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Running head: EMOTION AND WORKING MEMORY

Recollecting positive and negative autobiographical memories disrupts working memory

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Abstract

The present article reports two experiments examining the impact of recollecting emotionally valenced autobiographical memories on subsequent working memory (WM) task performance. Experiment 1 found that negatively valenced recollection significantly disrupted performance on a supra-span spatial WM task. Experiment 2 replicated and extended these findings to a verbal WM task (digit recall), and found that both negative and positive autobiographical recollections had a detrimental effect on verbal WM. In addition, we observed that these disruptive effects were more apparent on early trials, immediately following autobiographical recollection. Overall, these findings show that both positive and negative affect can disrupt WM when the mood-eliciting context is based on autobiographical memories. Furthermore, these results indicate that the emotional disruption of WM can take place across different modalities of WM (verbal and visuo-spatial).

Recollecting positive and negative autobiographical memories disrupts working memory

It is well-known that emotions can influence cognitive function across a diverse range of tasks and settings. This interplay between emotions and cognitive function can have potentially serious consequences, for example, Young (2008) has identified negative effects of stress on cognitive performance as a major risk factor in airplane pilots. One key area of cognition that might be particularly susceptible to the effects of emotion is working memory (WM), that is, the ability to temporarily retain, manipulate, and respond to information drawn from the environment and long-term memory. For example, Baddeley and colleagues (2007, 2013; and Baddeley, Banse and Huang, 2012) have argued that WM may be the cognitive control centre in which emotional processing and evaluation takes place. In line with this idea, a substantial body of evidence indicates that WM performance is impaired in individuals experiencing greater life event stress (e.g. Klein & Boals, 2001) and those with mood disorders such as depression (e.g. Christopher & MacDonald, 2005; Hartlage et al., 1993). Likewise, studies testing healthy participants have also shown that experimentally-induced emotional states can affect WM performance (for a review, see Mitchell & Phillips, 2007). In particular, several studies have found that negative affect impairs WM performance (Kensinger & Corkin, 2003;Shackman et al. 2006; Koch et al., 2007; Osaka et al.; 2013)).

Classical models based on differences of allocation of cognitive resources between emotional and neutral contents are often invoked to explain these effects (e.g. Ellis & Ashbrook, 1987; Siebert & Ellis, 1998). According to these models, both negative and positive emotional states cause the occurrence of mood-related contents in WM. The maintenance and processing of these mood-related contents in WM would then mobilize attentional resources that would no longer be available for other tasks. This account leads to a prediction of emotional effects on WM that are nonspecific, that is, they are independent of whether affect is positive or negative. This account has received some support from data showing that both negative and positive affect can impair performance in tasks recruiting WM and executive control (e.g. Oaksford et al., 1996). In contrast, a different stream of evidence shows that negative and positive affect can have a differential effect on WM tasks. For instance, Gray (2001) found that spatial 2-back performance was enhanced by prior viewing of threat-related films and impaired following positive films, while verbal n-back revealed the reverse pattern of effects. In addition, many studies have also shown that positive affect can have a facilitating effect on WM and executive control tasks, which further challenges resource allocation models (Kuhl & Kazen, 1999; Dreisbach & Goschke, 2004; Gray, 2001). Many models have been invoked to account for these results. For instance, it has been argued that the effects of the neurotransmitter dopamine would mediate the effects of positive affect on cognitive tasks (Roesch-Ely et al, 2005; Dreisbach, et al, 2005; Fried et al, 2001). Other potential mediating factors have also been suggested, such as cognitive set, approach and withdrawal states, executive ability, and individual differences (e.g. Gray et al., 2002; Mitchell & Phillips, 2007;, Derakshan, Smyth, & Eysenck, 2009; Schaefer et al., 2006).

The picture emerging from these apparently divergent results is that the nature of the effects of emotion on WM and cognitive control depends on many factors, including the type of task used to induce affect (Banich, 2009; Gray et al., 2004). It is therefore important to map how different methods of emotion elicitation can lead to specific patterns of modulation of WM. A method of mood induction that has not previously been investigated in this context involves asking participants to retrieve emotional autobiographical memories (ABMs). Emotional ABMs are not only powerful methods to induce emotional states (Schaefer & Philippot, 2005), they also provide a particularly ecologically valid method of emotion elicitation, as retrieval of past memories is a frequent cause of emotional states in everyday life (e.g. Goodwin & Williams, 1982; Rimé, Noël, & Philippot, 1991).

Crucially, emotional induction through ABMs is very likely to involve WM processes, as the generation of ABMs is thought to involve the maintenance and manipulation of autobiographical contents in WM (Conway & Pleydell-Pearce, 2000). In other words, the generation of ABMs is usually considered to involve WM activity (see also Dalgleish et al., 2007; Piolino et al., 2009). Importantly, if the ABM contents held in WM vary according to their emotional intensity, then specific consequences for WM function can be predicted. Compared to neutral contents, emotional contents are known to strongly mobilize attentional and WM resources for a variety of reasons: emotional contents can automatically attract attentional resources (Mermillod et al., 2010; Ohman & Mineka, 2001); emotional contents lead to more rehearsal than neutral contents (Talarico & Rubin, 2004); emotional contents can also trigger attempts at cognitive regulation strategies that recruit WM resources (Ochsner et al., 2002; Schaefer et al., 2003). For all these reasons, there is a well-known asymmetry in the allocation of attentional and WM resources between emotional and neutral contents (Watts et al., 2014). Therefore, it could be hypothesized that the generation of emotional ABMs will recruit more WM resources than neutral ABMs, which could then impair performance on a WM task immediately following the generation of emotional ABMs.

