Effects of emotional content on working memory capacity

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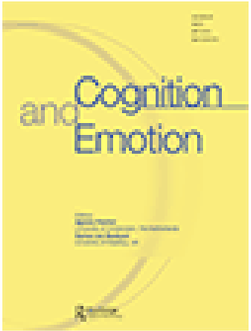

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BRIEF ARTICLE

Effects of emotional content on working memory capacity

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ABSTRACT
Emotional events tend to be remembered better than neutral events, but emotional states and stimuli may also interfere with cognitive processes that underlie memory performance. The current study investigated the effects of emotional content on working memory capacity (WMC), which involves both short term storage and executive attention control. We tested competing hypotheses in a preregistered experiment ($N = 297$). The emotional enhancement hypothesis predicts that emotional stimuli attract attention and additional processing resources relative to neutral stimuli, thereby making it easier to encode and store emotional information in WMC. The emotional impairment hypothesis, by contrast, predicts that emotional stimuli interfere with attention control and the active maintenance of information in working memory. Participants completed a common measure of WMC (the operation span task; Turner, M. L., & Engle, R. W. [1989]. Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127–154) that included either emotional or neutral words. Results revealed that WMC was reduced for emotional words relative to neutral words, consistent with the emotional impairment hypothesis.

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Working memory; emotion; OSPAN

Emotional events play a starring role in memory. Numerous studies have observed that emotional stimuli are better recalled than neutral stimuli (e.g. Bradley, Greenwald, Petry, & Lang, 1992; Doerksen & Shimamura, 2001). Emotional events enhance memory representations because they capture attention, increase stimulus processing and elaboration, and are strengthened during consolidation (for reviews see Hamann, 2001; Vuilleumier, 2005). For instance, rewarding or positive emotional stimuli spontaneously recruit cognitive resources that enhance recall among individuals high in approach motivation (Crowell & Schmeichel, 2016). The preferential processing of emotional relative to neutral events thus contributes to enhanced memory.

However, emotional states and emotional stimuli may also interfere with cognitive processes, including processes associated with memory. For instance, studies on the emotional Stroop task have found that emotion words shift attention away from the task-relevant dimension of the stimulus (i.e. colour) and toward the non-relevant dimension (i.e. word content), which slows response times on the task (Williams, Mathews, & MacLeod, 1996). Similarly, emotional contextual information has been found to disrupt the maintenance of information in memory, presumably by diverting attentional resources away from active memory maintenance (Schweizer & Dalgleish, 2016), and this disruption may be especially likely among more anxious individuals (e.g. Shi & Liu, 2016; Shi, Gao, & Zhou, 2014). The automatic capture of attention by emotional content may thus impair cognitive processes relevant for memory.

The present study examined the effects of emotional information on working memory capacity (WMC). Working memory can be defined as the mental capacity to store and update information in memory while simultaneously processing other information (for different definitions of working memory, see Cowan, 2017; Miyake & Shah, 1999). For example, remembering a short list of words (e.g. *pave*, *giant*, *easy*, *apple*) while calculating a simple mathematical equation (e.g. $7 \times 4 + 3$) engages working memory because it entails holding some information in mind

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while performing additional mental operations. Success at this type of cognitive task is challenging because the words may become dislodged from memory or forgotten during the mathematical calculations. In this sense working memory is more complex than simple short-term memory because working memory entails attention control – not only maintaining information in short-term memory but also engaging concurrent mental operations. What effect has emotional information on WMC?

Prior research on emotion and WMC

A number of previous studies have tested the effects of emotional information on WMC. Perhaps the most influential studies found virtually no effects across a variety of working memory tasks, including reverse span tasks and alphabetical span tasks (Kensinger & Corkin, 2003). In those studies, participants encoded either neutral words from a single "think" category (e.g. *think, mind*) or highly arousing taboo words (e.g. *bitch*, *slut*) and then recalled the words in either reverse or alphabetical order. Thus, in addition to storing information in short-term memory participants also had to manipulate the emotional or neutral stimuli (by reversing or alphabetising them) as part of the WMC test. No differences emerged in WMC for emotional versus neutral words.

