Depressive thoughts limit working memory capacity in dysphoria

Nicholas A. Hubbard\textsuperscript{a}, Joanna L. Hutchison\textsuperscript{ab}, Monroe Turner\textsuperscript{a}, Janelle Montroy\textsuperscript{c}, Ryan P. Bowles\textsuperscript{c} & Bart Rypma\textsuperscript{ab}

\textsuperscript{a} School of Behavioral and Brain Sciences, University of Texas at Dallas, Richardson, TX, USA
\textsuperscript{b} Department of Psychiatry, University of Texas Southwestern Medical Center, Dallas, TX, USA
\textsuperscript{c} Department of Human Development and Family Studies, Michigan State University, East Lansing, MI, USA

Published online: 06 Jan 2015.

To cite this article: Nicholas A. Hubbard, Joanna L. Hutchison, Monroe Turner, Janelle Montroy, Ryan P. Bowles & Bart Rypma (2015): Depressive thoughts limit working memory capacity in dysphoria, Cognition and Emotion, DOI: 10.1080/02699931.2014.991694

To link to this article: http://dx.doi.org/10.1080/02699931.2014.991694

Please scroll down for article

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions
Depressive thoughts limit working memory capacity in dysphoria

Nicholas A. Hubbard1, Joanna L. Hutchison1,2, Monroe Turner1, Janelle Montroy3, Ryan P. Bowles3, and Bart Rypma1,2

1School of Behavioral and Brain Sciences, University of Texas at Dallas, Richardson, TX, USA
2Department of Psychiatry, University of Texas Southwestern Medical Center, Dallas, TX, USA
3Department of Human Development and Family Studies, Michigan State University, East Lansing, MI, USA

(Received 24 February 2014; accepted 20 November 2014)

Dysphoria is associated with persistence of attention on mood-congruent information. Longer time attending to mood-congruent information for dysphoric individuals (DIs) detracts from goal-relevant information processing and should reduce working memory (WM) capacity. Study 1 showed that DIs and non-DIs have similar WM capacities. Study 2 embedded depressive information into a WM task. Compared to non-DIs, DIs showed significantly reduced WM capacity for goal-relevant information in this task. Study 3 replicated results from Studies 1 and 2, and further showed that DIs had a significantly greater association between processing speed and recall on the depressively modified WM task compared to non-DIs. The presence of inter-task depressive information leads to DI-related decreased WM capacity. Results suggest dysphoria-related WM capacity deficits when depressive thoughts are present. WM capacity deficits in the presence of depressive thoughts are a plausible mechanism to explain day-to-day memory and concentration difficulties associated with depressed mood.

Keywords: Depressed mood; Attention; Working memory capacity; Memory deficits; Processing speed.

Day-to-day memory and concentration difficulties are a defining feature of both clinical depression and dysphoria (Beck, Steer, & Brown, 1996; Radloff, 1977; Rush et al., 2003)—a significant and prolonged depressed mood state highly related to clinical depression, but designated to the general population. Such deficits take a personal toll on these individuals with depressed mood and have societal consequences via loss of productivity and an increased rate of disability (e.g., Stewart, Ricci, Chee, Hahn, & Morganstein, 2003). It is likely that persistent thinking about affectively negative, mood-congruent information (i.e., information that is concordant with depressed mood), can impair real-world functioning for those with depressed mood (see Lyubomirsky & Tkach, 2004).

In one study, Lyubomirsky, Kasri, and Zehm (2003) asked dysphoric and non-dysphoric college students either to focus their attention on critical
thoughts of themselves or on neutral thoughts that were unrelated to themselves or emotion. Participants then completed a series of typical academic tasks (e.g., reading a passage from a text, viewing a lecture, proofreading written text). Dysphoric students in the self-focused group were slower, less accurate and reported greater concentration difficulties on the academic tasks compared to dysphoric students in the neutral-focus group, or non-dysphoric students in either group. Lyubomirsky et al. (2003) suggested that even though the self-focused phase of the study had finished when the academic tasks commenced, residual processing of self-relevant information persisted for dysphoric students—that is, they ruminated on the self-relevant information. They speculated that disproportionate attentional focus on this information reduced the amount of task-related (i.e., goal-relevant) information that dysphoric students could maintain [i.e., working memory (WM) capacity], resulting in impaired performance on the academic tasks.

Consistent with Lyubomirsky and colleagues’ (2003) hypothesis, extant work (e.g., Joormann, 2004; Joormann & Gotlib, 2008; Koster, De Raedt, Goelven, Franck, & Crombez, 2005; Koster, De Raedt, Leyman, & De Lissnvy, 2010) has shown that persons with depressed mood have difficulty efficiently disengaging their attention from mood-congruent information. For instance, when individuals with depressed mood are given mood-congruent information within a fluid cognitive task, these individuals tend to focus attention on such information longer than emotionally neutral or task-relevant information, relative to those without depressed mood (e.g., Joormann, 2004, 2010; Joormann & Gotlib, 2008; Koster et al., 2005, 2010; Levens & Gotlib, 2010; Siegle, Ingram, & Matt, 2002). These results have been shown in both clinically depressed persons and dysphoric individuals (DIs).

DIs and clinically depressed persons maintain their attention on mood-congruent information for a longer amount of time compared to persons without depressed mood (see Foland-Ross & Gotlib, 2012). In one study, Joormann and Gotlib (2008) used a modified WM task wherein participants were asked to encode lists of positive and negative words. The authors examined clinically depressed persons’ and non-depressed controls’ response time (RT) to verify positive and negative probes that were taken from either to-be-remembered or to-be-forgotten lists of these valenced words. Joormann and Gotlib’s results showed that, compared to non-depressed controls, clinically depressed individuals took longer to reject the to-be-forgotten probes from negative lists. No such results were observed for positive to-be-remembered, positive to-be-forgotten or negative to-be-remembered probes. These results suggested that clinically depressed participants had difficulty efficiently removing negative information from WM (see also Levens & Gotlib, 2010).