These characteristics of emotional ABMs therefore create a context in which WM could be modulated by ABM-induced emotion following the prediction of resource allocation models of emotion-cognition interactions. Specifically, emotional ABMs are very likely to activate mood-relevant contents in WM (Ellis & Ashbrooke, 1987; Conway & Pleydell-Pearce, 2000) that will divert cognitive resources necessary to perform a WM task immediately following ABM retrieval. However, to date, emotional ABM retrieval has had only limited use in investigations of emotional effects on cognitive processes. For instance, Phillips, Bull, Adams, and Fraser (2002) observed that retrieval of positive ABMs impaired inhibition and switching performance in a subsequent Stroop task, thus revealing disruption of executive function.To our knowledge no previous studies have examined how retrieval of valenced ABMs impacts on a standard measure of WM incorporating temporary storage.

We aimed to address this gap in the existing literature using the ABM retrieval methodology developed by Schaefer and Philippot (2005), in which participants retrieve and describe emotionally valenced and neutral personal autobiographical memories. This method has been shown to produce reliable changes in self-reported emotional feelings and autonomic nervous system measures for valenced memories compared to neutral memories, with these effects being equivalent in magnitude for positive and negative memories (Schaefer & Philippot, 2005; Fay & Finlayson, 2011).

Under our approach, each participant performed a WM task immediately following each of the ABM retrieval phases. The measure we used to gauge the effects of ABM mood induction was immediate serial recall of supra-span sequences, either using a spatial Corsi task in Experiment 1 or an aurally presented digit recall task (Experiment 2). Both Corsi and digit recall are commonly used measures of WM (Baddeley, 2003), and are often assumed to tap separable visuospatial and phonological sub-components, as set out in the model of WM proposed by Baddeley and Hitch (1974). Therefore, significant effects of emotion on either or both types of WM task would indicate whether these effects are modality-specific (i.e. visuospatial or verbal) , or if they rely on modality-general attentional control. Few studies have examined effects of emotion induction across different modalities, and these have typically used very different elicitation methods (e.g. Gray, 2001). In line with classical models of emotion-cognition interaction (Siebert & Ellis, 1991; Ellis & Ashbrook, 1987), and with the assumption that emotional ABMs will tap WM resources to a greater extent than neutral ABMs, we expected that recollecting emotional ABMs would have a detrimental effect on an immediately subsequent WM task.

The supra-span method allows the use of a single sequence length titrated to each participant's memory span. This approach provides a sensitive measure of WM that is constant in length, enabling us to track the impact of ABM-based emotion induction across trials. As measures of WM and executive function are typically obtained following induction, it is likely that any effect of these manipulations will be particularly powerful during early trials immediately following the induction procedure, before waning across the course of the trial block.

Experiment 1

This experiment examined performance on a Corsi spatial WM task, immediately after retrieval of a neutral or negatively valenced ABM. Physical and computerized variants of this task have been frequently used to assess spatial WM processing and capacity (e.g. De Renzi, 1982; Burke, Allen, & Gonzalez, 2012), with studies suggesting a dissociation from verbal (Vandierendonck et al., 2004) and visual WM (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999) and a role for executive function, particularly for longer sequences (Vandierendonck et al., 2004). Due to recollection of a negatively valenced ABM possibly eliciting more vivid visual imagery, and/or leading to attentional capture and thus loading on executive resources, we predicted that this condition would reveal less accurate performance on the subsequent visuospatial WM task, relative to the neutral recollection condition.

Method

Participants

There were 24 English-speaking participants (8 male, 16 female) in this study, aged between 19 and 36 years (mean = 23.4). All participants were right-handed and had normal or corrected-to-normal vision.

Design and Procedure

Emotional valence of ABM was manipulated using a repeated measures design, with valence having two levels (negative, neutral). The single testing session consisted of a Corsi span pre-test and the two experimental blocks (each featuring ABM recollection followed by a set of spatial recall trials). Order of conditions was fully counterbalanced across participants.

In line with the supra-span method, each experimental session started with a Corsi span pre-test to establish, for each participant, the sequence length to implement in the main phase of the study. Stimuli were displayed on an 18.4" screen, using an adapted version of the Psychology Experiment Building Language (PEBL) computerized Corsi task (Mueller, 2011).

Each trial started with a screen displaying the text "Ready" for 1000 ms. Next, a screen presenting an array of 9 blue squares (each 3x3cm in size) was presented during 1000 ms on a black background, in locations that were consistent across participants and trials (see Figure 1). Next, one of the squares (the "target") was highlighted by flashing in yellow for 1000ms, before reverting back to blue. Just after this, another one of the locations would become a target, being highlighted in the same fashion. The number of targets that were sequentially highlighted in this way depended on the sequence length determined by the experiment (We will hereafter use the word "sequence" to refer to a sequence of highlighted targets in a given trial). The order of the highlighted targets was pre-arranged by the experimenter, and varied from trial to trial. No target was highlighted more than once in each sequence. At the end of each trial, a rectangular icon containing the text 'Done' was displayed at the bottom of the screen. Using a mouse, participants were then required to click on the targets that were previously highlighted, in the same order. Selection of each location by mouse-clicks was signalled by highlighting the relevant square for 500ms and playing a 250ms tone. No feedback was provided. Every trial included one sequence.

For the span pre-test, sequences started at length 2 (i.e. two highlighted targets to maintain in WM), and gradually increased (up to a maximum of 9) with 2 sequences presented at each length, until participants failed to recall both sequences entirely correctly at a given length. For each participant, span was defined as terminal length-1. On the basis of this performance measure, a sequence length of span+2 was used in the main experimental conditions (e.g. for span = 6, experimental sequence length = 8). Due to the display containing 9 locations, possible experimental sequence length had an upper limit of 9 items.

