Working memory cannot regulate overt emotional capture ☆

Kimberly M. Wingert[a], Chris Blais[a], B. Hunter Ball[b], Gene A. Brewer[a],*

[a] Department of Psychology, Arizona State University, United States
[b] Department of Psychology, Washington University in St. Louis, United States

ABSTRACT

Individual differences in working memory capacity partly arise from variability in attention control, a process influenced by negative emotional content. Thus, individual differences in working memory capacity should predict differences in the ability to regulate attention in emotional contexts. To address this hypothesis, a complex-span working memory task was modified so that negative arousing images or neutral images subtended the background during the encoding phase. Across three experiments, negative arousing images impaired working memory encoding relative to neutral images, resulting in impoverished symmetry span scores. Contrary to the primary hypothesis, individual differences in working memory capacity derived from three complex span tasks failed to moderate the effect of negative arousing images on working memory encoding across two large scale studies. Additionally, in Experiment 3, both negative and arousing images captured attention and were processed despite their incongruence with task goals which led to increased memory for the images in a subsequent recognition task. Implications for theories of working memory and attention control in emotional contexts will be discussed.

1. Introduction

Working memory is responsible for the transient registration, maintenance, and retrieval of novel and previously learned information in primary memory. Three important sources of individual differences in working memory are active maintenance of task goals in primary memory, the capacity of primary memory, and controlled retrieval of momentarily displaced goals from secondary memory (Shipstead, Harrison, & Engle, 2015; Unsworth, Brewer, & Spillers, 2012; Unsworth & Engle, 2007; Unsworth, Fukuda, Awh, & Vogel, 2014). Active maintenance of task goals in primary memory partly depends on the ability to control attention in distraction-rich environments (Engle & Kane, 2004). Although working memory has traditionally been studied in environments devoid of emotion, growing evidence suggests that individual differences in working memory capacity (WMC) may play a critical role in how well individuals are able to manage or prioritize emotional content to achieve task goals (Barrett, Tugade, & Engle, 2004; Unsworth, Heitz, & Engle, 2005). For example, recent work has shown that emotional content can obligatorily capture attention leading to decrements in ongoing cognitive processing (Mather, 2007). According to these views, working memory should be important for

dealing with emotional distractions. The purpose of the present study was to determine whether individual differences in WMC moderate the effect of distracting emotional content on overt attention capture away from goal relevant information.

1.1. Working memory capacity

WMC is typically measured using complex-span tasks such as the symmetry-span task (Shah & Miyake, 1996; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). During a symmetry-span task (see Fig. 1A for an illustration) participants remember the spatial locations of red squares presented in a 4 × 4 grid. Interspersed with the to-be-remembered spatial locations are patterns that the participant identifies as symmetrical or nonsymmetrical. WMC in a symmetry-span task is defined as the total number of spatial locations that can be recalled in the correct serial order (partial-unit span score). The symmetry judgment task serves as distracting information, and participants are asked to achieve at least 85% accuracy on the distraction task while still maintaining the locations of the squares in memory. According to Engle and Kane (2004), attention control is the theoretical mechanism responsible for active maintenance of the spatial locations while
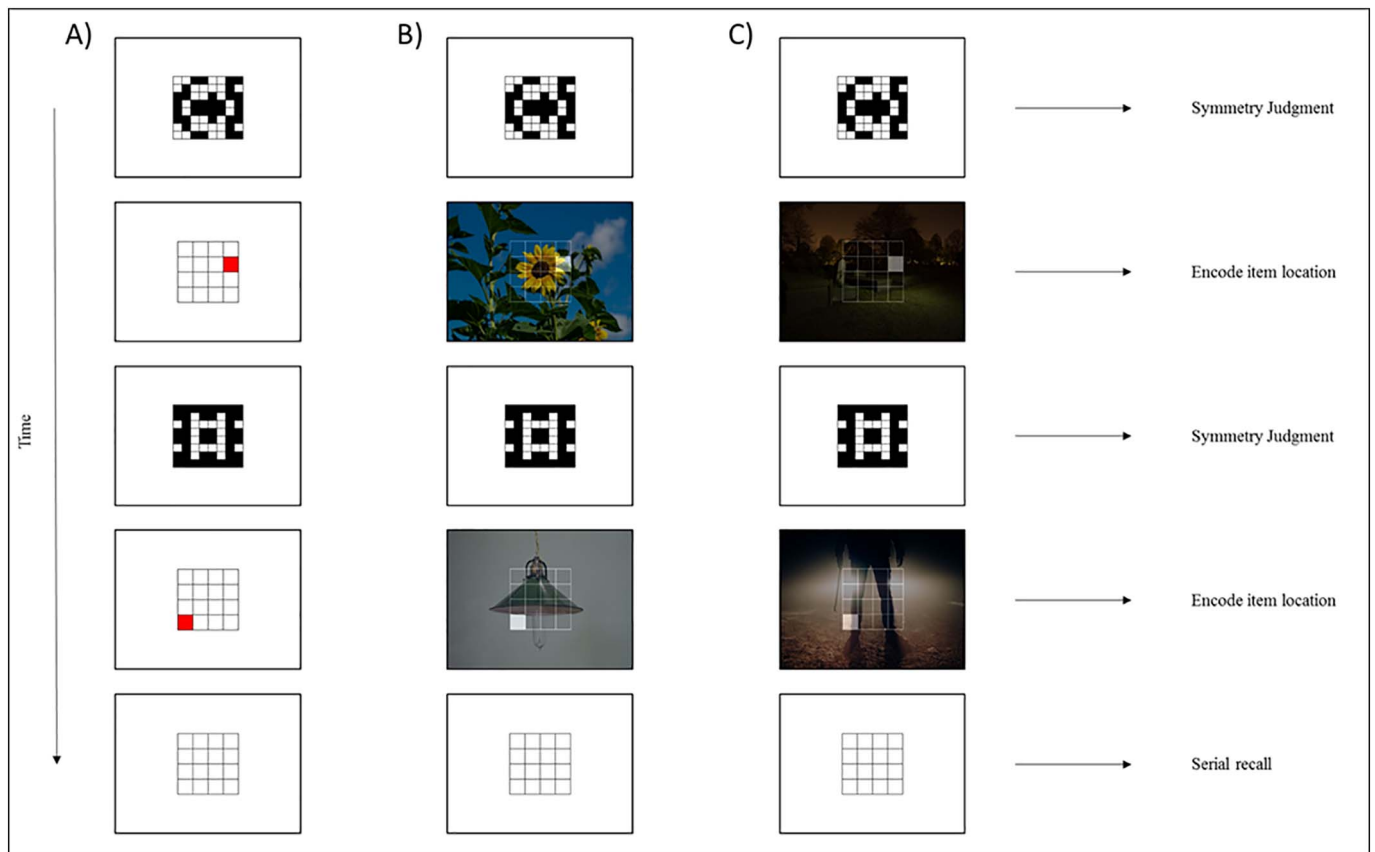
Fig. 1. Sequence of events in a A) traditional, B) neutral, and C) emotional symmetry span task for a list length of two. Described in detail in the text. Photos in the figure were retrieved from https://www.pexels.com/ and are not included in the IAPS database.

simultaneously processing the symmetry judgment task. It is this attention control mechanism that partly contributes to correlations between working memory and higher-order cognitive abilities.

1.2. Working memory capacity and attention control

Variance in complex-span tasks is not only related to a diverse array of higher-order cognitive abilities (Conway, Kane, & Engle, 2003; Daneman & Carpenter, 1980) but it is also related to performance on tasks that measure lower-order abilities such as goal maintenance and resisting prepotent responses. For example, WMC predicts performance on the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001). In a computerized version of the antisaccade task developed by Kane et al. (2001), the participants' goal was to identify a target that appeared on the same side (prosaccade condition) or opposite side (antisaccade condition) of a flashing cue. Individual differences in working memory were correlated with antisaccade performance but were not correlated with prosaccade performance. Specifically, in an antisaccade condition participants with low WMC made more target identification errors and were slower on correct trials. Additionally, participants with low WMC were slower to make a correct saccade toward the target and made more incorrect saccades toward the flashing cue (Kane et al., 2001; Unsworth, Schrock, & Engle, 2004).