However, some studies have observed enhanced WMC for emotional relative to neutral words. One study examined the effects of emotional or attachment-related words relative to neutral words on WMC using an operation span task (OSPAN), which requires participants to remember lists of words while simultaneously evaluating math operations (Edelstein, 2006). Thus, participants had to manipulate non-emotional information (i.e. numbers) in working memory as part of the WMC test. Participants recalled more emotional words than both attachment-related and neutral words, consistent with an emotion enhancement hypothesis. Another study observed enhanced WMC for emotional versus neutral words using an OSPAN task (Mammarella, Borella, Carretti, Leonardi, & Fairfield, 2013). Presumably, WMC is increased for emotional information because emotional information attracts attention and processing resources.

Yet other research has observed that emotional content impairs WMC. For example, Joormann, Levens, and Gotlib (2011) had participants encode lists of three negative, neutral, or positive words. Participants were required either to maintain the words in the order presented or to manipulate them into reverse order before being prompted to indicate the serial position of a particular word (i.e. 1st, 2nd, or 3rd position). Response latencies were longer to the probes when participants had to sort the words in reverse order. The sorting cost, or difference in response latencies between the forward and reverse conditions, revealed an effect of word valence such that negative lists carried greater sorting costs than positive or neutral lists, but only among depressed participants. Healthy controls did not show different sorting costs as a function of word valence. Thus, negative emotional content appeared to interfere with working memory for some participants.

In another study, participants recalled the last three words from a sequence of words, and memory was impaired when the lists contained emotional versus neutral words (Fairfield, Mammarella, Di Domenico, & Palumbo, 2015). Similarly, research has revealed that WMC for neutral stimuli is impaired in the context of emotional information. In a series of experiments by Schweizer and Dalgleish (2016), participants stored neutral words in memory while they engaged in a visuospatial search task overlaid on neutral or negative background images. Memory for the neutral words was impaired in the context of negative versus neutral images. However, a later study by Schweizer et al. (2017) found that WMC was enhanced for words in the context of depressogenic (i.e. affective) sentences relative to neutral sentences.

Previous research on the effects of emotional information on WMC is thus mixed. Some studies have found enhanced WMC for emotional information, some have found reduced WMC for emotional information particularly among anxious or depressed subgroups, and some studies have found null effects. The current study shed new light on the effects of emotional content on WMC by combining a canonical measure of working memory, the OSPAN task (Turner & Engle, 1989), with a widely-used and well-validated set of emotional words from the database of Affective Norms for English Words (ANEW; Bradley & Lang, 1999) and by testing a large group of healthy undergraduate students to ensure adequate statistical power. Following emerging norms in psychological science we also preregistered our methods and hypotheses online.

Based on previous research we considered competing predictions. As noted above, the *emotional enhancement hypothesis* predicts that emotional information attracts attention and mobilises processing

resources and is therefore easier to encode and store in working memory relative to neutral information. In this view, WMC should be increased for emotional relative to neutral information. Evidence to support this hypothesis would be congruent with previous findings that emotional information occupies a privileged place in memory (e.g. Edelstein, 2006; Mammarella et al., 2013).

By contrast, the *emotional impairment hypothesis* holds that emotional information reduces WMC by interfering with attention control. In this view emotional stimuli capture processing resources and thereby disrupt the active maintenance of other information, including other emotional information, in the context of a working memory task (e.g. Fairfield et al., 2015; Joormann et al., 2011; Schweizer & Dalgleish, 2016). In other words, the capture of attention by emotional information diverts processing resources away from the storage of items in short-term memory, thereby reducing performance on WMC tests. The current experiment put these competing possibilities, which we spelled out in a preregistration document archived online, to an empirical test.