The two experimental conditions then followed. ABM recollection followed the methodology developed by Schaefer and Philippot (2005). Each condition started with a 1-minute relaxation phase, followed by a retrieval stage in which participants were asked to retrieve a negative or emotionally neutral episode of their lives as quickly as possible. Specific instructions followed the procedure used in Schaefer & Philippot (2005):

"Now, I would like you to recall as quickly as possible an event that you have lived and during which you have felt positive emotions (or *negative emotions* or *an emotionally neutral event*)*."*

. They were then instructed to think of this memory and orally describe each of its elements, for at least 1 minute (recollection stage):

"Now, I would like you to orally describe what happened during this event. I ask you to describe each element of your memory, as it comes to your mind. I also ask you to describe the event for at least one minute."

The main spatial recall task then immediately followed autobiographical recollection in each condition. This consisted of 12 Corsi sequences, each span+2 in length. Sequence presentation and response method was identical to that used in the span pre-test phase.

The final stage in each condition involved a manipulation check requiring participants to report the emotional states they experienced during ABM recollection in order to verify if emotional states had been induced by emotional ABMs compared to neutral ABMs. This was measured using a modified version of the Differential Emotions Scale (DES; Izard et al., 1974; modified by McHugo, Smith, & Lanzetta, 1982; Philippot, 1993; and Schaefer et al, 2010), which consists of 13 groups of emotional adjectives: (1) interested, concentrated, alert; (2) joyful, happy, amused; (3) sad, downhearted, blue; (4) angry, irritated, mad; (5) fearful, scared, afraid; (6) anxious, tense, nervous; (7) disgusted, turned off, repulsed; (8) disdainful, scornful, contemptuous; (9) surprised, amazed, astonished; (10) loving, affectionate, friendly; (11) ashamed, embarrassed; (12) guilty, remorseful; (13) moved. For each group of adjectives, participants used a 9-point scale (1 = "not at all; 9 = "very intense") to rate the extent to which each emotional state was experienced during ABM recollection.

Results

Visuospatial recall

Mean span was 6 (SE = .21), resulting in a mean sequence length in the main experimental session of 7.92 (range 6-9). Performance in the main experimental recall task was scored as the mean proportion of locations correct in each sequence, using a strict serial position criterion. To examine the temporal course of the potential effects of ABM recall on digit span, we averaged the performance of the 6 first Corsi Sequences together to create a “Time 1” performance index, and we averaged the remaining 6 sequences to form a “Time 2” performance index. Mean proportion correct per sequence is displayed in Table 1. A Valence (Negative ABMs vs. Neutral ABMs) X Time (First vs. second half of the trial blocks) ANOVA revealed a significant effect of Valence , $F(1, 23) = 6.8$, $p<.02$, $\eta^2 = .23$. This effect indicates that visuospatial recall was markedly impaired in the Negative ABM condition compared to the neutral ABM.

Mean proportion correct rates for the first and second half of the trial blocks are also displayed in Table 1. It is apparent that performance differences between conditions are somewhat more reliable in the first half of the trial block. Comparing performance on the neutral and negative conditions on the first half of the trial block revealed a significant difference, $t\,(23) = 2.35$, $p < .05$ ($d = .60$). In contrast, there was no significant difference between recall in the negative and neutral conditions for the latter half of the trial block, $t\,(23) = 1.05$, $p = .303$

(d = .25). However, this specific finding has to be considered with caution, given that the Time X Valence interaction was not significant (F<1).

Manipulation check: Subjective emotional experience

Mean ratings on the DES for each valenced ABM condition are displayed in Table 2. A repeated-measures MANOVA with valence as the within-subject factor was performed on participants' self-ratings of the 13 specific emotions. The multivariate effect of valence was significant, F (13,312) = 20.44 $p < .001$, partial η^2 = 96. The univariate effects of valence were significant at $p < .001$ for *joyful, sad, anger, guilty,* and *anxious,* at $p < .01$ for *fearful and moved,* and $p < .05$ for *disgust, ashamed, and disdain,* but were not significant for *interest, surprise,* or loving ($p > .05$). It can be seen from Table 1 that the negative condition led to activation of negative emotions, indicating that ABM recollection of negative experiences had successfully induced negative emotional states.

Discussion

This experiment revealed a significant effect of negatively valenced ABM recollection on subsequent spatial WM performance, with proportionally fewer locations selected in correct serial order relative to the neutral recollection condition. Furthermore, comparison of performance in the early and later trials in each block indicated that the effect of valence was significant only in trials immediately following recollection. However, this specific finding involving the timing of trial blocks was not strong enough to produce a significant Time X Valence interaction. These findings will be further discussed in the context of the outcomes of Experiment 2, in the General Discussion.

Experiment 2

It remains unclear whether the impacts of the induction technique observed in Experiment 1 were executive in nature, or more specifically visuospatial. For example, valenced ABM recollection may have elicited more associated mental imagery, which in turn influenced visuospatial WM. The first aim of this experiment therefore was to extend our exploration to a different modality. Under our approach, each participant performed a verbal WM task immediately following each of the ABM retrieval phases. The task we used to gauge the effects of ABM mood induction was immediate serial recall of supra-span digit sequences. While verbal serial recall is primarily viewed as a measure of verbal short-term memory, attentional control processes also have an important role in such tasks (e.g. Baddeley, Hitch, & Allen, 2009; St. Clair Thompson & Allen, 2013). As in Experiment 1, the supra-span method allows the use of a single sequence length titrated to each participant's memory span. This provides a sensitive measure of WM that is constant in length, enabling us to track the impact of ABM-based mood induction across trials.

Secondly, we extended our investigation to examine effects of both negative and positive induction. Induced positive affect has produced somewhat divergent findings in measures of WM and executive control. Spies et al. (1996) found disruptive effects of positive induction using music and Velten statements, while Phillips et al. (2002) observed that inhibition and switching performance were impaired by retrieval of positive ABMs and presentation of positive stories. However, Phillips et al. found that the latter induction method facilitated performance on fluency tests. Furthermore, Gray (2001) found that while spatial 2-back performance was enhanced by prior viewing of threat-related films and impaired following positive films, verbal n-back revealed the reverse pattern. Thus, while on the one hand we expected to observe similar disruption of WM by positive and negative induction (relative to the neutral condition) as a result of general attentional capture, it was also possible that divergent effects of these conditions would emerge.