Engle and Kane (2004) posited that attention control is needed to both maintain task goals and to resolve response competition by suppressing the reflexive tendency to glance at the flashing cue. In the antisaccade task, failing to maintain the task goal will result in an incorrect saccade toward the flashing cue. By contrast, resolving response competition by suppressing reflexive glances toward the flashing cue will result in slower, but correct, saccades away from the flashing cue (Engle & Kane, 2004). This view suggests that low WMC participants have deficits in both

goal maintenance and resolving response competition by suppressing prepotent responses. In the present study we aim to evaluate whether WMC is similarly related to the ability to suppress the tendency to look at distracting images containing emotional content.

Other research indicates that some aspects of attentional capture by irrelevant content are not related to WMC. Fukuda and Vogel (2011) demonstrated that high and low WMC participants do not differ in whether or not their attention is captured by distracting stimuli. Rather, they differ in how long it takes them to disengage from the stimuli that distracted them and recover from attentional capture. Along these lines, Shipstead, Lindsey, Marshall, and Engle (2014) demonstrated that although attention control was needed to filter out irrelevant information presented on the opposite side of the screen as relevant information, working memory was not predictive of this filtering ability. Across these studies, WMC was not related to attentional capture when the distracting stimulus and the task-relevant stimulus were simultaneously presented. As a result, an alternative view is that WMC will be unrelated to the tendency to look at distracting emotional images if the distracting images are presented at the same time as task-relevant information.

1.3. Emotion, attention, and working memory capacity

Emotional content is argued to obligatorily capture attention in order to orient organisms toward salient information that may be relevant for survival (Mather, 2007; Öhman, Flykt, & Lundqvist, 2000). Cohen, Henik, and Mor (2011) argued that attention and emotion interact in the executive control network of attention (e.g., also see Fan, McCandliss, Sommer, Raz, & Posner, 2002). Specifically, response times for congruent flanker trials were slower following negative cues compared to neutral cues. On incongruent trials emotion did not influence response times. Similarly, Redick and Engle (2006) reported that high

and low WMC participants differed in this executive control attention network. Taken together, these studies support the hypothesis that individual differences in WMC and attention control processes will be predictive of individual differences in the ability to suppress the tendency to look at distracting emotional images.

However, Redick and Engle (2006) also found that low WMC participants were slower on incongruent trials than high WMC participants. There were no differences between high and low WMC participants on congruent trials. Therefore, it remains possible that emotional content affects different attention components than WMC. Thus, consistent with the predictions based on Fukuda and Vogel (2011) it is possible that emotion is affecting attentional processes that are independent from working memory. If this is indeed the case, then WMC should not moderate the effect of emotional content on attention processes at encoding. Rather, high and low WMC participants may similarly be affected by the distracting emotional content.

The research reviewed thus far has primarily treated emotion as a unidimensional construct. In fact, previous research indicates that valence (positive, negative, or neutral) and arousal (high or low) describe two separate dimensions of emotion (for a review of a two-dimensional view of emotion see Barrett & Russell, 1999). In the procedure implemented by Cohen et al. (2011) valence and arousal were confounded, and thus, it was unclear whether the interaction between emotion and the executive control attention network was being driven by valence and/or arousal. Evidence that valence and arousal are indeed separable dimensions of emotion comes from research conducted by Kensinger and Corkin (2004).

Kensinger and Corkin (2004) indicated that there are two routes to emotional memory. Specifically, emotional content that is arousing activates an amygdala-hippocampal network and affects memory encoding relatively automatically. By contrast, emotional content that is not arousing activates a prefrontal cortex-hippocampal network and reflects controlled processing (Kensinger & Corkin, 2004). Therefore, WMC may differentially impact the ability to suppress reflexive responses away from goal-relevant information that vary as a function of emotional valence or arousal (e.g., Mather, 2007; Öhman et al., 2000). Specifically, when controlled processing is needed individuals with high WMC should be better at suppressing reflexive glances toward negatively valenced content in favor of task goals. By contrast, when arousing content is automatically processed it may be impacting attention components at encoding that are not under top-down control. The ability to engage top-down attention control in interference rich environments (such as environments containing negatively valenced distractors) is dependent on the dorsolateral prefrontal cortex (Kane & Engle, 2002). Thus, differences in dorsolateral prefrontal cortex integrity seen between high and low WMC participants (Kane & Engle, 2002) should lead to individual differences in regulating attention in emotionally evocative contexts.

Unsworth, Heitz, and Engle (2005) argue that low WMC participants should not differ from high WMC participants for automatic processing, but should differ when controlled processing is needed for goal completion. They further suggest that high WMC participants should be better at resisting attentional capture by salient information (however, see Fukuda & Vogel, 2011). Thus, participants who have low WMC should be worse at suppressing the reflexive processing of emotional distractions in their environment in favor of focusing on their task goals. Unsworth, Heitz, and Engle (2005) posited that a general executive attention component of working memory is needed to negotiate the effect of environmental distractors to achieve task-relevant goals. It can be argued that controlled processing is needed to ignore the automatic tendency to shift attention to emotional content. Evidence for this view comes from research showing that high WMC participants are better able to suppress reactions to negative emotional content than low WMC participants (Schmeichel, Volokhov, & Demaree, 2008). However, the different routes that valence and arousal take may lead to differential effects on attention to emotional distracting content rather than task goals. This may create a more nuanced pattern of sensitivity to emotional content in individual differences in WMC.

1.4. The present study

In the present study we examined how valence and arousal independently and interactively impact attentional processes during working memory encoding in a standardized complex-span task (i.e., the symmetry span task). We selected images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) database to serve as distractors during the encoding phase of a symmetry span task. In Experiment 1 we selected negative, high arousal images and neutral, low arousal images to serve as distractors (similar to Cohen et al., 2011). Experiment 1 was designed to first evaluate whether emotional content captures attention and is reflexively processed leading to reduced WMC estimates in a symmetry span task. Experiment 2 replicates and extends the findings of Experiment 1 by testing the hypothesis that WMC would moderate the deleterious effect of emotional content on attention control during working memory encoding. Finally, Experiment 3 deconfounded the valence and arousal dimensions of emotion in order to determine whether individual differences in WMC predict whether valenced but not arousing content captures overt attention to the detriment of task goals. To accomplish this, an additional subset of negative, low arousal images and neutral, high arousal images from the IAPS database were selected in addition to negative, high arousal and neutral, low arousal images. Additionally, a recognition task was administered at the end of Experiment 3 to provide evidence that attention was indeed captured by and allocated to high arousal images. Unless otherwise stated, all statistics are two-tailed and evaluated at the 0.05 level of significance.

2. Experiment 1 methods

2.1. Participants

A total of 50 participants were recruited from the introductory psychology research participation pool at Arizona State University. Data were collected from up to eight people at a time and the number of participants in a session varied based upon participant availability. Three participants left the study before completing the task because they were unable to cope with the negative, high arousal images, and one participant was unable to complete the task because of computer error. An additional two participants were excluded from analyses due to extreme performance (i.e., mean $+/- 1.5 \times$ the interquartile range). Thus, results reflect data from the remaining 44 participants.