Method

Participants and design

Three hundred twelve undergraduate students participated in exchange for credit toward a course requirement. They were assigned at random between an emotional words condition and a neutral words condition in a two-cell design. We decided prior to data collection to sample 300 participants (150 in each condition). A sample of this size affords 80% power to detect a small-to-medium sized effect ($d = 0.32$) of the experimental manipulation. We also decided a priori to exclude participants if they were the first or second participant run by each experimenter ($n = 12$), or if they scored below 85% accuracy on the math operations ($n = 3$; accuracy $M = 97.6\%$, $SD = 0.03$; see Conway et al., 2005).[1] After exclusions the final sample included 297 participants (age $M = 19.05$, $SD = 1.42$; 70.8% female), and neither gender composition, $x^2(1) = 0.64$, $p = .423$, nor age, t (288) = 0.06, $p = .950$, differed between conditions.

Materials and procedure

Participants first completed questionnaires assessing demographic information and various personality characteristics. The personality questionnaires were included for exploratory purposes, and those results are not reported here beyond noting that none of the personality measures moderated the findings reported below.

Next, participants attempted a common test of WMC known as the operation span task (OSPAN; Turner & Engle, 1989). The OSPAN measures the capacity to maintain information in short term memory while simultaneously evaluating mathematical operations. The mathematical operations were simple equations to be evaluated as true or false (e.g. "is $(8/2) + 4 = 9$?" yes/no). Following each equation was a word to be recalled (e.g. "build"). So, each trial of the OSPAN consisted of an equation to solve and a word to be remembered, which was immediately followed by another trial (i.e. another equation and word). Participants read the OSPAN trials out loud. After a series of equation/word pairings, participants tried to recall all the words presented in the set. Set sizes ranged from two to five equation/word pairings. In all, participants saw 16 sets with a total of 56 words to be recalled. Participants spent an average of 10 min 11 s on the OSPAN, and this duration did not differ between conditions, t (294) = 0.72, $p = .470$.

We created two versions of the OSPAN: a neutral version and an emotional version. The neutral version has been used in past research and included neutral words (e.g. *world*, *back*) as in a traditional OSPAN task (e.g. Schmeichel, Volokov, & Demaree, 2008). The emotional version consisted of positive (e.g. *love*) and negative (e.g. *knife*) emotion words from the ANEW database (Bradley & Lang, 1999). Positive words were high in valence ($M = 7.82$, $SD = 0.48$) and arousal ($M = 6.21$, $SD = 1.12$), whereas negative words were low in valence ($M = 2.55$, $SD = 0.71$) and high in arousal ($M = 6.52$, $SD = 0.99$), according to ANEW norms. Emotional words and neutral words were matched for length and number of syllables (words were one or two syllables; see Appendix).

Participants were randomly assigned to complete either the neutral OSPAN (*neutral condition*, $n = 153$) or the emotional OSPAN (*emotional condition*, $n = 144$). We scored the OSPAN in four different ways based on the procedures described by Conway et al. (2005). Specifically, we counted the number of words from perfectly recalled sets in the correct serial order (all-or-nothing scoring) and calculated the proportion of words recalled in a set regardless of whether the entire set was correctly recalled (partial-credit

scoring). Within each of these scoring procedures we both summed the total number of words recalled, thereby giving greater weight to larger sets (load scoring), and we averaged the proportion of words recalled in each set (unit scoring).

Following the OSPAN participants completed additional personality questionnaires before being debriefed about the purpose of the study and dismissed. The entire experiment lasted approximately 40 min and was approved by the local Institutional Review Board. Prior to data analysis we registered the methods, hypotheses, exclusion criteria, and analysis plan online (https://osf.io/6szhv/).

Results

To test the hypothesis that WMC differs for emotional versus neutral content, we first conducted a multivariate analysis (MANOVA) including OSPAN scores based on all four scoring methods as our dependent measures: all-or-nothing load scores (ANL), all-or-nothing unit scores (ANU), partial-credit load scores (PCL), and partial-credit unit scores (PCU). The correlations among the four scoring measures ranged from $r = .841$ to $r = .99$. Task condition (emotional versus neutral) was the between-subjects factor. See Table 1 for emotional and neutral WMC scores based on each method.