Method

Participants

There were 24 English-speaking participants (9 male, 15 female) in this study, aged between 20-35 years.

Design and Procedure

Emotional valence of ABM was manipulated using a repeated measures design, with valence having 3 levels (positive, negative, neutral). The single testing session consisted of a digit span pre-test and the 3 experimental conditions (each featuring ABM recollection followed by a set of digit recall trials). Order of conditions was fully counterbalanced across participants.

As in Experiment 1, each experimental session commenced with a span pre-test to establish the sequence length to implement in the main phase of the study. Digit sequences were verbally presented at a rate of 1 digit per second, and participants were required to verbally recall each sequence immediately upon presentation offset. Sequences started at length 4, and gradually increased with 2 sequences presented at each length, until participants failed to recall both sequences entirely correctly at a given length, with digit span classed as terminal length-1. On the basis of this performance measure, a sequence length of span+2 was used in the main experimental conditions (e.g. for span = 7, experimental sequence length = 9).

The three experimental conditions then followed. ABM recollection followed the methodology developed by Schaefer and Philippot (2005) and outlined in Experiment 1. The main digit recall task then immediately followed autobiographical recollection in each condition. This consisted of 12 digit sequences, each span+2 in length. Sequences consisted of randomized digit strings, presented aurally at a rate of 1 per second. As in the span pre-test, participants attempted to verbally recall the sequence in its original order immediately following presentation completion. The final stage in each condition involved participants reporting the emotional states they experienced during ABM recollection, again using a modified version of the DES (e.g. McHugo et al., 1982; Schaefer et al, 2010).

Results

Digit recall

Mean digit span was 6.79 (*SE* = .22), resulting in a mean sequence length in the main experimental session of 8.79 (range 7-11). Performance in the digit recall task was scored as the mean proportion of digits correct in each sequence, using a strict digit-position scoring criterion. Proportion of correct digits in each recollection condition overall, in the first and second half of each trial block, is displayed in Table 1.

A repeated measures Valence X Time ANOVA on the overall accuracy rates showed a highly significant effect of Valence, F (2,46) = 76.6, $p < .0001$, η^2 = .77). Planned comparisons revealed significant differences between neutral and negative, t (23) = 9.15, $p < .001$ *(Cohen's d =1.64)*, and neutral and positive, t (23) = 7.60, $p < .001$ *(d = 1.56)*, but not between negative and positive t (23) = 1.20, p = .244 *(d = .19)*.

As in Experiment 1, it is apparent that performance differences between conditions are more reliable in the first half of each trial block. This observation was confirmed by a robust Valence X Time interaction, F(2,46) = 74.6, p <.001, η^2= .76. This interaction was driven by effects of Valence that were larger for the first compared to the second half of the span trials, F(2, 46) = 127.9, 6.2; p< .0001, .004; η^2= .85, .21. Paired-samples t-tests testing negative-neutral and positive-neutral differences in the first half of the trial block revealed highly significant differences, t(23) = 11.6, 13.2, *ps*<.001 (Cohen's d = 2.9 and 2.3), respectively. In the second half of the trial block, the comparisons were significant, but the effect sizes were markedly smaller, t(23) = 2.8, 2.4, p = .01, .02, (Cohen's d = .48, .55). Positive-Negative contrasts were non-significant in all cases.

Manipulation check: Subjective emotional experience

Mean ratings on the DES for each valenced ABM condition are displayed in Table 1. A repeated-measures MANOVA with valence as the within-subject factor was performed on participants' self-ratings of the 13 specific emotions. The multivariate effect of valence was significant, F (26,312) = 7.94, p < .001, partial η^2 = 75. The univariate effects of valence were significant at p < .001 for *joyful, sad, anger, fearful, loving,* and *moved,* at p < .01 for *anxious*, *disdain, surprise, ashamed, and guilt,* and p < .05 for *disgust,* but were not significant for *interest* (p = .61). It can be seen from Table 1 that the positive condition led to activation of positive emotions, and the negative condition correspondingly to negative emotions.

Finally, we examined whether positive and negative memory retrieval led to equivalent levels of emotional intensity. To obtain a measure of intensity, we extracted the peak-rated item from the DES for each memory, separately for positive and negative memories (see Gross & Levenson, 1995, for a similar method). This measure should not be seen as a measure of global arousal, but instead as an estimate of the intensity of the specific state most representative of the actual state felt by the participant. Mean score of peak-rated emotions was 7.13 (SE = .38) for positive and 7.00 (SE = .32) for negative memories, with no significant difference between these conditions, t (23) = .41, p = .69.

Discussion

This experiment revealed a substantial disruption in digit span performance following the recollection of emotional autobiographical memories (ABM). This effect was observed for both positive and negative ABMs, and the magnitude of the effect was similar between these 2 conditions. In addition, the observed disruption of digit span performance appeared to change over trials; this effect was largest for trials immediately following the recollection procedure, and was reduced in the second half of trial blocks. These findings therefore extend those observed in Experiment 1 to a verbal working memory task, and also show similar impacts of positive and negative ABM recollection.

General Discussion

Two experiments revealed that recollection of emotionally valenced ABMs can significantly disrupt subsequent working memory performance. Effects of negative memory recollection were apparent in both spatial (Experiment 1) and verbal (Experiment 2) working memory, with positive recollection also showing similar impacts on verbal recall in the second experiment. In addition, effects of recollection were most apparent in early trials, before reducing later in the trial blocks. However, this specific effect of time was more reliable when verbal WM was tested.