2.2. Materials and procedure

All participants consented to participate in accordance with the standards of Arizona State University's Institutional Review Board. After consenting to participate, all participants completed a symmetry span task that was split into two blocks containing negative, high arousal images in one block and neutral, low arousal images in the second block. The negative, high arousal and neutral, low arousal images were presented in separate blocks rather than mixed lists to ensure that any effect of negative, high arousal images on performance would not contaminate performance on neutral, low arousal image trials. The presentation order of the two Emotion blocks was counterbalanced across participants. Participants were instructed to ignore the background images and focus on remembering the locations of the squares.

2.2.1. Modified symmetry span task

In the present study we modified the traditional version of the symmetry span task described earlier in E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and presented it on a computer screen to participants. The traditional version of the symmetry span task that was

modified for use in this study can be found online.[1] Specifically, negative, high arousal (e.g., mutilated bodies) and neutral, low arousal (e.g., flowers) images were obtained from the IAPS database (Lang et al., 2008). Efforts were made in the selection of images to ensure that negative, high arousal and neutral, low arousal images (see Appendix A) contained similar content (if a selected negative, high arousal image contained a face, a neutral, low arousal image was selected from the database that also contained a face). Negative, high arousal and neutral, low arousal images differed in valence, $t(110) = 27.881$, $p < 0.001$, and in arousal, $t(110) = 37.806$, $p < 0.001$; see Table 1. These images subtended the background of the encoding phase of a symmetry span task. The matrix was altered so that it was larger, black with white lines, and the squares filling in the black matrix were also changed to white. The matrix was then set at 60% transparency and superimposed over the image. All other aspects of the symmetry span task remained identical to the symmetry span task discussed previously. Fig. 1B & C shows an example of a list length of two for a typical trial in the modified symmetry span task used in this experiment.

List lengths for a single trial in our modified symmetry span task varied from two to five items similar to the typical version used in the literature (see Fig. 1A). However, instead of presenting three trials of each list length as is commonly done in the symmetry span task, participants completed four trials of each list length (16 total trials). Presentation of each list length was randomized, and the negative, high arousal and neutral, low arousal images were presented in blocks that were counterbalanced. For this version of the modified symmetry span task, a unique image was presented on each sub-trial during the presentation of the to-be-remembered square location (56 images for the negative, high arousal condition, and another 56 images for the neutral, low arousal condition) and the location of the to-be-remembered spatial location was presented randomly. The proportion of spatial locations correctly recalled in each serial position was our dependent variable of interest (partial-unit span score[2]; see Conway et al., 2005), and the task took 15–30 min to complete.

3. Experiment 1 results and discussion

Partial-unit span scores for each list length were calculated by averaging across scores for similar list lengths separately for negative, high arousal and neutral, low arousal trials. These scores were then converted to proportions by dividing by how many items were in the list (e.g., the mean score for all negative, high arousal trials with a list length of two divided by two). These scores were then submitted to a three-factor repeated-measures ANOVA with Emotion (negative, high arousal vs. neutral, low arousal) and List Length (2 vs. 3 vs. 4 vs. 5) as within-subjects factors and Order (negative, high arousal block first vs. neutral, low arousal block first) as a between-subjects factor. We controlled for order effects by adding the Order factor to the design and this factor did not interact with the emotion factor. As predicted, proportional partial-unit span scores were lower when negative, high arousal images served as distractors during working memory encoding (neutral, low arousal: $M = 0.75$, $SD = 0.15$ vs. negative, high arousal: $M = 0.71$, $SD = 0.18$), $F(1, 42) = 5.454$, $MSE = 0.029$, $p < 0.05$, partial $\eta^2 = 0.115$ (see Fig. 2). Thus, relative to neutral, low arousal images, negative, high arousal images led to reduced partial-unit span scores in the symmetry span task when presented along with to-be-remembered information at encoding. This reduction in WMC is consistent with the interpretation that when emotional content is present it

Table 1
Valence and arousal means for Experiments 1–3.

Experiment	Dimension	Image type	Mean (SD)
1 & 2	Valence	Negative, high arousal	2.22 (0.56)
		Neutral, low arousal	5.38 (0.64)
	Arousal	Negative, high arousal	6.35 (0.44)
		Neutral, low arousal	3.35 (0.40)
3	Valence	Negative, high arousal	3.49 (0.33)
		Negative, low arousal	3.70 (0.55)
		Neutral, high arousal	5.31 (0.56)
		Neutral, low arousal	5.51 (0.24)
	Arousal	Negative, high arousal	5.82 (0.11)
		Negative, low arousal	3.98 (0.22)
		Neutral, high arousal	5.94 (0.48)
		Neutral, low arousal	3.91 (0.09)

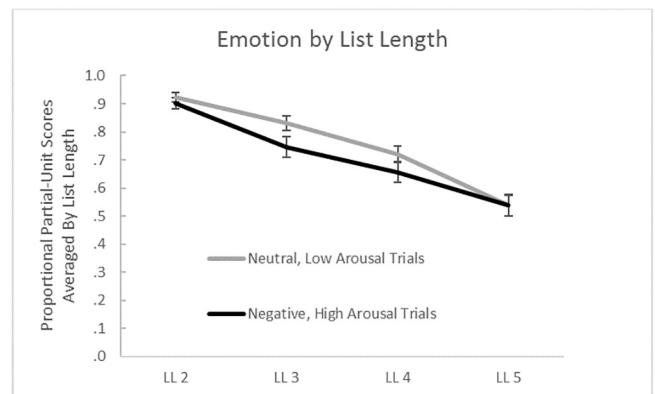Note: the same images were used for Experiment 1 and Experiment 2.

Fig. 2. Experiment 1 partial-unit span scores for neutral, low arousal and negative, high arousal trials, averaged for each list and then converted to proportions. Described in detail in the text. LL 2 = List Length 2, LL 3 = List Length 3, LL 4 = List Length 4, LL 5 = List Length 5. Note: Error bars: $+/-$ SEM.

captures attention and automatic processing of this content causes a detriment to a WMC measure (see Mather, 2007).

Additionally, proportional partial-unit span scores decreased on average as list length increased from two to five, $F(3, 126) = 80.422$, $MSE = 0.027$, $p < 0.05$, partial $\eta^2 = 0.657$.[3] However, the interaction between Emotion and List Length did not reach significance, $F(3, 126) = 2.509$, $MSE = 0.014$, $p = 0.062$, partial $\eta^2 = 0.056$, indicating that negative, high arousal images did not differentially impact performance at specific list lengths. However, further examination of this marginal effect in Fig. 2 indicates that the effect of emotion on proportional partial-unit span scores was only present at middle list lengths, particularly at a list length of 3. In Experiment 2 we aimed to replicate these effects and further address whether individual differences in WMC moderate the effect of Emotion on overt attention at encoding of information into working memory. Specifically, we hypothesized that individual differences in goal maintenance and the ability to suppress reflexive responses to task-irrelevant but salient information would predict whether attention is captured and maintained on task-irrelevant emotional content.

4. Experiment 2 methods

4.1. Participants

A total of 213 participants that did not participate in Experiment 1 were recruited from the introductory psychology research participation

---

[1] The traditional symmetry span task can be downloaded from Randy Engle's website: http://englelab.gatech.edu/tasks.html.
An in depth discussion of complex span tasks as measures of WMC, along with a discussion of the variables within a task and an evaluation of the use of those variables is presented in Conway et al. (2005).
[2] For example with a list length of 5, if participants recall the 1st, 3rd, and 5th item correctly in the correct serial position, their score on that trial would be 3/5.

[3] Follow-up paired-samples t-tests on these proportional partial-unit span scores confirmed a significant decrease for each list length increasing from two to five, all $ps < 0.001$.

Table 2
Modified complex span and recognition task performance as a function of emotion in Experiments 1–3.

