main effect of group was due to depressed participants taking significantly longer than did nondepressed participants to respond to match-set trials, $t(56) = 1.97$, $p < .05$.

Break set. Mean RTs and standard deviations for the break-set trials are presented in Table 2, and *z*-scores are presented graphically in Figure 3. The two-way ANOVA conducted on *z*-scores yielded a main effect of emotion, $F(2, 112) = 5.15$, $p < .005$, $\eta^2 = .084$, which was qualified by an interaction of group and emotion, $F(2, 112) = 19.71$, $p < .001$, $\eta^2 = .26$. One-way ANOVAs conducted within each group indicated that *z*-scores for both depressed participants, $F(2, 56) = 15.8$, $p < .001$, $\eta^2 = .36$, and nondepressed participants, $F(2, 56) = 8.56$, $p < .001$, $\eta^2 = .23$, differed significantly across emotions. Paired *t* tests revealed that depressed participants broke set, or disengaged, from sad faces significantly more slowly than they did from neutral, $t(28) = 3.8$, $p < .001$, and happy, $t(28) = 6.11$, $p < .001$, faces; in contrast, nondepressed participants showed the opposite pattern, disengaging from happy faces significantly more slowly than they did from neutral, $t(28) = 3.54$, $p < .001$, and sad, $t(28) = 3.62$, $p < .001$, faces. Depressed participants were also significantly slower than were nondepressed participants to disengage from sad faces, $t(56) = 3.65$, $p < .001$, and significantly faster to disengage from happy faces, $t(56) = 4.89$, $p < .001$; the two groups did not differ in their RTs to disengage from neutral faces, $t(56) = 0.45$, $p > .1$.

Perseveration set. Mean RTs and standard deviations for the perseveration-set trials are presented in Table 2, and *z*-scores are presented graphically in Figure 3. The two-way ANOVA conducted on these *z*-scores yielded no significant main effects or interactions.

No set. Mean RTs and standard deviations for the no-set trials are presented in Table 2, and *z*-scores are presented graphically in Figure 3. The two-way ANOVA conducted on no-set *z*-scores yielded main effects of emotion, $F(2, 112) = 5.73$, $p < .01$, $\eta^2 = .093$, and group, $F(1, 56) = 4.4$, $p < .05$, $\eta^2 = .07$, which were qualified by an interaction of group and emotion, $F(2, 112) = 4.97$, $p < .01$, $\eta^2 = .08$. One-way ANOVAs conducted within each group indicated that RTs for both depressed participants, $F(2, 56) = 6.58$, $p < .01$, $\eta^2 = .2$, and nondepressed participants, $F(2, 56) = 4.28$, $p < .05$, $\eta^2 = .13$, differed significantly across emotions. Depressed participants took significantly longer to integrate neutral faces into WM than they did happy, $t(28) = 2.08$, $p < .05$, and sad, $t(28) = 3.85$, $p < .001$, faces. In contrast, nondepressed participants showed a different pattern, integrating happy faces significantly faster than they did neutral, $t(28) = 2.45$, $p < .05$, and sad, $t(28) = 3.1$, $p < .01$, faces. Depressed participants were also significantly faster than were nondepressed participants to integrate sad faces, $t(56) = 3.84$, $p < .001$; the two groups did not differ in their RTs to integrate happy and neutral faces (*p*s $> .1$).

Discussion

The present study was designed to examine the ability of depressed and nondepressed participants to update emotional stimuli in WM, with the specific goal of testing the hypothesis that biases in linking stimuli within, and removing stimuli from, WM might underlie the mood dysregulation experienced by depressed individuals. On a 0-back task and a 2-back task designed to assess time

[4] To examine the possibility that the group differences in response rates affected the reaction-time effects that we report in the primary analyses below, we repeated each of the 0-back and 2-back ANOVAs with the corresponding response rates entered as a covariate (e.g., response rates for match-set trials were used as a covariate in the ANOVA conducted on RTs for match-set trials). The results of these analyses indicate that response rate was not a significant factor in any of the analyses and that it did not change any of the obtained effects for group, emotion, and their interaction.

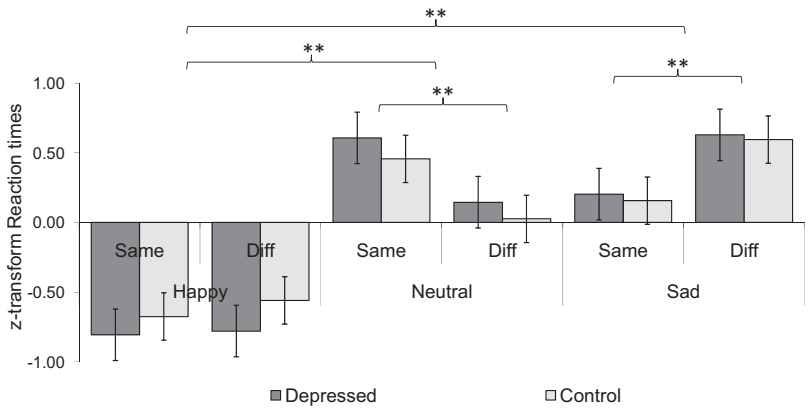

Figure 2. The *z*-scores and standard deviations for 0-back *same* and *different* trials for depressed and nondepressed participants. The error bars represent standard error. Diff = different. ** $p < .01$ (within group comparisons).