These effects of emotion induction on WM performance indicate that such manipulations are capable of influencing tasks with storage components, in addition to measures of executive function (e.g. Philips et al., 2002). The finding of nonspecific effects of emotion on WM performance is consistent with earlier models (Ellis & Ashbrook, 1987; Siebert & Ellis, 1991), but apparently inconsistent with studies that show valence-specific effects of emotion on WM and attention (e.g. Gray, 2001; Phillips, Bull, et al., 2002). This difference may be due to the particular elicitation technique used, as most previous studies used methods such as film and picture presentation. As explained in the introduction, generating emotional ABMs is not only a powerful means of inducing emotional changes (Schaefer & Philippot, 2005, Fay & Finlayson, 2011), but it is also thought to recruit WM resources . Specifically, the generation of ABMs per se is thought to involve maintaining and processing autobiographical contents in WM (Conway & Pleydell-Pearce, 2000), and emotional contents are known to mobilize WM and attentional resources to a greater extent than neutral contents (Watts et al, 2014). Therefore, it is possible that recollecting emotional ABMs may have recruited WM resources more than neutral ABMs, thereby depleting the subsequent WM task. This interpretation does not imply that valence-specific models are not valid. Instead, these models may better describe the effects of emotion on WM when the method of emotional elicitation relies less on WM processes. Further research will be needed to investigate more deeply how different techniques of emotion elicitation impact on working memory.

An important question that needs to be discussed concerns the specific mechanisms mediating the relationship between emotional ABMs and the subsequent impairment of WM performance. In other words, how could the recruitment of WM resources by emotional ABMs impact on a subsequent cognitive task? Our experiments do not allow us to isolate a unique account, but two explanations derived from previous research are possible. First, it is possible that emotional ABMs have taxed WM and attentional resources to the extent that these resources were no longer available for the span tasks immediately following the ABM task. This could be consistent with the notion that reallocating WM and executive resources between two different tasks incurs a cognitive cost (Meiran et al., 2000), and with data showing that performing tasks that tax cognitive control resources can impair tasks immediately following it (Richeson & Shelton, 2003). Second, it is possible that the recruitment of WM processes by the generation of emotional ABMs may have been sustained in time, to the point that these processes were running concurrently to the span tasks.

Consistent with the model of Ellis & Ashbrook (1987), emotion (and emotional ABMs in particular) is known to trigger rehearsal and rumination more than neutral ABMs (Talarico & Rubin, 2004; Rime et al., 1991). Thus, it is possible that emotional ABMs may have triggered a greater amount of rehearsal than neutral ABMs, and therefore, rehearsal processes concurrent to the span tasks would have acted as a distracting task. This explanation would be consistent with recent results showing that rehearsal mediates the impact of negative emotion on WM (Curci et al., 2014).

Valenced ABM recollection impacted on supra-span versions of both spatial and verbal WM performance. These findings suggest that such effects are modality-general in nature, rather than arising purely as a result of modality-specific processes. It may be that ABM-related emotion captures central executive control resources (Baddeley 1986), or the central focus of attention (e.g. Cowan, 1995, 2005). This notion is consistent with observed effects of emotion on measures of executive function (Banich et al., 2009), and of the role of such resources in WM tasks (e.g. St. Clair-Thompson & Allen, 2013; Vandierendonck et al., 2004), particularly when using longer sequences at or beyond the limits of capacity. Another possibility might be that ABM-based induction results in storage of related thoughts in the episodic buffer (Baddeley, 2013), though it is unclear to what extent the spatial and verbal tasks used in the current study also involve this proposed modality-independent store. Finally, beyond Baddeley's (1986) central executive construct, our modality-independent results could also suggest that emotional ABMs affect modality-independent general mechanisms of active maintenance in WM (Braver & Cohen, 2000; Reilly et al., 1999).

It is apparent that the effects of valenced recollection were larger on verbal (Experiment 2) than spatial (Experiment 1) WM. This might be surprising, given claims that visuospatial WM is more closely related to executive function than verbal WM (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). A possible interpretation is based on the work of Rapee (1993), who found that loading on the phonological loop element of WM using articulatory suppression had a somewhat larger effect on worry-related thought than spatial tapping, and that a verbal-based executive task had a larger effect than both. This might indicate that worry and rumination are relatively more verbal than visuospatial in nature, as well as placing a more substantial load on the central executive. Therefore, consistent with classical models of emotion-cognition interaction (Ellis & Ashbrook, 1987; Siebert & Ellis, 1991) it is possible that recollecting emotional ABMs produces emotionally-relevant contents rich in verbal materials (e.g. worries and ruminations). These materials would then disrupt verbal WM to a greater extent than spatial WM, which could explain why emotional recollection had a larger effect on verbal compared to spatial WM in our experiments. Another possibility is that participants might have relied on strategies such as "chunking" in the digit span task (Baddeley, 1996) which is thought to be under the control of central executive processes (Kane et al., 2007). If emotion does affect central executive processes, then it is likely that the implementation of such strategies may be impaired, which could explain the larger effect of emotion in the digit span task. Finally, it is also possible that the differences in effect sizes are caused by a greater difficulty in performing the spatial compared to the verbal task. This explanation would be supported by the data described in Table 1 indicating that performance in the neutral condition is much higher in the verbal compared to the spatial task. Therefore, it is possible that performance in the spatial task was closer to a baseline floor level, and thus any emotion-induced decrement would have been smaller compared to the verbal task.

A further finding of this study was that the effect of valenced recollection on digit span performance appeared to vary with the temporal order of task trials. More specifically, the effects of emotional disruption of WM performance appear to be larger in task trials immediately following ABM recollection, whereas this effect tended to dissipate in later trials. This trend might reflect a temporal decrease in intensity of the emotional state (see Fredrickson & Kahnemann, 1993; Kliegel et al., 2005). Alternatively, these effects may reflect displacement or distraction caused by the requirement to perform the spatial or verbal tasks themselves. This would be consistent with studies indicating that performance of simple cognitive tasks can inhibit emotional processing (e.g. Rapee, 1993; Van Dillen & Koole, 2007; King & Schaefer, 2011; Vytal & Grillon, 2012). It has also to be noted that, although pairwise tests indicate that the effects of valence vary with time in both studies, the Emotion X Time interaction was clearly significant in Study 2 but not in Study 1. These results indicate that this effect is more reliable when verbal WM is tested, and could be explained by the fact that the overall effects of Valence are larger in Study 2 than Study 1.