Experiment	Condition	Span scores		Errors			Hit rate
		Partial-unit	Whole-list	Accuracy	Speed	Total	
1	Negative, high arousal	37.45 (11.12)	25.02 (13.48)	2.55 (2.08)	1.11 (3.13)	3.66 (3.70)	–
	Neutral, low arousal	39.64 (9.42)	27.55 (12.85)	2.25 (1.93)	0.61 (0.89)	2.86 (2.06)	–
2	Negative, high arousal	33.04 (12.09)	20.76 (12.54)	3.44 (3.43)	1.29 (1.90)	4.73 (4.04)	–
	Neutral, low arousal	37.89 (11.25)	25.58 (12.53)	3.17 (3.30)	1.03 (1.59)	4.19 (3.86)	–
3	Negative, high arousal	36.04 (13.37)	24.82 (14.44)	3.86 (3.81)	0.68 (1.34)	4.54 (4.32)	0.51 (0.24)
	Negative, low arousal	37.34 (13.29)	26.37 (14.53)	3.85 (4.21)	0.74 (1.09)	4.59 (4.50)	0.47 (0.24)
	Neutral, high arousal	37.12 (13.96)	27.08 (14.85)	3.97 (4.03)	0.57 (1.04)	4.53 (4.42)	0.43 (0.23)
	Neutral, low arousal	36.96 (13.18)	25.74 (14.56)	4.10 (4.25)	0.71 (1.13)	4.81 (4.57)	0.40 (0.23)

Note: mean performance (standard deviation in parentheses).

pool at Arizona State University. Data were collected from up to eight people at a time and the number of participants in a session varied based upon participant availability. Three participants dropped out because they were unable to cope with the negative, high arousal images, and one participant was excluded because one of the complex span tasks crashed. One participant was excluded from analyses due to a failure to follow task instructions (i.e., extremely low span scores and high errors on the distracting task), and an additional two participants were excluded because they were classified as multivariate outliers.[4] Thus, results reflect data from the remaining 206 participants. All participants consented to participate in accordance with the standards of Arizona State University's Institutional Review Board. After consenting to participate, all participants completed shortened versions of the operation span, reading span, and symmetry span tasks[5] (e.g., Foster et al., 2014) in that order. Following the shortened version of the traditional symmetry span task, participants completed the modified symmetry span task described in Experiment 1. The negative, high arousal and neutral, low arousal blocks were counterbalanced as they were before. The total duration of the experiment was around 1 h, and all tasks were programmed in E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and presented on a computer screen to participants.

4.2. Complex span tasks

4.2.1. Operation span

In the automated version of the operation span complex span task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005) participants solved math operations and determined whether a provided answer to the math operation was true or false while trying to encode unrelated letters. After being presented with the first math operation, participants viewed a to-be-remembered letter for 1 s. A trial alternated between the math operation and the letters for list lengths ranging from three to seven after which the participant was asked to recall the letters in serial order. In the shortened version of the task used in this experiment, each list length was presented once (i.e., for a total of 5 trials) and the task took around 10 min to complete. The dependent variable was the total number of memoranda recalled in the correct serial order (i.e., partial-unit span scoring).

4.2.2. Reading span

In the reading span complex span task (Daneman & Carpenter, 1980; Unsworth et al., 2009) participants determined whether a sentence made sense or not while trying to encode unrelated letters. Half of the sentences in the task made sense, and sentences that did not make sense were

created by substituting a word into a sentence that made sense. After being presented with the first sentence, participants viewed a to-be-remembered letter for 1 s. A trial alternated between sentences and the letters for list lengths ranging from three to seven after which the participant was asked to recall the letters in serial order. As in operation span, each list length was presented once (i.e., for a total of 5 trials) in this experiment and the dependent variable was the total number of memoranda recalled in the correct serial order (partial-unit span score). Similar to operation span, this task took around 10 min to complete.

4.2.3. Symmetry span

The symmetry span task is as it was described in the introduction (see Fig. 1A). Participants first determined if an image of an 8×8 matrix with some squares colored in black was symmetrical around the vertical center. Half of the images were symmetrical images and the other half were not. After being presented with the first symmetry judgment, participants viewed a to-be-remembered spatial location for 650 milliseconds. A trial alternated between symmetry judgments and to-be-remembered spatial locations for list lengths ranging from two to five after which the participant was asked to recall the spatial locations in serial order. As in operation and reading span, each list length was presented once in this experiment (i.e., for a total of 4 trials) and the dependent variable was the total number of memoranda recalled in the correct serial order (partial-unit span score). The matrices in this symmetry span task were enlarged and were all black with white lines for the matrix and the squares (see description of the matrix size and color alteration in Experiment 1). There were no images presented in this version of the task, and the task took around 10 min to complete.

5. Experiment 2 results and discussion

To remove task specific variance and consider only variance shared across different types of working memory tasks (Conway et al., 2005), all three complex span tasks (operation span, reading span, symmetry span) were submitted to a factor analysis and factor scores were derived (Span Factor Score) for use in subsequent analyses (see Table 3). The correlation matrix for partial-unit span scores is presented in Table 4. As in Experiment 1, partial-unit span scores for each list length were first averaged across similar list lengths and Emotion conditions and then converted to proportions by dividing by how many items were in the list. These scores were then submitted to a three-factor repeated-measures ANCOVA with Emotion and List Length as within-subjects factors, Order of the blocks within our modified symmetry span task as a between-subjects factor, and Span Factor Score as a covariate. In contrast to the previous experiment, the effect of Order on task performance interacted with Emotion, $F(1, 203) = 6.038$, $MSE = 0.037$, $p < 0.05$, partial $\eta^2 = 0.029$. While this interaction indicated that the effect that negative, high arousal images had on task performance was greater when the negative, high arousal block was presented first, negative, high arousal distracting images led to significantly reduced

Table 3
Complex span task performance in Experiments 2 and 3.

Experiment	Task	Span scores		Errors		
		Partial-unit	Whole-list	Accuracy	Speed	Total
2	Operation span	15.69 (4.52)	9.96 (6.25)	1.34 (1.21)	0.78 (1.37)	2.12 (1.83)
	Reading span	15.27 (4.45)	8.86 (6.30)	1.20 (1.43)	0.55 (0.79)	1.75 (1.63)
	Symmetry span	9.85 (2.80)	6.53 (3.80)	0.80 (1.02)	0.42 (0.71)	1.22 (1.35)
3	Operation span	56.62 (12.04)	39.34 (16.82)	5.88 (5.13)	1.53 (1.81)	7.42 (5.84)
	Reading span	53.07 (14.22)	34.49 (17.26)	4.92 (4.99)	1.49 (1.53)	6.41 (5.20)
	Symmetry span	28.70 (8.22)	20.21 (9.45)	3.01 (2.71)	0.96 (1.35)	3.96 (3.25)

Note: mean performance (standard deviation in parentheses). Participants did not complete these span tasks in Experiment 1. Operation span, reading span, and symmetry span had different possible mean values for Experiment 2 and Experiment 3. See text for details.

proportional partial-unit span scores for both orders. As a result, the interaction between Order and Emotion is interesting but does not have any impact on the results reported.

Replicating Experiment 1, proportional partial-unit span scores were lower when negative, high arousal images served as distractors (neutral, low arousal: $M = 0.72$, $SD = 0.19$ vs. negative, high arousal: $M = 0.64$, $SD = 0.21$), $F(1, 203) = 76.211$, $MSE = 0.037$, $p < 0.001$, partial $\eta^2 = 0.273$ (see Table 2). To evaluate the main effect in more detail, the partial-unit span scores for the negative, high arousal and neutral, low arousal conditions as well as the partial-unit span scores for the traditional symmetry span were converted to proportions (because negative, high arousal and neutral, low arousal conditions were out of 56 possible points whereas the traditional symmetry span was out of 14). The proportion correct partial-unit span scores were submitted to a one-factor repeated measures analysis of variance (ANOVA) with Task Type (negative, high arousal vs. neutral, low arousal vs. Traditional) as a within-subjects factor. This analysis was conducted to discriminate between two opposing predictions: (1) partial-unit span scores in the neutral, low arousal condition were the same as the Traditional condition vs. (2) partial-unit span scores in the neutral, low arousal condition were lower than the Traditional condition. In either case it was predicted that partial-unit span scores in the negative, high arousal condition would be the lowest. We predicted that hypothesis (2) would be supported given that images provide an additional source of distraction compared to no distracting information presented at encoding. Additionally, this analysis provides a type of control condition that can help rule out the unlikely, but possible, alternative that neutral, low arousal images improve task performance.