Similar results have been demonstrated in persons with dysphoria. In one study, Joormann (2004) used a negative affective priming task wherein DIs and non-DIs were required to respond to target words and ignore interference words. Compared to non-DIs, DIs took longer to respond when negatively valenced interference words appeared as target words on subsequent trials. No such effects were found for positively valenced words. These results were thought to reflect DIs’ difficulty in efficiently removing mood-congruent information from WM (see also Joormann, 2010; Joormann & D’Avanzato, 2010; Joormann, Yoon, & Zetsche, 2007). Consistent with these findings, a series of studies by Koster et al. (2005) showed that DIs maintained their attention on negative words longer than non-DIs (see also Koster et al., 2010).

Studies with clinically depressed and dysphoric participants show that mood-congruent information persists longer in the focus attention for those with depressed mood relative to those without depressed mood. This longer time spend processing mood-congruent information is often at the expense of goal-relevant processing (Joormann, 2004; Lyubomirsky et al., 2003; Siegle et al., 2002). These works suggest that the ability to autonomously select goal-relevant information and maintain it in the focus of attention (i.e., control attention) is compromised for individuals with depressed mood when mood-congruent information is present. Results from these studies imply that mood-congruent
information evokes controlled attention deficits in individuals with depressed mood. If mood-congruent information is not able to be efficiently removed from the focus of attention, we would expect this to result in a relative decrease in WM capacity for individuals with depressed mood compared to those without depressed mood (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse, Hitch, & Hutton, 2000). This hypothesis could be tested by comparing performance on complex span tasks for individuals with and without depressed mood.

In the seminal complex span task study, Daneman and Carpenter (1980) developed a paradigm (i.e., R-span) wherein participants were asked to read sentences (i.e., the interference task) and remember the last word of each sentence (i.e., the storage task). After several iterations of this procedure, participants were asked to recall the last word of each sentence they had read in the trial. The total amount of words a participant could recall is considered to reflect his or her WM capacity (e.g., Conway et al., 2005; Unsworth & Engle, 2005, 2007). Daneman and Carpenter (1980) showed that R-span performance accounted for significant proportions of variance in measures of higher-order cognition (e.g., reading comprehension). This shared variance reflects a common psychological mechanism underlying performance on these tasks. This mechanism is suggested to be the ability for controlled attention (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Kane, & Engle, 2003; Daneman & Carpenter, 1980; Engle, 2002, 2010; Kane et al., 2004; Kane & McVay, 2012; Unsworth, Heitz, Schrock, & Engle, 2005).

In the current studies, we hypothesised that in the presence of mood-congruent information, DIs would show decreased WM capacity compared to non-DIs. We first examined whether there was general impairment in DIs’ WM capacity. In Study 1, we tested whether DIs showed a deficit in the amount of goal-relevant information they could recall compared to non-DIs on a standard complex span task (i.e., R-span). Next, we utilised a novel paradigm featuring depressive interference stimuli (i.e., D-span task) to test whether a deficit in WM capacity existed for DIs in the presence of depressive information. We hypothesised that if this information was present, the persistence of these depressive thoughts in the focus of attention (cf. Joormann, 2004; Joormann & Gotlib, 2008; Koster et al., 2005, 2010; Levens & Gotlib, 2010; Lyubomirsky et al., 2003) would reduce the amount of goal-relevant information that DIs could retain in WM, compared to non-DIs. Thus, we predicted that DIs in Study 2 would show reduced WM capacity in the presence of inter-task depressive information (i.e., D-span task) compared to non-DIs. Finally, in Study 3, we administered neuropsychological tests together with the R-span and D-span tasks. We assessed whether results replicated from Studies 1 and 2 in Study 3. Further, Study 3 examined whether the relationship between processing speed—the speed with which elementary cognitive operations are executed (e.g., Salthouse, 1996; Rypma et al., 2006)—and D-span performance differed between DIs and non-DIs. We hypothesised that, because DIs are known to have a relative difficulty removing mood-congruent information from the focus of attention, individual differences in processing speed would be more relevant for the recall of goal-relevant information on the D-span task for DIs compared to non-DIs (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000).

STUDY 1: DYSPHORIA AND R-SPAN

In Study 1, we assessed whether general complex span performance was affected in dysphoria. This study was part of a larger series of studies in which unselected (i.e., not prescreened) undergraduate students were given a standard depression inventory and performed several general fluid ability tasks.

Method

Participants and procedure
One hundred and fifty-seven (n = 157) university undergraduate students completed the Center for Epidemiological Studies Depression (CESD), a Raven’s Advanced Progressive Matrices (RAPM)
task and the R-span task. Tasks were administered via E-prime® 2.0 software (Schneider, Eschman, & Zuccolotto, 2002). Participants were comprised of college-age students. Approximately 81% of participants were female (80.9%). Participants were compensated with course credit for their undergraduate psychology courses. All procedures were approved by the governing Institutional Review Board (IRB). Data collection was scheduled a priori for two semesters. All participants completing the CESD, RAPM and D-span task were included in these analyses (n = 157).

Tasks

**CESD inventory.** All participants completed an automated CESD (Radloff, 1977). This metric was designed for use in the general population and measures self-reported, depressive symptomology with emphasis on the affective component of depression—that is, depressed mood (Radloff, 1977). We utilised the threshold suggested by Radloff (1977) to classify individuals with significant depressive symptomology (i.e., DIs; CESD ≥ 16). This procedure classified 60 participants as DIs (38.2%) and 97 participants as non-DIs (61.8%).