to perceive, categorize, and update emotional content in WM, depressed and nondepressed individuals did not differ in accuracy, but did differ in response rates and valence-specific RTs. On the 0-back task, both depressed and nondepressed participants identified happy stimuli faster than they did neutral and sad stimuli, but participants did not differ from each other. This absence of group main effects or interactions in RT is unexpected, given negative attention biases that have been documented in depression (Gotlib & Joormann, 2010). To our knowledge, however, in no studies have researchers examined facial identification RTs in a WM task in a depressed sample, and it is therefore possible that the negative attention biases found in attention tasks are not evident in a more rapid classification or a slower classification of facial expressions in WM.

Consistent with our hypotheses, however, depressed individuals differed from controls in their latencies to integrate, match, and break sets of emotional stimuli in WM on the 2-back task. Depressed participants integrated sad stimuli, or determined no set for sad stimuli, faster than did nondepressed controls and also broke sets of happy stimuli faster and sad stimuli more slowly than did control participants. In addition, depressed individuals were slower to match emotional stimuli in WM than were controls, regardless of valence. Thus, depressed individuals integrate sad content relatively quickly and are slow to link emotional stimuli in WM. Once the content is linked, however, depressed participants are faster to remove happy content from WM than are controls, suggesting weaker connections with happy stimuli in WM; they are also slower to remove sad content from WM, suggesting stronger connections with sad stimuli in WM. Also consistent with our hypotheses, nondepressed participants exhibited a bias in their processing of positive stimuli, disengaging from happy stimuli in WM more slowly than they did from neutral or sad stimuli. Moreover, depressed and control participants did not differ in their response to neutral stimuli in the 2-back task, suggesting that each group has valence-specific updating biases in WM.

The depressed participants' rapid disengaging or removal from WM of happy stimuli supports the positive attenuation hypothesis, which posits that depressed persons exhibit blunted reactivity to positive emotional stimuli (Rottenberg, Gross, & Gotlib, 2005). It is interesting that combined with the equivalent 0-back perfor-

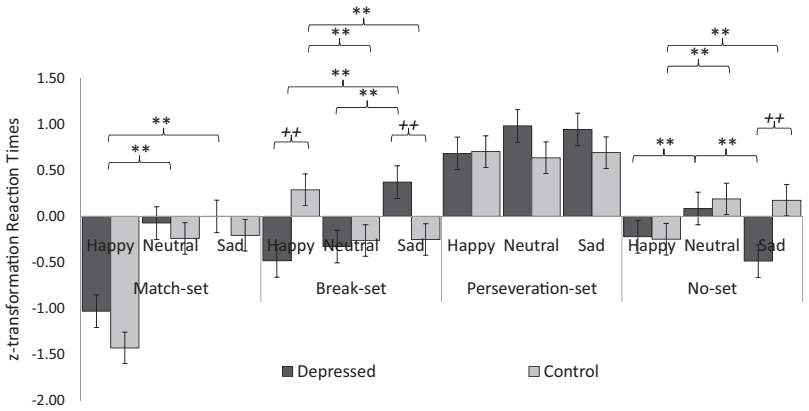

Figure 3. The *z*-scores for match-set, break-set, perseveration-set, and no-set trials for depressed and nondepressed participants. The error bars represent standard error. ** $p < .01$ (within group comparisons). ++ $p < .01$ (between group comparisons).

mance of depressed and nondepressed participants in response to happy expressions, these findings suggest that depressed individuals are able to identify and categorize happy stimuli as quickly as are nondepressed individuals but have difficulty sustaining engagement with this positive information in WM. This pattern indicates that positive attenuation in depression may stem not from perceptual processing biases against positive stimuli but from executive control processes in WM that are comparatively insensitive to positive stimuli.

Contrary to predictions, depressed individuals did not match sad stimuli more quickly than did nondepressed persons; as expected, however, they integrated sad stimuli more quickly than did controls and were slower to disengage from sad stimuli, supporting findings of previous studies indicating that depressed individuals have a potentiated response to negative material (Deveney & Deldin, 2006). For example, in a study examining whether depressed individuals have difficulty removing irrelevant negative emotional content from WM, Joormann and Gotlib (2008) administered a modified Sternberg task to depressed and nondepressed individuals that required participants to memorize lists of positive and negative words and then ignore one of the lists. The ability to remove irrelevant information from WM was indexed by response latencies on a recognition task in which the participants decided whether a probe was a member of the relevant to-be-remembered list. To measure intrusion, Joormann and Gotlib compared RTs for probes from the irrelevant lists and RTs for novel probes of the same valence. These investigators found that although depressed and nondepressed participants exhibited equivalent responses to negative relevant words (a finding similar to the present finding concerning matching of sad expressions), depressed participants showed greater intrusion effects for negative irrelevant words, indicating that they have difficulty deactivating and expelling negative task-irrelevant material from WM.