There was a main effect of Task Type on partial-unit span scores $F(2, 410) = 46.228$, $MSE = 0.016$, $p < 0.001$, partial $\eta^2 = 0.184$ (see Tables 2 and 3). Follow-up paired-samples t-tests were conducted on the proportion-correct partial-unit span scores to assess the main effect in more detail. In line with our primary prediction, the presence of images at encoding led to differences in partial-unit span scores for the neutral, low arousal ($M = 0.68$, $SD = 0.20$) and Traditional ($M = 0.70$, $SD = 0.20$) conditions, $t(205) = 2.044$, $p = 0.042$, $d = 0.106$. Also, the partial-unit span scores were lower for the negative, high arousal condition ($M = 0.59$, $SD = 0.22$) relative to both the Traditional condition, $t(205) = 8.310$, $p < 0.001$, $d = 0.580$, and the neutral, low arousal condition, $t(205) = 8.772$, $p < 0.001$, $d = 0.615$. Thus, presenting images in the background at encoding reduced WMC estimates, and negative, high arousal images had the strongest effect. The smaller effect of neutral, low arousal images on task performance compared to the Traditional condition represents an ideal situation in the present study. Although the presence of any image is distracting, it is specifically the negative, high arousal images have the largest effect on performance.

Returning to the initial analysis, there was no interaction between Emotion and Span Factor Score, $F(1, 203) = 0.281$, $MSE = 0.037$, $p > 0.05$, partial $\eta^2 = 0.001$. While the present study did not find an interaction between Emotion and Span Factor Score, this does not necessarily mean that WMC does not moderate the effect of Emotion on

Table 4
Correlation matrix for partial-unit span scores in Experiment 2.

	1	2	3	4	5	6
1. Negative, high arousal	1					
2. Negative, low arousal	0.771**	1				
3. Ospan	0.368**	0.475**	1			
4. Rspan	0.381**	0.426**	0.466**	1		
5. Sspan	0.557**	0.557**	0.208**	0.294**	1	
6. WMC	0.479**	0.544**	0.676**	0.957**	0.426**	1

** Correlation is significant at the 0.01 level (2-tailed). Note: Ospan = operation span; Rspan = reading span; Sspan = symmetry span; WMC = working memory capacity factor scores.

attention control at encoding in a symmetry span task. That is, the p-value cannot provide evidence for the null hypothesis. Additionally, a p-value does not provide information that allows a researcher to compare the null hypothesis to the alternative hypothesis (e.g., see Jarosz & Wiley, 2014 or Wagenmakers, Verhagen, & Ly, 2015). A difference score for neutral, low arousal - negative, high arousal trials was computed and the data were examined by estimating a Bayes factor in a Bayesian Linear Regression predicting the partial-unit span difference score from Span Factor Score using JASP (Version 0.7; Love et al., 2015; Morey, Jan-Willem, & Rouder, 2016). This Bayes factor compares the fit of the data under the null hypothesis (i.e., that WMC is unrelated to the effect of emotional content on attention control at encoding in a symmetry span task) to the fit of the data under the alternative hypothesis (i.e., that WMC moderates the effect of emotional content on attention control at encoding in a symmetry span task). The estimated Bayes factor indicated that the data were 5.590:1 in favor of the null hypothesis indicating that the data are 5.590 times more likely under a model that excludes WMC as a predictor.[6]

The proportional partial-unit span scores at each list length decreased from a list length of two to a list length of five (List Length 2: $M = 0.84$, $SD = 0.17$; List Length 3: $M = 0.75$, $SD = 0.21$; List Length 4: $M = 0.62$, $SD = 0.23$; List Length 5: $M = 0.49$, $SD = 0.23$), $F(3, 609) = 392.737$, $MSE = 0.024$, $p < 0.001$, partial $\eta^2 = 0.659$.[7] This main effect of List Length was qualified by an interaction with Span Factor Score, $F(3, 609) = 11.065$, $MSE = 0.024$, $p < 0.001$, partial $\eta^2 = 0.052$. To evaluate this interaction in more detail, the proportional partial-unit span scores at each list length were examined separately for the upper and lower Span Factor Score quartiles. The interaction between List Length and Span Factor Score appeared to be driven by the fact that low WMC participants were more dramatically affected by increasing list lengths than high WMC participants. There was also an interaction between List Length and Emotion, F(3, 609) = 5.580,

---

[6] Reporting of the Bayes factor analysis was modeled after Jarosz and Wiley (2014).
[7] Replicating Experiment 1, follow-up paired-samples t-tests on these proportional partial-unit span scores confirmed a significant decrease for each list length increasing from two to five, all $ps < 0.001$.

Table 5
Correlation matrix for partial-unit span scores in Experiment 3.

	1	2	3	4	5	6	7	8
1. Negative, high arousal	1							
2. Negative, low arousal	0.862**	1						
3. Neutral, high arousal	0.834**	0.792**	1					
4. Neutral, low arousal	0.869**	0.853**	0.830**	1				
5. Ospan	0.471**	0.463**	0.447**	0.510**	1			
6. Rspan	0.547**	0.522**	0.480**	0.583**	0.660**	1		
7. Sspan	0.762**	0.741**	0.751**	0.824**	0.552**	0.562**	1	
8. WMC	0.653**	0.633**	0.608**	0.702**	0.885**	0.901**	0.754**	1

** Correlation is significant at the 0.01 level (2-tailed). Note: Ospan = operation span; Rspan = reading span; Sspan = symmetry span; WMC = working memory capacity factor scores.
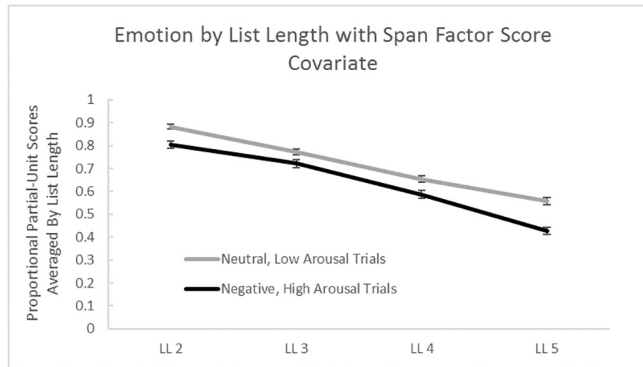

Fig. 3. Experiment 2 partial-unit span scores for neutral, low arousal and negative, high arousal trials, averaged for each list length and then converted to proportions. Described in detail in the text. LL 2 = List Length 2, LL 3 = List Length 3, LL 4 = List Length 4, LL 5 = List Length 5. Note: Error bars: +/− SEM.

MSE = 0.022, $p < 0.01$, partial $\eta^2 = 0.027$. Overall, the interaction between List Length and Emotion appeared to be driven by the largest effect of emotion occurring at a list length of five (see Fig. 3). However, there was no interaction between Emotion, List Length, and Span Factor Score, $F(3, 609) = 0.608$, $MSE = 0.022$, $p > 0.05$, partial $\eta^2 = 0.003$.