**Raven’s advanced progressive matrices.** Participants received the RAPM. This task is thought to measure the ability to reason in novel conditions. Measures of fluid reasoning are heavily dependent upon a variety of fluid cognitive factors, such as WM (Marshalek, Lohman, & Snow, 1983). Thus, RAPM has been shown to be significantly related to WM performance (e.g., Carpenter, Just, & Shell, 1990; Conway et al., 2002, 2003; Kane et al., 2004; Unsworth et al., 2005) and was therefore used to ensure DIs and non-DIs had similar general fluid ability.

**R-span.** The automated R-span task (Kane et al., 2004; Unsworth et al., 2005) required participants to store a single digit number (0–9; i.e., storage task), semantically process and respond “True” or “False” to a sentence (i.e., interference task), and repeat these tasks for 3–7 iterations. Participants were then asked to select from a grid of numbers (0–9), the numbers presented during the storage task in the order they were presented in the current set (Figure 1A). Participants practiced the interference portion of the task for 5 trials, the storage portion of the task for 2 trials at set sizes 2 and 3, and the full task for 3 trials at set size 2. During the interference task practice, mean RT was recorded. Task instructions notified participants that during the actual task, if the individual exceeded 2.5 standard deviations of his or her mean RT on the interference practice, the current item would be skipped and the current set would be recorded as incorrect. This was done in order to minimise strategic rehearsal of storage stimuli during the interference task (Unsworth et al., 2005). Accuracy for the interference task was high (M = 94.15% [4.87%]) and there was no significant association with WM recall (r = .068, p = .392), suggesting that participants did not trade interference task performance for recall task performance (see Conway et al., 2005). Thus, no performance cut-offs were placed on the interference task. There was no time limit set during the number recall phase of the task. There were a total of 15 trials on each task, with set sizes (3–7) presented three times each in random order. No feedback was given on performance.

For interference task trials, participants were asked to indicate whether or not an affectively neutral sentence made sense. After the participants read an interference sentence, a prompt appeared reading “This sentence makes sense”. Participants responded “True” or “False” by mouse click. Approximately 50% of these sentences were semantically acceptable (i.e., participants should respond “True”), whereas the other half of the sentences had one word changed to make the sentence nonsensical (i.e., participants should respond “False”; Kane et al., 2004). For example, a nonsensical sentence might have read, “Most people agree that Monday is the worst stick of the week.” During the interference task, sentences were randomly sampled without replacement from a pool of 81 items.

Accuracy for the storage task (R-span recall) was calculated as the sum of load-weighted, correct sets (Conway et al., 2005; Daneman & Carpenter, 1980). That is, participants were informed that, in
Figure 1. (A) Example of one-item set on the R-span task. (B) Example of one-item set on the D-span task.
order to receive credit for a set, they were required to recall all of the items in the current set in the order presented. The set credit was proportional to the amount of items in the set. For example, if the stimulus set was (5, 8, 9, 1) and the participant recollected (5, 8, 9, 1), the participant received a score of 4 for that set. However, if the participant recollected the stimulus set out of order (e.g., 8, 9, 1, 5), a score of 0 was received for that set. This method made correct guessing improbable:

\[ P(\text{correct guess} \mid n) = \frac{10! - n!}{10!} \]

where \( n \) refers to set size and 10 is the amount of possible choices on the recall grid (0–9). For example, the likelihood of correctly guessing on set size 7 would be about .0002%. This scoring procedure was used for all 15 sets, yielding a maximum possible score of 75 points for the task. R-span recall scores were z-transformed. Interference task RT and recall RT were recorded.

**Results and discussion**

DIs had significantly higher CESD scores (\( M_{\text{DI}} = 21.83 \) [\( SEM = .47 \)]) compared to non-DIs (\( M_{\text{non-DI}} = 8.92 \) [\( .69 \)]), \( t(84.65) = 15.01, p < .001, \text{Cohen’s} \ d = 3.26 \). DIs did not differ significantly from non-DIs on the RAPM (\( M_{\text{DI}} = 15.87 \) [\( .80 \)] vs. \( M_{\text{non-DI}} = 16.72 \) [\( .62 \)]), \( t(155) = -0.84, p = .40, d = .13 \). DI and non-DI groups did not significantly differ in their gender composition (DI = 88.3% female vs. Non-DI = 76.29% female), Pearson \( \chi^2(1) = 3.48, p = .06 \).

No group performance differences were found on R-span interference RT (\( M_{\text{DI}} = 785.46 \) [\( 22.57 \)] vs. \( M_{\text{non-DI}} = 799.65 \) [\( 17.75 \)]), \( t(155) = -0.49, p = .62, d = .08 \) or recall RT (\( M_{\text{DI}} = 5424.92 \) [\( 180.39 \)] vs. \( M_{\text{non-DI}} = 5687.58 \) [\( 141.87 \)]), \( t(155) = -1.14, p = .25, d = .18 \). DIs further did not significantly differ from non-DIs on R-span recall (\( p > .05, d = .03 \); see Figure 2A).

These results suggested that DIs’ WM capacity was comparable to that of non-DIs. Similar group performance on RAPM further suggests that general fluid ability is intact in DIs relative to non-DIs. These results are similar to those reported in prior research, in which it has been shown that individuals with depressed mood perform similarly to those without depressed mood on general measures of fluid ability (see Gotlib & Joormann, 2010). In contrast, we predicted that mood-congruent information would likely interfere with WM capacity for DIs relative to non-DIs (cf. Joormann, 2004; Joormann & Gotlib, 2008; Koster et al., 2005, 2010; Levens & Gotlib, 2010; Siegle et al., 2013).