In summary, this is the first study to show that recollecting either negative or positive emotional memories impairs working memory performance across both verbal and visuo-spatial modalities. These findings suggest that generating emotional ABMs might recruit WM processes, which can potentially impair other cognitive activities relying on similar processes. Furthermore, our results suggest that future research should examine whether rehearsal-based processes mediate the effects of ABM recollection on WM performance.

References

Vandierendonck, A.; Kemps, E., Fastame, M.C. & Szmalec, A. (2004). Working memory components of the Corsi blocks task . *British Journal of Psychology*, 95 (1)pp. 57–79,

Ashby, F.G., Isen, A.M., & Turken, A.U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review, 106 (3),* 529-550.

Baddeley, A. D. (1986). *Working Memory*. NY: Oxford university Press.

Baddeley, A.D. (2003). Working memory: looking back and looking forward, Nature Reviews Neuroscience 4, 829-839

Baddeley, A.D. (2007) *Working Memory, Thought and Action*. NY: Oxford university Press

Baddeley, A.D. (2013) Working memory and emotion: Ruminations on a theory of depression. *Review of General Psychology*, Vol 17(1), Mar 2013, 20-27

Baddeley, A.D., Banse, R. & Huang, Y.M. (2012). Working memory and emotion: Detecting the hedonic detector. Journal of Cognitive Psychology, 24 (1), 6-16.

Baddeley, A.D., Hitch, G.J., & Allen, R.J. (2009). Working memory and binding in sentence recall. *Journal of Memory and Language, 61,* 438-456.

Banich MT, Mackiewicz KL, Depue BE, Whitmer AJ, Miller GA, et al. (2009) Cognitive control mechanisms, emotion and memory: a neural perspective with implications for psychopathology. Neurosci Biobehav Rev 33: 613-630.

Braver TS and Cohen JD (2000) On the control of control: The role of dopamine in regulating prefrontal function and working memory. In: S. Monsell and J. Driver, editors. Attention and Performance XVIII. Cambridge, MA: MIT Press. pp. 713-738.

Christopher, G., & MacDonald, J. (2005). The impact of clinical depression on working memory. *Cognitive Neuropsychiatry, 10 (5),* 379-399.

Conway, M., & Pleydell-Pearce, C.W. (2000). The construction of autobiographical memories in the self memory system. *Psychological Review, 107,* 261-288.

Conway, M.A. (2005). Memory and the Self. journal of Memory and Language, Volume 53, Issue 4, pp. 594–628

Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford Psychology Series (No. 26). New York: Oxford University Press.

Cowan, N. (2005). *Working memory capacity*. Hove, East Sussex, UK: Psychology Press.De Renzi, E. (1982). Disorders of space exploration and cognition. Chichester: Wiley.

Curci, A.; Lanciano, T.; Soleti, E. & Rimé, B. (2013). Negative emotional experiences arouse rumination and affect working memory capacity. Emotion, 13, 867-880.

Depue, R.A., and Collins, P.F. (1999) Neurobiology of the structure of personality: Dopamine, facilitation of incentive motivation, and extraversion. *Behavioral and Brain Sciences* 22, 491-569

Derakshan, N.; Smyth, S. & Eysenck, M.W. (2009). Effects of state anxiety on performance using a task-switching paradigm: An investigation of attentional control theory. *Psychonomic bulletin & Review*, 16(6), 1112-1117.

Dreisbach, G., and Goschke, T. (2004) How positive affect modulates cognitive control: reduced perseveration at the cost of increased distractibility. *Journal of Experimental Psychology: Learning Memory and Cognition* 30, 343-353

Dreisbach, G.*, et al.* (2005) Dopamine and cognitive control: the influence of spontaneous eyeblink rate and dopamine gene polymorphisms on perseveration and distractibility. *Behav Neurosci* 119, 483-490

Ellis, H.A. & Ashbrook, P.W. (1988). Resource allocation model of the effects of depressed mood states on memory. In K. Fielder & J. Forgas (Eds.), *Affect, cognition, and social behavior* (pp. 25-43). Lewiston, NY: Hogrefe.

Fredrickson, B.L. & Kahneman, D. (1993). Duration neglect in retrospective evaluations of affective episodes. *Journal of Personality and Social Psychology, 65 (1),* 45-55.

Fried, I.*, et al.* (2001) Increased dopamine release in the human amygdala during performance of cognitive tasks. *Nat Neurosci* 4, 201-206

Gray, J. R., Braver, T. S., & Raichle, M. E. (2002). Integration of emotion and cognition in the lateral prefrontal cortex. *Proceedings of the National Academy of Sciences, 99*, 4115-4120.

Gray, J.R. (2001). Emotional modulation of cognitive control: Approach-withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology: General, 130 (3),* 436-452.

Gray, J.R. (2004) Integration of emotion and cognitive control. *Current Directions in Psychological Science, 13,* 46-48

Gross, J.J., & Levenson, R.W. (1995). Emotion elicitation using films. *Cognition and Emotion, 9 (1),* 87-108.

Hartlage, S., Alloy, L.B., Vazquez, C., & Dykman, B. (1993). Automatic and effortful processing in depression. *Psychological Bulletin, 113 (2),* 247-278.

Izard, C.E., Dougherty, F.E., Bloxom, B.M., & Kotsch, N.E. (1974). *The Differential Emotions Scale: A method of measuring the meaning of subjective experience of discrete emotions.* Nashville: Vanderbilt University, Department of Psychology.