In Experiment 2 we replicated the main effect of Emotion found in Experiment 1. However, we were unable to obtain support for the hypothesis that WMC moderates the effect of emotional content on attention control at encoding in a symmetry span task. In fact, a Bayesian analysis supported the null hypothesis that WMC was not predictive of emotional capture in the modified symmetry span task. However, it is interesting to note that the marginal interaction between emotion and list length in experiment 1 was driven primarily by an effect of emotion at a list length of three. By contrast, in Experiment 2 Span Factor Score was entered as a covariate and thus the means driving the interaction with emotion were adjusted for differences in Span Factor Score, and the largest effect of emotion occurred in Experiment 2 at a list length of five. Thus, it is possible that accounting for individual differences in working memory capacity is necessary to understand why emotional content has such a detrimental effect at specific list lengths. For example, in Experiment 1 it is possible that the effects of emotion observed at a list length of three were driven by participants whose capacity was closer to three than five (if the marginal interaction in experiment 1 represents a true effect, which should have resulted in an interaction with span factor in Experiment 2). In Experiment 3 our aim was to conceptually replicate Experiment 2 and extend these findings to account for the differential impact of valence and arousal on attention control and memory processes (Kensinger & Corkin, 2004). In Experiment 3 we orthogonally manipulated Valence and Arousal for the distracting images to examine if individual differences in WMC moderate the effect of Valence but not Arousal on proportional partial-unit span scores and hit rates on a subsequent recognition memory task.

6. Experiment 3 methods

6.1. Participants

A total of 195 participants that did not participate in Experiment 1 or Experiment 2 were recruited from the introductory psychology research participation pool at Arizona State University. Data were collected from up to eight people at a time and the number of participants in a session varied based upon participant availability. Six participants were excluded from analyses due to a failure to follow task instructions. One participant was excluded due to technical issues with the equipment, and one participant did not complete all of the complex span tasks. An additional participant was excluded because they were classified as a multivariate outlier and four participants were excluded due to extreme performance on the processing task (i.e., mean +/− 3 SD on total errors for the processing task averaged across all three traditional complex span tasks), Thus, results reflect data from the remaining 182 participants.

6.2. Materials and procedure

All participants consented to participate in accordance with the standards of Arizona State University's Institutional Review Board. After consenting to participate, all participants completed the full versions of the operation span, reading span, and symmetry span tasks[8] (three of each list length: 15 trials for operation and reading span, and 12 trials for symmetry span) in that order. Each of these tasks took approximately 15 min to complete. Following the traditional symmetry span task, participants completed an altered version of the modified symmetry span task split into four blocks containing negative, high arousal images (e.g., animals poised to attack), negative, low arousal images (e.g., a broken bulb), neutral, high arousal images (e.g., lightning striking during a storm), and neutral, low arousal images (e.g., a clock). The presentation order of the four Emotion blocks was counterbalanced according to a Latin Squares design across participants: order 1 – negative, high arousal, negative, low arousal, neutral, high arousal, then neutral, low arousal, order 2 - negative, low arousal, neutral, low arousal, negative, high arousal, then neutral, high arousal, order 3 – neutral, high arousal, negative, high arousal, neutral, low arousal, then negative, low arousal, and order 4 – neutral, low arousal, neutral, high arousal, negative, low arousal, then negative, high arousal. As in the previous two experiments, participants were instructed to ignore the images and focus on remembering the locations of the squares. After participants completed the altered version of the modified symmetry span task they completed a recognition task to provide a more direct assessment of overt attentional capture by emotional content. The total duration of this experiment was around 1.5 h, and all tasks were programmed in E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) and presented on a computer screen to

---

[8] These tasks can be found on the website noted in Footnote 1.

participants.

6.2.1. Altered version of the modified symmetry span task

The modified symmetry span task from Experiments 1 and 2 was further altered in Experiment 3. Specifically, an additional subset of negative, high arousal, negative, low arousal, neutral, high arousal, and neutral, low arousal images were selected from the IAPS database (Lang et al., 2008). Each block presented four of each list length for a total of 16 trials per condition (a possible score of 56 per block as before but this version contained two additional blocks). Instead of a separate image being associated with the presentation of each square on a given sub-trial, an image remained on the screen for each encoding trial for the entire list length (16 images for the negative, high arousal condition, 16 images for the negative, low arousal condition, 16 images for the neutral, high arousal condition, and 16 images for the neutral, low arousal condition). This was necessary due to the *V*-shaped relation between valence and arousal (Kuppens, Tuerlinckx, Russell, & Barrett, 2013). Specifically, the *V*-shaped relation between valence and arousal is characterized by negative and positive images being more likely to be highly arousing compared to neutral images. Due to the relation between valence and arousal, there were not as many negative, low arousal and neutral, high arousal images in the IAPS database.

Efforts were made in the selection of images to ensure that all conditions contained similar content (i.e., if a negative, high arousal image selected contained an outdoor scene, a negative, low arousal, neutral, high arousal, and neutral, low arousal image was also selected from the database that contained an outdoor scene). See Table 1 for valence and arousal means for Experiment 3. There were no differences in valence means for negative, high arousal and negative, low arousal images ($t < 1.276$) or for neutral, high arousal and neutral, low arousal images ($t < 1.261$). Additionally, there were no differences in arousal means for negative, high arousal and neutral, high arousal images ($t < 1.054$) or for negative, low arousal and neutral, low arousal images ($t < 1.143$). There were differences in valence means for negative, high arousal and neutral, high arousal images, $t(30) = 11.223$, $p < 0.001$, negative, high arousal and neutral, low arousal images, $t(30) = 19.627$, $p < 0.001$, negative, low arousal and neutral, high arousal images, $t(30) = 8.231$, $p < 0.001$, and for negative, low arousal and neutral, low arousal images, $t(30) = 11.991$, $p < 0.001$. Additionally, there were differences in arousal means for negative, high arousal and negative, low arousal images, $t(30) = 29.954$, $p < 0.001$, negative, high arousal and neutral, low arousal images, $t(30) = 54.696$, $p < 0.001$, negative, low arousal and neutral, high arousal images, $t(30) = 14.913$, $p < 0.001$, and for neutral, high arousal and neutral, low arousal images, $t(30) = 16.701$, $p < 0.001$. Thus, the valence means were similar for negative compared to other negative and neutral compared to other neutral images, but differed when negative was compared to neutral images. Similarly, the arousal means were similar for high arousal compared to high arousal and low arousal compared to low arousal images, but differed when high arousal was compared to low arousal images. This task took participants < 30–45 min to complete. All other aspects of this altered version of the task remained identical to the modified symmetry span task discussed previously.

6.2.2. Recognition task

A recognition task consisting of the 16 negative, high arousal, 16 negative, low arousal, 16 neutral, high arousal, and 16 neutral, low arousal images along with 16 new images for each condition was administered to all participants. The new images were matched for features of the image (e.g., if an old negative, high arousal image contained a face, a new image was selected that also contained a face). Participants were asked to decide whether each item was old (was a distracting image during the modified symmetry span task) or new (they have never seen the image before). All images in the recognition task were presented randomly, and this task took participants < 10 min to complete.