![Figure 2](image-url)
Thus, in Study 2 we assessed whether embedding depressive information in the R-span interference task (i.e., D-span task) would decrease WM recall for DIs compared to non-DIs.

STUDY 2: DYSPHORIA AND D-SPAN

We created the D-span task to test the hypothesis that DIs have decreased WM capacity compared to non-DIs in the presence of depressive information. Thus, we substituted the affectively neutral interference stimuli from the R-span with interference stimuli that probed typical ruminative content in depression/dysphoria such as concern about one’s depressive symptoms (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). We suggested that the self-referential, depressive nature of the interference stimuli would unduly maintain DIs’ attention for longer periods of time (e.g., Bernblum & Mor, 2010; Daches, Mor, Winquist, & Gilboa-Schechtman, 2010; Lyubomirsky et al., 2003; Wisco, 2009). This in turn would lead to less time to maintain goal-relevant stimuli and would result in decreases in WM capacity (e.g., Salthouse, 1996; Salthouse & Babcock, 1995; Towse et al., 2000).

Method

Participants and procedure

Similar to Study 1, this study was also part of a larger series of studies from which unselected undergraduates were given the CESD and performed several fluid ability tasks. Eighty-two (n = 82) university undergraduate students completed the CESD, RAPM and the D-span task. RAPM and the D-span task were administered via E-prime® 2.0 software. The CESD was administered as in Study 1. Participants were compensated with course credit for their undergraduate psychology courses. Participants were comprised of college-age students. Approximately 70% of participants were female (69.5%). All procedures were approved by the governing IRB. Data collection was scheduled a priori for a one semester maximum. All participants completing the CESD, RAPM and D-span task were included in our analyses (n = 82).

Tasks

Center for Epidemiological Studies Depression. As in Study 1, we utilised the threshold suggested by Radloff (1977) to classify individuals with significant depressive symptomatology (i.e., DIs; CESD ≥ 16). This procedure classified 31 participants as DIs (37.8%) and 51 participants as non-DIs (62.2%). Base rates of DI and non-DI status were not significantly different from Study 1 (p > .05), suggesting consistent classification of DI status across these two samples.

Raven’s Advanced Progressive Matrices. Participants completed the same computerised RAPM as in Study 1 to ensure that groups did not differ on general fluid ability.

D-span. The D-span task was built on identical program code as the R-span task presented in Study 1. Thus practice, stimulus presentation, recall instructions, recall stimuli and storage task scoring were equivalent. Differences between the R-span and D-span tasks were in the interference stimuli and the directions for responding to these stimuli. In the interference task, participants were asked to answer whether or not a sentence was indicative of their recent thoughts, feelings and behaviours (Figure 1B). There were 81 unique interference sentences which were interspersed pseudo-randomly in an order that ensured sentences that might be considered similar did not occur within the same set. No sentences were repeated. These sentences were based on amalgams of self-referential mood items adapted from depression inventories (Beck et al., 1996; Radloff, 1977; Rush et al., 2003). Thus, all sentences probed thoughts, feelings or behaviours related to one’s depression. For example, one self-referential, depressive item read, “I feel discouraged about my future.” The interference sentences probed the following 11 categories: Anhedonia, Crying, Guilty Feelings, Past Failure, Pessimism, Punishment, Sadness, Self-dislike, Self-criticalness,
Thoughts of Self-harm and Worthlessness (Beck et al., 1996; Radloff, 1977; Rush et al., 2003). After participants read an interference sentence, a prompt appeared reading “This is a way I feel or have felt recently.” Participants responded “True” or “False” by mouse click.

Interference items were scored as either depressive-relevant or depressive-neutral. Depressive-relevant endorsements were those indicative of depressive thoughts on depression inventories (Beck et al., 1996; Radloff, 1977; Rush et al., 2003). For example, responding “True” to “I have thoughts of harming myself”, or responding “False” to “I am a happy person”, reflect depressive ideation and were both coded as depressive-relevant responses. Scores were summed out of a possible 81; lower values represented a more depressive-relevant response pattern and higher values represented a less depressive-relevant response pattern.

Results and discussion

DIs had significantly higher CESD scores ($M_{DI} = 24.13$ [SEM = 1.03]) compared to non-DIs ($M_{non-DI} = 9.06$ [.50]), $t(44.46) = 13.16, p < .001$, Cohen’s $d = 3.95$. DIs did not perform significantly different than non-DIs on the RAPM ($M_{DI} = 19.52$ [1.18] vs. $M_{non-DI} = 19.71$ [.92]), $t(80) = −0.13, p = .90$, $d = .03$. DI and non-DI groups did not significantly differ in their gender composition (DI = 74.5% female vs. Non-DI = 66.7% female), Pearson $\chi^2(1) = 0.55, p = .47$.

Consistent with Study 1, DIs did not significantly differ from non-DIs’ RT to the interference stimuli ($M_{DI} = 1148.99$ [58.30] vs. $M_{non-DI} = 1040.25$ [45.45]), $t(80) = 1.47, p = .15, d = .33$, or in recall RT ($M_{DI} = 5744.97$ [291.50] vs. $M_{non-DI} = 5201.25$ [227.27]), $t(80) = 1.47, p = .15, d = .33$. DIs endorsed more depression-relevant responses as ways they had felt or behaved recently compared to non-DIs ($M_{DI} = 46.71$ [2.50] vs. $M_{non-DI} = 64.63$ [.82]), $t(36.58) = −6.80, p < .001, d = 2.25$. We hypothesised that DIs would have a significant deficit in the amount of goal-relevant information they could recall on the D-span task, relative to non-DIs. We utilised a one-tailed $t$-test to test this directional hypothesis (one-tailed $p < .05, d = .45$; See Figure 2B).