The multivariate effect of condition was significant, $F(292) = 3.58$, $p = .007$, $\eta_p^2 = 0.047$. Follow-up analyses revealed a significant univariate effect of condition on ANL scores, $F(1, 295) = 5.52$, $p = .019$, $\eta_p^2 = 0.018$, and ANU scores, $F(1, 295) = 3.99$, $p = .047$, $\eta_p^2 = .013$, such that participants in the emotional condition scored lower than participants in the neutral condition. The univariate effects of condition on PCL scores, $F(1, 295) = 1.41$, $p = .236$, $\eta_p^2 = 0.005$, and PCU scores, $F(1, 295) = 1.41$, $p = .236$, $\eta_p^2 = 0.005$, were in the same direction but not statistically significant.[2] In sum, WMC was reduced by emotional (versus neutral) content, particularly for all-or-nothing scoring measures.

In addition to overall WMC we also assessed differences in recall of positive versus negative words within the emotional OSPAN condition. A paired samples t test yielded a main effect of valence for both partial credit load scoring, $t(143) = 10.11$, $p < .001$, $d = 0.73$, and partial credit unit scoring, $t(143) = 10.75$, $p < .001$, $d = 0.78$.[3] Participants recalled more negative words (load scoring: $M = 21.79$, $SD = 3.16$; unit scoring: $M = 0.83$, $SD = 0.11$) than positive words (load scoring: $M = 19.38$, $SD = 3.45$; unit scoring: $M = 0.73$, $SD = 0.12$) on the emotional OSPAN.

Discussion

The current study found that emotional words reduce WMC relative to neutral words. These results support the emotional impairment view and suggest that emotional information interferes with effective attention control on a working memory span task. Based on previous research it was plausible that emotional content would increase WMC. Numerous experiments have observed enhanced memory for emotional relative to neutral information, particularly in long-term memory (Kensinger & Corkin, 2003; see Hamann, 2001 for review). But the current results suggest that working memory span, which entails storing and updating the contents of memory while performing other mental operations, is reduced for emotional information.

We presume that emotional words receive prioritised (i.e. fast, automatic) processing relative to neutral words (Vuilleumier, 2005). On simple short term memory tasks, prioritised processing and subsequent elaboration boosts memory for emotional words (e.g. Doerksen & Shimamura, 2001). In a working memory task, however, elaboration and rehearsal are disrupted by the requirement to perform concurrent cognitive operations, thereby preventing the strengthening of memory representations after initial encoding. Emotional words thus likely received prioritised processing initially, but not after encoding.

Table 1. Working memory capacity in the neutral and emotional OSPAN conditions.

	Scoring method			
Condition	PCL	PCU	ANL	ANU
Neutral ($n = 153$)	42.15 (7.00)$_a$	0.79 (0.11)$_a$	20.37 (11.68)$_a$	0.45 (0.21)$_a$
Emotional ($n = 144$)	41.26 (5.76)$_a$	0.78 (0.10)$_a$	17.37 (10.09)$_b$	0.41 (0.19)$_b$

Note: OSPAN scoring measures (*M*s and *SD*s) include partial-credit load (PCL), partial-credit unit (PCU), all-or-nothing load (ANL), and all-or-nothing unit (ANU). Means in the same column with different subscripts differ at $p < .05$.

So why did participants recall fewer words on the emotional OSPAN if emotional (relative to neutral) words initially received prioritised processing? We propose that the prioritised processing of emotional words at encoding diverted resources away from the maintenance of other (emotional) words in short-term storage. Put differently, arousing emotional words competed for limited working memory capacity (see Mather, 2007; Pessoa, 2009); in light of the evidence that participants recalled more negative words than positive words on the emotional OSPAN task, negative words usually won (see also Mammarella et al., 2013). The (perhaps ironic) result of the competition among emotion words was poorer memory for emotional relative to neutral words. (It is possible that any unusual or attention-grabbing words would have similar effects, but we focused on emotional words in the current experiment.)