7. Experiment 3 results and discussion

All three complex span tasks (operation span, reading span, symmetry span) were submitted to a factor analysis and factor scores were derived (Span Factor Score) for use in subsequent analyses (see Table 3). The correlation matrix for the partial-unit span scores is presented in Table 5. The partial-unit span scores for each list length were first averaged across similar list lengths separately for Valence (Negative vs. Neutral) and Arousal (High vs. Low) conditions and then converted to proportions by dividing by how many items were in the list. These scores were then submitted to a four-factor repeated-measures ANCOVA with Valence, Arousal, and List Length as within-subjects factors, Order as a between-subjects factor, and Span Factor Score as a covariate. There was an interaction between Arousal and the order of presentation of the blocks, $F(3, 177) = 4.335$, $MSE = 0.036$, $p < 0.05$, partial $\eta^2 = 0.068$. A series of one-factor repeated-measures ANOVAs with Arousal as a within-subjects factor were conducted for each Order condition to evaluate the interaction in more detail. These analyses revealed that the interaction was primarily driven by the fact that on average high arousal stimuli (negative, high arousal and neutral, high arousal for all combined list lengths) only led to significantly reduced proportional partial-unit span scores when the negative, high arousal trials were presented first (Order 1: negative, high arousal, negative, low arousal, neutral, high arousal, then neutral, low arousal), $F(1, 48) = 4.021$, $MSE = 0.005$, $p = 0.051$, partial $\eta^2 = 0.077$.[9]

This interaction is difficult to interpret but potentially reflects a similar finding as the Emotion by Order interaction in Experiment 2, with the size of the effects in Experiment 3 constrained by the fact that all arousing images in Experiment 3 were less arousing (this was necessary to ensure an orthogonal manipulation of valence and arousal). Similar to Experiment 2, the strongest average effect of Arousal occurs when the negative, high arousal block is presented first. Notably, this effect of Arousal was not present when negative, high arousal trials followed neutral, high arousal trials in the first two blocks, indicating that it is not just Arousal (which is equal in those two conditions) driving the average increase in failures to attend to goal relevant information that reduce proportional partial-unit span scores. Rather, even when negative and neutral valence stimuli are equally matched in arousal ratings, it is specifically the negatively valenced arousing stimuli that have the most lasting effect on behavioral performance in a symmetry span task.

There were no main effects of Valence, $F(1, 177) = 1.244$, $MSE = 0.036$, $p > 0.05$, partial $\eta^2 = 0.007$, or Arousal, $F(1, 177) = 2.351$, $MSE = 0.036$, $p > 0.05$, partial $\eta^2 = 0.013$, on proportional partial-unit span scores. However, there was an interaction between Valence and Arousal, $F(1, 177) = 4.068$, $MSE = 0.029$, $p < 0.05$, partial $\eta^2 = 0.022$. Follow-up paired-samples t-tests were conducted on the proportional partial-unit span scores to assess the interaction in more detail. The replication effect comparing proportional partial-unit span scores on negative, high arousal trials ($M = 0.68$, $SD = 0.24$) to neutral, low arousal trials ($M = 0.70$, $SD = 0.23$) was significant, $t(181) = 2.155$, $p < 0.05$, $d = 0.08$, with negative, high arousal images leading to lower proportional partial-unit span scores. Although this effect is not as pronounced compared to the first two experiments, this is to be expected due to the constraints placed on image selection. All images in Experiment 3 were more similar than the images in either of the first two experiments to ensure that valence and arousal were orthogonally manipulated. As shown in Table 1, the difference between valence ratings for negative, high arousal compared to neutral, low arousal trials for Experiments 1 and 2 was 3.16, whereas the difference between valence ratings in Experiment 3 for the average negative (negative, high arousal and negative, low arousal) compared to average neutral (neutral, high arousal and neutral, low arousal) trials was only

---

[9] The main effects of Arousal were *NS* for the other three Order conditions.

1.82. Similarly, the difference between arousal ratings for negative, high arousal compared to neutral, low arousal trials for Experiments 1 and 2 was 3.00, whereas the difference between arousal ratings in Experiment 3 for average high arousal (negative, high arousal and neutral, high arousal) compared to average low arousal (negative, low arousal and neutral, low arousal) trials was only 1.94. Less distance between images' mean valence and arousal ratings appears to have reduced the effect of emotion on task performance.

Negative, high arousal images also attracted participants' overt attention more than neutral, high arousal images. That is, proportional partial-unit span scores were reduced when negative, high arousal images ($M = 0.68$, $SD = 0.24$) served as distractors rather than neutral, high arousal images ($M = 0.70$, $SD = 0.24$), $t(181) = 2.080$, $p < 0.05$, $d = 0.091$. Negative, high arousal images also captured participants' overt attention more than negative, low arousal images. Proportional partial-unit span scores were lower when negative, high arousal images ($M = 0.68$, $SD = 0.24$) served as distractors relative to negative, low arousal images ($M = 0.70$, $SD = 0.23$), $t(181) = 2.752$, $p < 0.05$, $d = 0.104$. However, there were no differences between proportional partial-unit span scores for negative, low arousal ($M = 0.70$, $SD = 0.23$) and neutral, low arousal ($M = 0.70$, $SD = 0.23$) trials, $t(181) = 0.588$, $p > 0.05$, $d = 0.022$, negative, low arousal and neutral, high arousal ($M = 0.70$, $SD = 0.24$) trials, $t(181) = 0.226$, $p > 0.05$, $d = 0.011$, or neutral, high arousal and neutral, low arousal trials, $t(181) = 0.240$, $p > 0.05$, $d = 0.011$. Thus, valence and arousal appear to have the strongest effect on attention allocation when the images are both negative and arousing.

Returning to the initial analysis, WMC did not moderate the effect of valence, $F(1, 177) = 0.009$, $MSE = 0.036$, $p > 0.05$, partial $\eta^2 < 0.001$, or arousal, $F(1, 177) = 0.111$, $MSE = 0.036$, $p > 0.05$, partial $\eta^2 = 0.001$, on attention control at encoding. Additionally, WMC did not differentially interact with valence or arousal, $F(1, 177) = 3.733$, $MSE = 0.029$, $p = 0.055$, partial $\eta^2 = 0.021$. To examine whether this marginal interaction was meaningful, the average of neutral (neutral, high arousal and neutral, low arousal), negative (negative, high arousal and negative, low arousal), low arousal (negative, low arousal and neutral, low arousal), and high arousal (negative, high arousal and neutral, high arousal) proportional partial-unit span scores averaged across list lengths were calculated and difference scores were calculated for neutral - negative scores as well as low arousal - high arousal scores. These difference scores were plotted against Span Factor Score (see Fig. 4) and the source of the three-way interaction was determined by examining the difference in slopes across Panel A and Panel B. The difference between the slopes in Panel A and Panel B appears to driven by a few extreme scores for high WMC participants that were especially affected by the arousing content. Thus, it is unlikely that the marginal three-way interaction between Valence, Arousal, and Span Factor Score represents a real effect in the population.

As in Experiment 2, difference scores for Valence and Arousal were computed and the data were examined by estimating Bayes factors separately for Valence and Arousal in two Bayesian Linear Regressions predicting partial-unit span difference score from Span Factor Score. The difference score for Valence was computed as the average of the partial-unit span scores in the two neutral conditions – the average of the partial-unit span scores in the two negative conditions. Similarly, the difference score for Arousal was computed as the average of the partial-unit span scores in the two low arousal conditions – the average of the partial-unit span scores in the two high arousal conditions. An estimated Bayes factor indicated that the data were 4.841 times more likely under a model that excludes WMC as a predictor of the effect of valence on overt allocation of attention at encoding in a symmetry span task. Similarly, an estimated Bayes factor indicated that the data were 5.438 times more likely under a model that excludes WMC as a predictor of the effect of arousal on attention control at encoding in a symmetry span task. Thus, the primary hypothesis that WMC would moderate the effect of valence but not arousal on attention control at
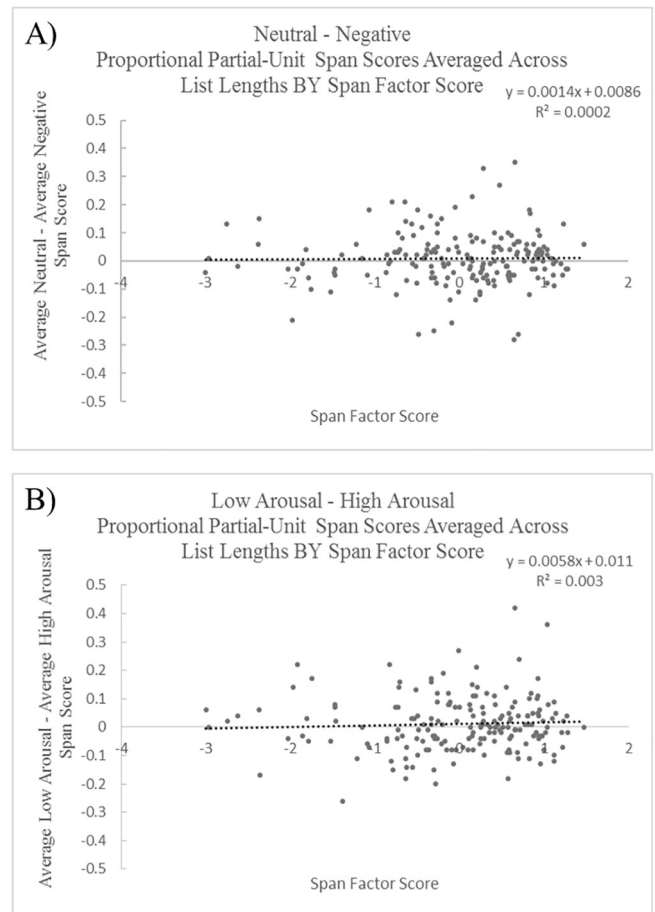