Study 2 showed that when we replaced the affectively neutral interference stimuli of the R-span with depressive stimuli (i.e., the D-span), DIs recalled less goal-relevant stimuli compared to non-DIs. Importantly, we found that DIs and non-DIs did not significantly differ in the amount of time to decide on these interference items suggesting that the temporal demands of the interference task did not bias group recall performance (e.g., Towse & Hitch, 1995; Towse et al., 2000). Further, similar RAPM performance between groups suggested that general fluid ability was not compromised for DIs relative to non-DIs.

We suggest that DIs had difficulty removing the depressive interference stimuli from their focus of attention (cf. Joormann, 2004; Joormann & Gotlib, 2008; Koster et al., 2005, 2010; Levens & Gotlib, 2010; Lyubomirsky et al., 2003). This disproportionate time spent on the depressive interference information would have resulted in decreased WM capacity for the storage stimuli (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000).

The ability to efficiently remove interference stimuli is predictive of the amount of target information that can be recalled from WM (e.g., Towse & Hitch, 1995; Towse et al., 2000). In the R-span and D-span tasks, participants directed their focus of attention to an interference stimulus (i.e., the emotion-neutral sentences of the R-span task or the depressive sentence of the D-span task). This stimulus was subsequently removed from the focus of attention, and attentional focus was oriented to a storage stimulus (i.e., the to-be-remembered number). Next, focus was oriented to another interference stimulus which prevented rehearsal of the storage stimulus. The interference stimulus was then removed from the focus of attention and a new storage stimulus was added to the accumulating list of storage stimuli in WM, which had to be rehearsed in order to be kept active (e.g., Baddeley & Hitch, 1974; Cowan, 2001; Engle, 2002, 2010; Towse & Hitch, 1995; Towse et al., 2000).
When information is kept unrehearsed or inactive, time causes it to become susceptible to displacement or decay (e.g., Baddeley & Hitch, 1974; Cowan, 2001; Engle, 2010; Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000). A deficit in DIs’ ability to efficiently remove the interfering information from the focus of attention would have left storage stimuli inactive for a longer period of time. The limited activity of the storage stimuli would have reduced the probability of its retrieval, resulting in reduced WM capacity (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000).

In Study 3, we assessed whether group results replicated from Studies 1 and 2, and whether group means in Study 3 were consistent with those observed in Studies 1 and 2. We further tested whether the relationship between individual differences in processing speed and D-span performance differed between DIs and non-DIs. We proposed that if DIs had difficulty efficiently removing the depressive interference stimuli from their focus of attention, this would be evident in the relationship between individual differences in processing speed and the amount of goal-relevant information recalled on the D-span task. Specifically, we hypothesised that DIs would show a greater association between digit-symbol substitution task (DSST; a measure of processing speed known to predict individual differences in WM performance; e.g., Salthouse, 1992; Salthouse & Babcock, 1991; Rypma & Prabhakaran, 2009; Rypma et al., 2006) performance and D-span performance, compared to non-DIs. We did not predict a substantive group-difference in this relationship for the R-span task.

STUDY 3: COMPLEX SPAN PERFORMANCE REPLICABILITY AND RELATIONSHIP TO PROCESSING SPEED

In Study 3, participants were given several neuropsychological tasks, a CESD and both the R-span and D-span tasks. We first examined results from the neuropsychological testing to ensure DIs and non-DIs performed similarly on these measures. Second, because results from Studies 1 and 2 have not been demonstrated in prior literature, we sought to examine if these results were replicable in Study 3. We therefore tested whether DIs and non-DIs differed on the R-span and D-span tasks. Further, we examined if DIs and non-DIs differed in their relationships between processing speed performance and D-span performance. We hypothesised that if DIs had difficulty removing the depressive interference stimuli from their focus of attention, the speed with which DIs could potentially rehearse information in WM (i.e., processing speed) would become increasingly important for WM recall (Salthouse, 1996; Salthouse & Babcock, 1991; Rypma & Prabhakaran, 2009; Rypma et al., 2006). Thus, we expected an increased correlation between DSST performance and WM recall performance for DIs on the D-span task, but no such effect on the R-span task.

Method

Participants and procedure

Eighty-four (n = 84) unselected university undergraduate students completed all portions of this study. Consistent with Studies 1 and 2, data were acquired as part of a larger study examining the effects of depressed mood on fluid cognitive performance. In the present study, a motor speed task, a processing speed task, a CESD and demographic questionnaire were administered in paper-and-pencil form. R-span, D-span and RAPM (Raven, Raven, & Court, 1998) were administered via E-prime® 2.0 software. Participants were given study components in the following order: speed tasks, sample characteristic measures, complex span task one, RAPM, complex span task two. Order of R-span and D-span administration was counterbalanced (i.e., complex span task one or two) with RAPM placed between the first and the second complex span task. Participants were compensated with course credit for their undergraduate psychology courses. All
procedures were approved by the governing IRB. Data collection was scheduled a priori for a one semester maximum.

**Complex span tasks**

R-span and D-span tasks were identical to those presented in Studies 1 and 2. Interference RT, recall RT and recall total were acquired similarly to Studies 1 and 2. D-span and R-span recall totals were also z-standardised. Consistent with Study 1, R-span interference task performance was near ceiling \( \bar{M} = 92.48\% \) and the correlation with R-span recall was significantly positive \( r = .36, p = .001\). This suggests that participants did not trade interference task performance for recall performance and thus we did not exclude R-span trials on the basis of interference task performance. Further R-span and D-span recall totals were significantly correlated, \( r = .723, p < .001\). This suggests that performance on these tasks was measuring a similar construct.