This account receives support from the fact that emotional content undermined WMC particularly for all-or-nothing but not partial-credit scoring of the OSPAN. The all-or-nothing scoring method only counts words from sets recalled in full and in the correct serial order, in contrast to the partial-credit scoring method, which counts words even from partially-recalled sets (Conway et al., 2005). Differences emerged between groups on the more stringent all-or-nothing scoring method. We presume that the capture of attention by emotional information disrupted the short-term maintenance of words, thereby reducing WMC, and this reduction was most apparent when scoring full set recall rather than partial set recall; recalling a full set requires one to remember all the words in the set in the correct order (i.e. a higher maintenance standard than partial credit scoring). Additional research is needed to verify this account. It is possible that emotional (relative to neutral) words also influence retrieval processes to reduce WMC.

Current findings in relation to past research

A number of previous studies have tested the effects of emotional states or moods on WMC and have often found that more emotional relative to neutral states reduce WMC (e.g. Schmader & Johns, 2003; Spies, Hesse, & Hummitzsch, 1996). For instance, states of anxiety have been shown to impair WMC, possibly because anxious thoughts draw attentional resources away from other processing in the limited WM system (Eysenck & Calvo, 1992). Some evidence suggests that positive emotional states can also impair WMC (e.g. Spies et al., 1996). It is thus possible that participants in the current experiment were in a more aroused or emotionally-charged mood state when completing the emotional (versus neutral) OSPAN, and this mood state reduced working memory. We did not include a mood measure in this study, so additional research is needed to test this possibility.

Perhaps the most influential prior studies of the effects of emotional information on WMC found virtually no effects across a variety of working memory tasks, including reverse span tasks, alphabetical span tasks, and *n*-back tasks (Kensinger & Corkin, 2003). But other research has observed either WMC impairment by emotional content (on a source location task; Mather et al., 2006), or WMC enhancement (on an *n*-back task; Lindström & Bohlin, 2011). Further, Schweizer and colleagues have used span tasks to measure WMC for neutral words in the context of emotional or neutral information and have found both enhanced WMC and impaired WMC for words in emotional relative to neutral contexts (Schweizer & Dalgleish, 2011, 2016; Schweizer et al., 2017). Other research has likewise observed WMC impairment in emotional contexts for specific subgroups of participants (Hubbard et al., 2016; Shi et al., 2014; Shi & Liu, 2016). Thus, research on the effects of emotional states and emotional stimuli on WMC is mixed, with published evidence of null results, emotional enhancement, and emotional impairment of WMC, respectively.

The current study tested again the hypothesis that emotional content influences WMC. Our main goal was to quantify the effect of emotional content on WMC in a well-powered study with preregistered methods, hypotheses, and data analysis plans. We used the OSPAN task to assess WMC because it is a valid and reliable test of working memory and has been used by psychologists as a gold-standard measure of WMC (Conway et al., 2005). Other span tasks, like the reading span or alphabet span, are similarly reliable but, unlike those tasks, the OSPAN does not entail emotional information as the concurrent mental operation. The WMC tasks used in the null effects studies by Kensinger and Corkin (2003), for instance, required participants to manipulate emotional information in working memory or to process emotional information as the concurrent task. This is in contrast to the OSPAN, which requires participants to perform mathematical calculations as

the concurrent task. Perhaps emotional information reduces WMC especially when concurrent operations involve mental calculations, but not when the concurrent operations involve emotional content (e.g. as in the reading span task; see also Mikels, Reuter-Lorenz, Beyer, & Fredrickson, 2008).

A few past studies have investigated the effects of emotional content on OSPAN performance and yielded different results than the current study. One study created separate emotional and neutral versions of the OSPAN and observed enhanced WMC for emotional compared to neutral words (Edelstein, 2006). Another study also observed enhanced WMC for emotional relative to neutral words, but the design mixed emotional and neutral words within the same task (Mammarella et al., 2013). A third study did not observe differences between emotional and neutral WMC in healthy controls but found reduced WMC in participants with social phobia for neutral compared to emotional words (Amir & Bomyea, 2011).