Kane, M.J, Conway, A.R.A., Hambrick, D.Z. & Engle, R.W. (2007). Variation in working memory capacity as variation in executive attention and control. In C. Jarrold (Ed.). Variation in Working Memory, Oxford University Press.

Kensinger, E.A., and Corkin, S. (2003) Effect of negative emotional content on working memory and long-term memory. *Emotion* 3, 378-393

King, R. & Schaefer, A. (2011). The emotional startle effect is disrupted by a concurrent working memory task. *Psychophysiology*, 48 , 269-276.

Klein & Boals 2001 The relationship of life event stress and working memory capacity. Applied Cognitive Psychology , 15(5), 565–579,

Kliegel, M., Jager, T., Phillips, L.H., Federspiel, E., Imfeld, A., Keller, M., & Zimprich, D. (2005). Effects of sad mood on time-based prospective memory. *Cognition and Emotion, 19 (8),* 1199-1213.

Kuhl, J., and Kazen, M. (1999) Volitional facilitation of difficult intentions: Joint activation of intention memory and positive affect removes Stroop interference. *Journal of Experimental Psychology: General* 128, 382-399

Lavric, A.*, et al.* (2003) Threat-evoked anxiety disrupts spatial working memory performance: an attentional account. *Cognitive Therapy and Research* 27, 489-504

McHugo, G.J., Smith, C.A., & Lanzetta, J.T. (1982). The structure of self-reports of emotional responses to film segments. *Motivation and Emotion, 6,* 365-385.

Meiran N, Chorev Z and Sapir A (2000) Component processes in task switching. Cognitive psychology 41: 211-253.

Mermillod, M.; Droit-Volet, S.; Devaux, D.; Schaefer, A. & Vermeulen, N. (2010) Are coarse scales sufficient for fast detection of visual threat? *Psychological Science, 21: 1429-1437*

Mitchell, R.L.C., & Phillips, L.J. (2007). The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia, 45,* 617-629.

Oaksford, M.*, et al.* (1996) Mood, reasoning, and central executive processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 22, 476-492

Ochsner K, Bunge S, Gross J, Gabrieli J (2002) Rethinking Feelings: An fMRI Study of the Cognitive Regulation of Emotion. Journal Of Cognitive Neuroscience 14:1215-1229.

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review, 108*(3), 483-5

O'Reilly RC, Braver TS and Cohen JD (1999) A biologically-based computational model of working memory. In: A. Miyake and P. Shah, editors. Models of Working Memory: Mechanisms of Active Maintenance and Executive Control. New York: Cambridge University Press.

Osaka, M.; Yaoi, K.; Minamoto, T. & Osaka, N. (2013). When do negative and positive emotions modulate working memory performance? *Scientific Reports*, 3, 1375.

Philippot, P. (1993). Inducing and assessing differentiated emotional feeling states in the laboratory. Cognition and Emotion, 7, 171-193

Philippot, P., Schaefer, A. & Herbette, G. (2003). Consequences of specific processing of emotional information: Impact of general versus specific autobiographical memory priming on emotion elicitation. *Emotion*. 3, 270-283.

Phillips, L.H., Bull, R., Adams, E., & Fraser, L. (2002). Positive mood and executive function: Evidence from Stroop and Fluency Tasks. *Emotion, 2 (1),* 12-22.

Piolino P, Coste C, Martinelli P, Mace AL, Quinette P, et al. (2010) Reduced specificity of autobiographical memory and aging: do the executive and feature binding functions of working memory have a role? Neuropsychologia 48: 429-440.

Piolino P, Desgranges B and Eustache F (2009) Episodic autobiographical memories over the course of time: cognitive, neuropsychological and neuroimaging findings. Neuropsychologia 47: 2314-2329.

Rapee, R.M. (1993). The utilisation of working memory by worry. *Behaviour Research and Therapy*, 31 (6), pp. 617–620

Richeson JA and Shelton JN (2003) When prejudice does not pay: Effects of interracial contact on executive function. Psychol Sci 14: 287-290.

Roesch-Ely, D.*, et al.* (2005) Differential dopaminergic modulation of executive control in healthy subjects. *Psychopharmacology (Berl)* 178, 420-430

Schaefer, A., & Philippot, P. (2005). Selective effects of emotion on the phenomenal characteristics of autobiographical memories. *Memory, 13 (2),* 148-160.

Schaefer, A., *et al.* (2003) Neural correlates of "hot" and "cold" emotional processing: A multilevel approach to the functional anatomy of emotions. *Neuroimage* 18, 938-949

Schaefer, A., Nils, F., Sanchez, X., & Philippot, P. (2010). Assessing the effectiveness of a large database of emotion-eliciting films: A new tool for emotion researchers. *Cognition and Emotion, 24 (7),* 1153-1172.

Schaefer, A.; Braver, T.S.; Reynolds, J. R.; Burgess, G.C.; Yarkoni, T.; & Gray, J.R. (2006). Individual differences in amygdala activity predict response speed during working memory. *Journal of Neuroscience*, 26(40): 10120-10128.

Seibert, P.S., & Ellis, H.C. (1991). Irrelevant thoughts, emotional mood states, and cognitive task performance. *Memory and Cognition, 19 (5),* 507-513.

Shackman, A.J., Sarinopoulos, I., Maxwell, J.S., Pizzagalli, D.A., Lavric, A., & Davidson, R.J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion, 6 (1),* 40-61.

Smyth, M.M. & Scholey, K.A. (1994). interference in immediate spatial memory. *Memory and Cognition*, 22 (1) 1-13.

St. Clair-Thompson, H., & Allen, R.J. (2013). Are backwards and forwards digit recall the same? A dual task study of digit recall. *Memory & Cognition, 41 (4),* 519-532.