**Neuropsychological tasks**

Four neuropsychological tests were administered to participants in the current study. Because processing speed (e.g., Salthouse, 1992; Salthouse & Babcock, 1991; Rypma & Prabhakaran, 2009; Rypma et al., 2006) and RAPM (e.g., Conway et al., 2002, 2003; Kane et al., 2004; Unsworth et al., 2005) performance relate highly to WM performance, we examined whether DIs and non-DIs differed on these measures. We also measured perceptual speed to assess whether DIs and non-DIs differed in the speed with which information can be encoded (e.g., Ackerman, Beier, & Boyle, 2002). Further, depressed mood is often associated with psychomotor retardation or agitation, which could generate differences in interference or recall RT. We therefore assessed whether motor speed was compromised in DIs compared to non-DIs.

**Motor, Perceptual and Processing Speed Tasks.** Participants were given a motor speed task (i.e., box completion; Salthouse, 1996), a perceptual speed task (letter comparison task; Salthouse, 1996) and a processing speed task (i.e., DSST; Salthouse, 1992). The box completion task was used to assess whether DIs and non-DIs differed in their motor speed, which could confound RT measures on the complex span tasks. This task measures motor speed by assessing the amount of incomplete (i.e., three-sided) squares that a participant can complete in 30 seconds. The number of completed squares reflects individual differences in the speed by which simple motor processes can be executed (Salthouse, 1996).

The letter comparison task requires participants to determine whether two strings of letters are the same. Participants are given 30 seconds to judge as many pairs of letter strings as possible. This task measures the speed with which basic encoding and comparison processes can occur (Ackerman, Beier, & Boyle, 2002). The number of correct responses reflected an individual’s perceptual speed.

The DSST was used in order to (1) assess whether DIs and non-DIs differed in their processing speed abilities and (2) assess whether DIs and non-DIs differed in their relationships between processing speed and complex span performance. This task requires participants to visually search a key of nine digit-symbol pairs and assess which number in the key matches a probe symbol; participants are given 120 seconds to complete as many digit-symbol pairs as they can. The number of correct digit-symbol pairs reflects the execution speed of basic cognitive operations (e.g., visual search, memory rehearsal; Rypma & Prabhakaran, 2009; Rypma et al., 2006).

**RAPM.** Participants completed the same computerised RAPM as in Studies 1 and 2. Consistent with Studies 1 and 2, this task was used to ensure that our groups did not differ in general fluid ability.

**Group characteristics**

**Affect Intensity Scale.** Participants completed the 40-item, self-report Affect Intensity Scale (AIS; Larsen & Diener, 1987). Participants indicated how often they experienced an emotional reaction. This scale is suggested to measure the degree to
which an individual experiences emotion (Larsen & Diener, 1987).

Center for Epidemiological Studies Depression. We utilised the same DI status threshold in the present study as in Studies 1 and 2 (i.e., DIs; CESD ≥ 16). This procedure classified 30 participants as DIs (36.1%) and 53 participants as non-DIs (63.8%). Base rates of DI and non-DI status were not significantly different from Studies 1 or 2 (all ps > .05), suggesting consistent classification of DI status across all three separate samples.

Demographic Questionnaire. A demographic questionnaire was created to collect several key variables including age, sex and ethnicity.

Ruminative Responses Scale. Participants completed a Ruminative Responses Scale (RRS; Treynor, Gonzalez, & Nolen-Hoeksema, 2003). This self-report inventory required participants to indicate how often they utilised specific ruminative strategies when coping with negative mood. The RRS-B reflects the tendency to focus attention on self-critical and negative thoughts, whereas the RRS-R has been characterised as promoting active thinking about problem solving (Treynor et al., 2003).

Results

Group neuropsychological and sample characteristics

Table 1 illustrates group comparisons on the neuropsychological, CESD and demographics. There were no significant differences between DIs and non-DIs on the neuropsychological measures. Further, no group differences were found on the age, AIS, sex or ethnicity (all ps > .05). As expected, DIs had significantly greater CESD scores and RRS scores (p < .001).

DI and non-DI complex span results

R-span task. Consistent with Study 1, no group performance differences were observed on R-span interference RT (M_DI = 1049.95 [52.51] vs. M_non-DI = 1011.78 [40.16]), t(82) = 0.58, p = .57, Cohen’s d = .13, or recall RT (M_DI = 4546.94 [207.82] vs. M_non-DI = 4478.63 [158.94]), t(82) = 0.26, p = .79, d = .18. Further, DIs did not significantly differ from non-DIs on R-span recall (p > .05, d = .23; see Figure 3A).

D-span task. Several results were consistent with Study 2. First, no group performance differences were observed on D-span interference RT (M_DI = 1171.25 [71.61] vs. M_non-DI = 1008.70 [54.77]), t(82) = 1.80, p = .08, d = .39, or recall RT (M_DI = 5856.26 [358.06] vs. M_non-DI = 5043.52 [273.84]), t(82) = 1.80, p = .08, d = .40. Second, DIs indicated that a significantly greater number of interference sentences were depressive-relevant compared to non-DIs (M_DI = 44.29 [2.13] vs. M_non-DI = 63.60 [.98]), t(42.86) = −8.22, p < .001, d = 2.51. Third, DIs showed a significant deficit in the amount of goal-relevant information they could recall on the D-span task, relative to non-DIs (one-tailed p < .05, d = .59; See Figure 3B).

Processing speed and complex span performance

We sought to assess the relationships between DSST performance and the amount of goal-relevant information DIs and non-DIs could recall on the R-span and D-span tasks. We suggested that DIs had relative difficulties removing depressive interference information from their focus of attention. Thus, we hypothesised that individual differences in the speed with which they could rehearse information in WM (i.e., processing speed) would be more important for successful maintenance of goal-relevant information on the D-span task for DIs relative to non-DIs. We also examined this relationship for the R-span task.