The current study differs from those prior studies in a number of ways. First, the neutral and emotional lists in the current study contained mostly one-syllable words (e.g. *back*, *paint, east* versus *treat, dead, kiss*), whereas the words from Edelstein (2006) were often two-syllable words, and the neutral words all came from the category of "government" (e.g. *account*, *frontier, mayor*). The different words and word lengths used in the current study versus that of Edelstein may account for some of the discrepant findings.

Another difference between the current study and past studies is that the current study assessed the effects of emotional content on WMC in a healthy sample of college students, whereas past research focused at least in part on special populations or subgroups. For instance, Edelstein (2006) was interested in individuals with avoidant attachments styles, Mammarella et al. (2013) assessed older individuals, and Amir and Bomyea (2011) included individuals with social phobia. Although each of those studies also included a control condition of healthy young participants, the performance of the control groups was not the primary interest in those studies. The current study included a large sample of healthy young participants and therefore had greater statistical power to detect effects of emotional content on WMC. And in keeping with emerging norms in psychological science, our hypotheses and analysis plan were preregistered prior to data analysis, thereby restricting flexibility in data analysis and reducing experimenter degrees of freedom and *p*-hacking. These steps increase confidence in the observed evidence that emotional (relative to neutral) words reduce WMC.

Conclusion

The current study found reduced WMC for emotional relative to neutral words. This result suggests that emotional words are more difficult to maintain in working memory, perhaps because emotionally-charged words consume limited processing resources. Previous research has found that individual differences in WMC for neutral words predicts several emotion-related outcomes (see Schmeichel & Tang, 2015). One promising route for future research will be to test whether individual differences in performance on the emotional OSPAN contribute to emotion-related outcomes above and beyond the contributions of neutral WMC.

Notes

1. An additional five participants were outliers on the time spent to complete the OSPAN task (i.e. greater than 3 *SD* from the mean; OSPAN duration $M = 10$ m 12 s; $SD =$ 2 m 22 s). We did not specify a priori that we would exclude participants based on this criterion, so they were included in subsequent analyses. Results did not change when these outliers were excluded.
2. In the preregistration document we planned to conduct *t* tests on the OSPAN scores, but in retrospect the MANOVA seemed more appropriate. Results did not change when WMC scores were analyzed with *t* tests: for ANL, t (292.87) = 2.36, $p = .019$, 95% CI [0.50 to 5.47], $d = 0.27$; for ANU, t (295) = 2.00, $p = .047$, 95% CI [0.001 to 0.09], $d = 0.23$; for PCL, t (289.92) = 1.19, $p = .233$, 95% CI [−0.57 to 2.35], $d = 0.14$; and for PCU, t (295) = 1.19, $p = .236$, 95% CI [−0.01 to 0.40], $d = 0.14$.
3. Word sets included a mixture of both positive and negative words (i.e. no list contained only positive or only negative words), so recall of positive versus negative words was necessarily only part of the set. Therefore, all-or-nothing scoring was not appropriate; we quantified recall for positive versus negative words using partial-credit scoring only.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Neutral words		Emotional words	
back	face	thrill	hug
fish	start	rage	debt
bread	bike	cash	proud
bush	world	love	fame
cheek	ants	kiss	grief
jar	nail	fire	wise
chart	dad	cheer	sex
hall	bar	shark	gun
clouds	arm	treat	hurt
nerve	dock	scared	fun
class	cot	fight	cruel
east	paint	joke	joy
hat	flute	war	drown
brass	chalk	corpse	champ
lamp	job	star	sad
card	man	bride	win
ground	home	scream	gift
germs	up	bomb	slap
drill	give	hate	mad
aunt	pave	flirt	baby
ears	giant	nude	hell
game	easy	thief	party
corn	apple	lust	roach
bench	build	peace	rape
bear	teeth	dead	gloom
mold	move	food	snake
calf	floor	pain	free
net	peak	lice	spring