By examining the updating of emotional content within WM, the present study fills a gap in elucidating the elaborative cognitive processes that operate between the admission of emotional material into, and its removal from, WM that might contribute to the maintenance of depressive symptomatology. Although Joormann and Gotlib (2008) demonstrated that depressed individuals are impaired at expelling negative content from WM, the present results indicate why this might be the case. In Joormann and Gotlib's study, participants were presented with lists of words, asked to remember them, and then asked to expel one of the lists from WM, with no additional information presented to replace the expelled list. In contrast, to perform the 2-back task administered in the present study, participants must maintain a set of three stimuli in WM, adding and subtracting stimuli from this triad on each trial. To disconnect from sad content that they previously endorsed, therefore, participants must add a new valenced stimulus to the to-be-maintained items in WM: a sad expression in perseveration-set trials and a happy or neutral expression in break-set trials. The finding that depressed individuals disengage from sad stimuli more slowly than do nondepressed individuals in break-set trials, coupled with the finding that they do not differ from control participants in their RTs to sad perseveration-set trials, indicates that depressed persons find it difficult to make the necessary WM representation changes to effectively replace sad stimuli in WM with happy stimuli or neutral stimuli. The variable response pattern across the four trial types for depressed and nondepressed participants also illustrates that RTs are affected not only by the valence of the stimuli that enter or leave WM but by what participants must do with that content in WM on that particular trial—link stimuli, disconnect linked stimuli, or integrate and maintain stimuli.

The valence-specific biases in updating emotional content exhibited by depressed and nondepressed participants on this task reflect a tendency to keep negative and positive information, respectively, active in WM, which may underlie susceptibility or resilience to MDD. It will be important in future research to examine mechanisms that might underlie these cognitive effects. In this context, it is noteworthy that catechol O-methyltransferase (COMT) and brain-derived neurotrophic factor (BDNF) have been found to affect both WM performance and depression (e.g., Bertolino et al., 2004; Galloway, Woo, & Lu, 2008; Mata, Thompson, & Gotlib, 2010). In addition, it is possible that particular aspects of a depressive episode influence WM processes to selectively impair depressed individuals' ability to effectively regulate affect. For example, depressed persons may develop a mood-congruent bias that impairs their ability to update positive content in WM. Future research administering this emotion *n*-back task to genotyped individuals and to remitted depressed individuals is needed to explore these possibilities.

In addition to identifying and elucidating differences between depressed and nondepressed individuals in WM, the present study contributes to the literature concerning WM and emotion by presenting data from a novel emotion *n*-back task that assesses participants' ability to connect and disconnect from emotional categories in WM. Never-disordered participants disengaged from happy content in WM significantly more slowly than they did from neutral content or sad content. Given that almost 20% of individuals will be diagnosed with depression at least once in their lifetime (R. C. Kessler & Wang, 2009) and that these participants reported no lifetime psychopathology, this "positivity effect" may reflect an executive process bias in WM that underlies their ability to keep positive information active, an ability that may be a critical component of resilience (Fredrickson et al., 2003). Furthermore, limiting the *n*-back task stimuli, which normally consist of a large array of letters (Kane et al., 2007), shapes (Nystrom et al., 2000), words (Braver et al., 2001), or faces (Druzgal & D'Esposito, 2001; Kensinger & Corkin, 2003) to a smaller stimulus set (i.e., happy, neutral, and sad faces) essentially changes the traditional *n*-back task to a category *n*-back task. Not only can this emotion *n*-back task be used to explore emotion processing biases in other populations (e.g., anxiety disorders, bipolar disorder, and schizophrenia) but categorical stimuli other than emotional faces that vary across such domains as salience, concreteness, and expertise can be used to more fully explore the lability with which individuals connect and disconnect stimuli in WM. In future research, of course, one should also examine the performance effects of the absolute number of categories used as stimuli.

Thus, this task is not only among the first to show valence-specific impairments in updating content in WM that may underlie both the positive attenuation and the pervasive processing of negative stimuli that characterize depression, as well as a positive bias that may underlie resilience to psychopathology, but it also presents a novel adaptation of the classic *n*-back WM paradigm that paves the way for future lines of WM research. The present findings implicate executive processing biases within WM as an

important factor in depression: The difficulty experienced by depressed individuals in ameliorating their negative mood may be due to their relative inability to sustain engagement with positive information in WM. This would result in less elaboration and fewer cognitive resources being directed to the processing of positive stimuli, with consequent weaker memory representations in long-term memory and difficulty replacing negative stimuli with positive material. All of these factors would result in depressed individuals experiencing difficulty in being able to use WM resources adaptively to regulate mood. In the future, researchers should continue to examine the interactions of emotion and executive processes in WM to increase our understanding of the role of these processes in the development and maintenance of depression and assess changes in these processes in response to successful treatment of this disorder.

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