DSST performance significantly related to both R-span (r = .37, p < .001) and D-span (r = .38, p < .001) recall. R-span performance was significantly related to performance for DIs (r = .40, p = .03) and non-DIs alike (r = .35, p = .01). A Fisher z-test of R-span and DSST correlations did not show a significant difference in these associations between-groups, z = .25, p = .80 (Figure 3C). We hypothesised that DIs would show a significantly greater relationship between DSST performance and D-span recall than non-
This directional hypothesis was confirmed, 
DIs ($r = .54$, $p = .002$) vs. non-DIs ($r = .20$, $p = .15$), 
z = 1.70, one-tailed $p = .04$ (Figure 3D).

**Discussion**

In Study 3 we first examined whether unselected 
DIs and non-DIs differed on several key neuropsychological variables. DIs and non-DIs did not show significant differences in motor speed, perceptual speed, processing speed, or fluid reasoning performance. Second, we tested whether our results from Studies 1 and 2 replicated within a single study (i.e., DIs performed similar to non-DIs on R-span, worse on the D-span task. Results from Study 3 replicated those from Studies 1 and 2, in which DIs and non-DIs had recalled a similar amount of goal-relevant stimuli on the R-span task; however, DIs recalled significantly less goal-relevant information on the D-span task compared to non-DIs.

We assessed the contribution of processing speed to both R-span and D-span recall, and whether this relationship differed between DIs and non-DIs. We hypothesised, and our results confirmed, that DIs would show greater associations between processing speed and D-span recall performance, compared to non-DIs. These results suggested that the speed with which DIs could process information was more important for their D-span performance, relative to non-DIs. It is possible that, in DIs for whom efficient removal of depressive information is impaired (cf. Joormann, 2004; Joormann & Gotlib, 2008; Koster et al.,

<table>
<thead>
<tr>
<th>Non-DIs</th>
<th>DIs</th>
<th>Test statistic</th>
<th>$p$-value</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCT</td>
<td>46.75 (1.41)</td>
<td>50.81 (2.69)</td>
<td>1.46</td>
<td>.146</td>
</tr>
<tr>
<td>DSST</td>
<td>83.83 (1.66)</td>
<td>80.93 (3.00)</td>
<td>1.00</td>
<td>.320</td>
</tr>
<tr>
<td>LCT</td>
<td>23.09 (.68)</td>
<td>22.65 (1.01)</td>
<td>.38</td>
<td>.704</td>
</tr>
<tr>
<td>RAPM</td>
<td>19.23 (1.04)</td>
<td>17.68 (1.34)</td>
<td>.91</td>
<td>.365</td>
</tr>
</tbody>
</table>

**Self-report/demographic information**

| Age | 25.51 (.90) | 23.33 (.94) | 1.58 | .118 | .36$^a$ |
| AIS | 143.93 (2.95) | 151.26 (3.15) | 1.61 | .111 | .37$^a$ |
| CESD | 8.30 (.57) | 25.16 (1.53) | 12.19 | <.001 | 2.52$^a$ |
| Sex (% female) | 54.72% | 58.06% | .09 | .766 | −.03$^b$ |
| Race/Ethnicity | 5.44 | 5.44 | .365 | −.15$^c$ |
| African/African American (%) | 3.77 | 12.90 |
| Hispanic (%) | 20.75 | 22.58 |
| Indian or East Asian (%) | 18.87 | 22.58 |
| Middle Eastern (%) | 1.89 | 6.45 |
| Non-Hispanic Caucasian (%) | 52.83 | 35.48 |
| Other (%) | 1.89 | 0.00 |
| RRS-B | 8.85 (.43) | 12.55 (.59) | 5.13 | <.001 | 1.15$^a$ |
| RRS-R | 9.30 (.51) | 12.94 (.50) | 4.71 | <.001 | 1.11$^a$ |
| RRS-Total | 38.77 (1.33) | 57.74 (1.69) | 8.74 | <.001 | 1.98$^a$ |

Note: Mean (SEM) group scores on Study 3 ($n = 84$) neuropsychological and self-report measures.

AIS, affect intensity scale; BCT, box completion task; CESD, Center for Epidemiological Studies Depression Inventory; DSST, Digit-symbol substitution task; LCT, letter comparison task; RAPM, Raven’s Advanced Progressive Matrices; RRS-B, Ruminative Responses Scale brooding component; RRS-R, Ruminative Responses Scale reflection component; RRS-Total, Ruminative Responses Scale aggregate score.

$^a$Test statistic and $p$-value based on two-tailed, independent-samples $t$-test with 82 degrees of freedom, effect sized based on Cohen’s $d$.

$^b$Test statistic and $p$-value based on two-tailed, Pearson $\chi^2$-test with 1 degree of freedom, effect size based on Kendall’s Tau-b.

$^c$Test statistic and $p$-value based on two-tailed, Pearson $\chi^2$-test with 5 degrees of freedom, effect size based on Kendall’s Tau-b.
individual differences in processing speed were more important for WM capacity. We postulated that depressive information remained in DIs’ focus of attention for a longer time, leaving goal-relevant information unrehearsed or inactive for a longer time compared to non-DIs. This greater time spent attending to the depressive information would have detracted from time spent on DIs’ rehearsal of storage stimuli, rendering storage stimuli more liable to decay or displacement compared to non-DIs (e.g., Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000). Therefore, the efficiency with which DIs could rehearse goal-relevant information, once it was retrieved in the focus of attention (i.e., processing speed), would have been a more important factor for DIs’ WM capacity compared to non-DIs on the D-span task. These results also implicate processing efficiency as a protective factor for DIs’ WM capacity in situations when depressive thoughts are present.