Talarico JM, LaBar KS and Rubin DC (2004) Emotional intensity predicts autobiographical memory experience. Mem Cognit 32: 1118-1132.

Van Dillen, L.F. & Koole, S.L. (2007). Clearing the mind: A working memory model of distraction from negative mood. Emotion, Vol 7(4), pp. 715-723.

Vytal K, Cornwell B, Arkin N and Grillon C (2012) Describing the interplay between anxiety and cognition: from impaired performance under low cognitive load to reduced anxiety under high load. Psychophysiology 49: 842-852.

Watts, S; Buratto, L.G.; Brotherhood, E.V.; Barnacle, G.E. & Schaefer, A. (2014). The neural fate of neutral information in emotion-enhanced memory., *Psychophysiology*, *51* (7), 673-684.

Young, J.A. (2008). The Effects of Life-Stress on Pilot Performance. Moffett Field, California, U.S.: National Aeronautics and Space Administration Ames Research Center.

Table 1. Mean proportion correct (*and SE*) overall and in the first and second half of each trial block in Experiments 1 and 2

	Overall mean	1st half of trials	2nd half of trials
Experiment 1 (Spatial)			
Neutral	.57 *(.03)*	.55 *(.02)*	.58 *(.03)*
Negative	.50 *(.03)*	.46 *(.02)*	.54 *(.03)*
Experiment 1 (Verbal)			
Neutral	.74 *(.02)*	.71 *(.02)*	.76 *(.02)*
Negative	.58 *(.02)*	.44 *(.03)*	.71 *(.02)*
Positive	.59 *(.02)*	.47 *(.02)*	.72 *(.02)*

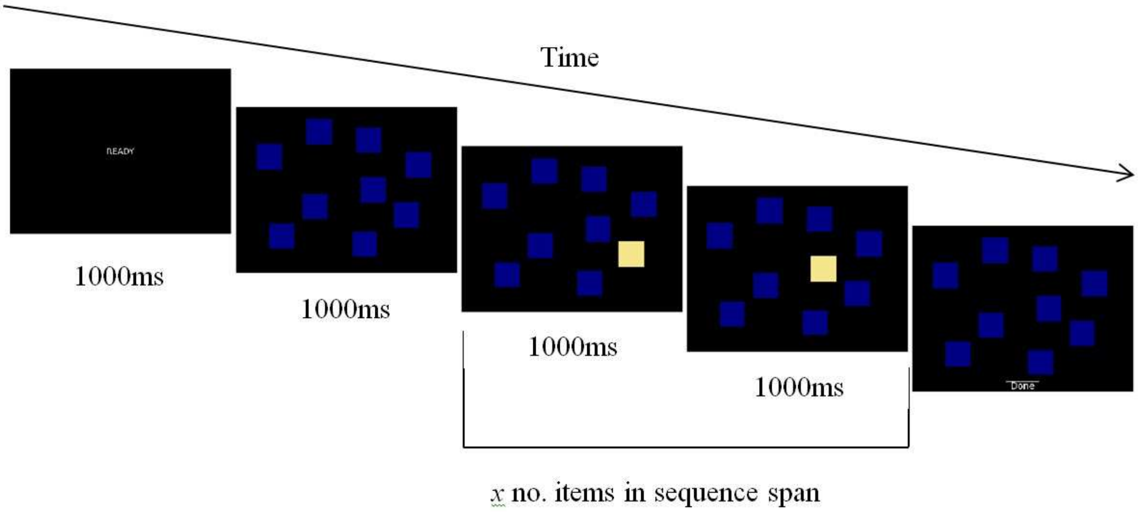
Table 2. Mean ratings (*and SE*) of discrete emotional feelings by autobiographical recollection condition

	Neutral		Negative		Positive
	Exp 1	Exp 2	Exp 1	Exp 2	Exp 2
Interest	5.04 *(.22)*	6.00 *(.45)*	5.17 *(.23)*	5.89 *(.36)*	6.25 *(.43)*
Joyful	3.71 *(.35)*	3.46 *(.37)*	1.46 *(.16)*	1.50 *(.24)*	6.83 *(.39)*
Sad	1.67 *(.18)*	1.00 *(.0)*	6.54 *(.30)*	4.96 *(.56)*	1.33 *(.13)*
Anger	1.62 *(.22)*	1.00 *(.0)*	3.79 *(.55)*	3.69 *(.59)*	1.25 *(.25)*
Fearful	1.63 *(.26)*	1.00 *(.0)*	3.08 *(.51)*	3.13 *(.49)*	1.17 *(.13)*
Anxious	2.13 *(.40)*	1.71*(.22)*	4.88 *(.60)*	3.46 *(.46)*	2.54 *(.39)*
Disgusted	1.00 *(.0)*	1.00 *(.0)*	2.08 *(.46)*	1.63 *(.33)*	1.00 *(.0)*
Disdainful	1.00 *(.0)*	1.00 *(.0)*	2.08 *(.44)*	2.25 *(.40)*	1.25 *(.18)*
Surprise	1.42 *(.29)*	1.21 *(.17)*	1.83 *(.33)*	1.58 *(.31)*	2.63 *(.47)*
Loving	2.63 *(.54)*	2.46 *(.39)*	2.58 *(.29)*	1.96 *(.48)*	5.88 *(.46)*
Ashamed	1.58 *(.32)*	1.04 *(.04)*	2.50 *(.40)*	2.46 *(.52)*	1.00 *(.0)*
Guilt	1.33 *(.27)*	1.00 *(.0)*	3.63 *(.52)*	2.42 *(.48)*	1.04 *(.04)*
Moved	1.46 *(.30)*	1.08 *(.06)*	2.42 *(.26)*	3.79 *(.50)*	3.83 *(.53)*

Figure captions

Figure 1. Illustration of an experimental trial of the Corsi task in Experiment 1. A detailed explanation is provided in the Methods section.

Figure 1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