**GENERAL DISCUSSION**

We assessed whether DIs and non-DIs differed in their WM capacity for goal-relevant information. In Study 1, we found no difference between DIs and non-DIs on general complex span tasks.

![Graphs showing mean DI and non-DI Z-standardised D-span recall, Z-standardised R-span recall by Group and Condition, scatterplot of Z-standardised R-span recall and DSST total correct, and scatterplot of Z-standardised D-span recall and DSST total correct.](image)
performance (i.e., R-span task). In Study 2, we utilised an experimental variant of a complex span task, wherein participants were required to process interference information consisting of depressive sentences (i.e., D-span task). DIs showed significantly compromised performance when recalling goal-relevant information on the D-span task. In Study 3, we confirmed the results from Studies 1 and 2, and showed that DIs’ and non-DIs’ performance was consistent on R-span and D-span tasks across separate samples. Study 3 further illustrated that, although DIs had similar processing speed performance compared to non-DIs, processing speed was more related to D-span performance in DIs than in non-DIs.

Our results suggest that if depressive thoughts are absent (owing to the absence depressive information in the R-span task) WM capacity is similar between DIs and non-DIs. However, when depressive thoughts are present (owing to the presence of depressive information in the D-span task) our results suggest that WM capacity will be decreased for DIs compared to non-DIs. This was evident in the WM capacity deficits found for DIs compared to non-DIs when participants were forced to process depressive information (D-span) within the task. We postulate that this effect occurred because depressive thoughts remained in DIs’ focus of attention for longer periods of time (cf. Joormann, 2004; Joormann & Gotlib, 2008; Koster et al., 2005, 2010; Levens & Gotlib, 2010; Siegle et al., 2002), which led to insufficient rehearsal of goal-relevant information, and subsequent loss of this information (cf. Salthouse, 1996; Salthouse & Babcock, 1991; Towse & Hitch, 1995; Towse et al., 2000). This hypothesis was supported by DIs’ greater relationship between processing speed and D-span recall, compared to non-DIs.

Like complex span task performance in the laboratory, real-world WM performance requires that goal-relevant information is maintained in the presence of distraction. For example, remembering a grocery list requires maintaining list items while also attending to competing demands such as those inherent in navigating one’s way through the grocery store. Indeed, complex span performance is broadly associated with higher-order cognitive performance both in and out of the laboratory. Some examples of these associations include reading and listening comprehension, language comprehension, following directions, vocabulary learning, fluid reasoning, hypothesis generation, bridge playing and complex skill learning (see Engle, 2010). Consistent with these associations, researchers have hypothesised that persistent depressive thinking in dysphoria reduces the amount of goal-relevant information that can be maintained during ecologically relevant, higher-order cognitive performance (e.g., Lyubomirsky et al., 2003). Our results suggest that if periods during which goal-relevant information would be actively rehearsed are instead occupied by depressive thoughts or ruminations, an inability to efficiently remove attention from these thoughts would preclude successful maintenance of the to-be-remembered information. In such a scenario, we would expect DIs to exhibit reduced WM capacity during ecologically relevant activities.

Because depressive thoughts are a ubiquitous part of daily life for those with clinical depression and dysphoria (see Nolen-Hoeksema et al., 2008), future research should examine the impact that decreased WM capacity might have on day-to-day functioning in persons with depressed mood. For instance, a prospective study might examine the relationship between individuals with depressed moods’ D-span performance and how often depressive thoughts interfere with their day-to-day cognitive performance (see Kane et al., 2007; Kane & McVay, 2012). Another future aim suggested by our results would be to examine the extent that processing speed acts as a protective factor for individuals with depressed moods’ WM capacity.

It remains unknown whether deficits in WM capacity in the presence of depressive information are the consequence of depressed mood, or rather a risk factor for the development and maintenance of depressed mood (cf. De Lissnyder, Derakshan, De Raedt, & Koster, 2011; Demeyer, De Lissnyder, Koster, & De Raedt, 2012). Future research should assess whether such deficits are present in populations at-risk for depressed mood (e.g.,
Gotlib, Joorman, Minor, & Cooney, 2006). Further, it is possible that dysphoric samples might represent a milder form of depressed mood. Therefore, future work should address whether these effects observed here extend to a clinically depressed sample. Future work should also explore the extent to which D-span performance relates to other measures of attention control (see Engle, 2010) in depressed and non-depressed populations.

The present work illustrated that WM capacity deficits emerged in DIs when depressive information was present in a WM task. To our knowledge, this was the first study to show WM capacity deficits in DIs when depressive information was present. WM capacity deficits in the presence of depressive thoughts represent a plausible mechanism for day-to-day concentration and memory lapses affecting those with depressed mood.

Acknowledgements

The authors wish to thank Vamsi Daliparthi, Sara Gamal and Travis Weaver for assistance in data collection and Ehsan Shokri-Kojori for lending his computational expertise.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Friends of Brain Health and the Linda and Joel Roebuck Distinguished New Scientist endowments and the Dianne Cash Fellowship Award (to NAH).

REFERENCES


symptomatology (QIDS), clinician rating (QIDS-C), and self-report (QIDS-SR): A psychometric evaluation in patients with chronic major depression. Biological Psychiatry, 54, 573–583. doi:10.1016/S0006-3223(02)01866-8


Rypma, B., & Prabhakaran, V. (2009). When less is more and when more is more: The mediating roles of capacity and speed in brain–behavior efficiency. Intelligence, 37, 207–222. doi:10.1016/j.intell.2008.12.004