Fig. 4. Experiment 3: the difference between A) average neutral and average negative proportional partial-unit span scores and B) average low arousal and average high arousal proportional partial-unit span scores plotted against Span Factor Score. Described in detail in the text.

encoding in a symmetry span task was not supported in Experiment 3. Attentional capture by and further processing of valenced and arousing information was further examined in the analyses on hit rates from the recognition task. If an image captured a participant's overt attention, then they will remember that image better than other images.

Hit rates were calculated as the proportion of old items called old in the recognition task. The new images were not selected from the IAPS database and thus did not have valence and arousal ratings. As a result, it is unclear if new items were entirely matched to the old items similarly for each condition. This could lead to differences in discriminability that may undermine interpretation of corrected recognition scores (i.e., hit rate - false alarm rate). To avoid such interpretational issues, only hit rates were examined in the present study. The hit rates were submitted to a two-factor repeated measures analysis of covariance (ANCOVA) with Valence and Arousal as within-subjects factors and Span Factor Score as a covariate.

Overall, the average hit rates for negative images ($M = 0.491$, $SD = 0.220$) were higher than the average hit rates for neutral images ($M = 0.417$, $SD = 0.211$), $F(1, 180) = 54.654$, $MSE = 0.018$, $p < 0.001$, partial $\eta^2 = 0.233$. Additionally, the average hit rates for high arousal images ($M = 0.472$, $SD = 0.215$) were higher than the average hit rates for low arousal images ($M = 0.436$, $SD = 0.222$), $F(1, 180) = 10.314$, $MSE = 0.023$, $p < 0.01$, partial $\eta^2 = 0.054$. However, there was no interaction between Valence and Arousal, $F(1, 180) = 0.489$, $MSE = 0.014$, $p > 0.05$, partial $\eta^2 = 0.003$. WMC did not interact with valence, $F(1, 180) = 0.963$, $MSE = 0.018$, $p > 0.05$, partial $\eta^2 < 0.001$, or arousal, $F(1, 180) = 0.218$, $MSE = 0.023$, $p > 0.05$, partial $\eta^2 = 0.001$, nor did WMC differentially interact with
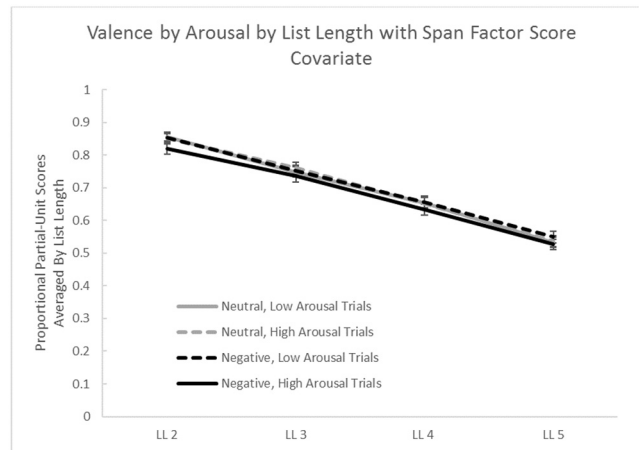
Fig. 5. Experiment 3 partial-unit span scores for neutral, low arousal, neutral, high arousal, negative, low arousal, and negative, high arousal trials, averaged for each list and then converted to proportions. Described in detail in the text. LL 2 = List Length 2, LL 3 = List Length 3, LL 4 = List Length 4, LL 5 = List Length 5. Note: Error bars: $+/-$ SEM.

valence and arousal, $F(1, 180) = 0.446$, $MSE = 0.014$, $p > 0.05$, partial $\eta^2 = 0.002$. In the present study participants were told to ignore these images. The fact that recognition memory was better for negative and arousing images (compared to neutral and not arousing images, respectively) supports the assertion that these images were attended to and processed despite the goal to ignore them and focus on the to-be-remembered location in the matrix. However, it is worth noting that because we were unable to calculate corrected recognition due to potential differences in discriminability, it is entirely plausible that the observed differences in recognition memory defined by hit rates are solely due to a shift in criterion. If this is the case, then participants may experience similar increases in false alarm rate for the emotional images.

These results indicate that both valence and arousal capture overt attention but only arousal leads to deficits in working memory scores. The fact that the arousal driven working memory deficit occurred equally across the WMC range supports the conclusion that individual differences in working memory are not predictive of individual differences in avoiding distraction from task-unrelated emotional content. However, in Experiment 2 the interaction between Emotion and List Length was driven by the largest effect of Emotion occurring at a list length of five. By contrast, the marginal interaction between List Length and Emotion in Experiment 1 was driven by an effect of emotion at a list length of three. If the interaction in Experiment 1 represents a true effect, it is possible that the greater effect at a list length of three reflected performance from a greater number of participants with a lower capacity (if capacity is even related to the effect of emotion which our data do not support). These findings combined with the pattern of results observed so far in Experiment 3 leave open the possibility that additional information about List Length may provide more nuanced information about why WMC did not moderate the effect of Valence (or Arousal) on partial-unit span scores.

Similar to Experiment 2, the proportional partial-unit span scores at each list length decreased from a list length of two to a list length of five (List Length 2: $M = 0.84$, $SD = 0.20$; List Length 3: $M = 0.75$, $SD = 0.24$; List Length 4: $M = 0.65$, $SD = 0.25$; List Length 5: $M = 0.54$, $SD = 0.25$), $F(3, 531) = 373.928$, $MSE = 0.034$, $p < 0.001$, partial $\eta^2 = 0.679$.[10] This main effect of List Length was qualified by an interaction with Span Factor Score, $F(3, 531) = 19.355$, $MSE = 0.034$, $p < 0.001$, partial $\eta^2 = 0.099$. To evaluate this interaction in more detail, the proportional partial-unit span scores at each

list length were examined separately for the upper and lower Span Factor Score quartiles. The interaction between List Length and Span Factor Score appeared to be driven by the fact that low WMC participants were more susceptible to interference across all increasing list lengths than high WMC participants. This interaction appeared more pronounced in Experiment 3 than Experiment 2, and persisted through a list length of five.

There was no interaction between List Length and Valence, $F(3, 531) = 0.583$, $MSE = 0.020$, $p > 0.05$, partial $\eta^2 = 0.003$, or between List Length and Arousal, $F(3, 531) = 0.481$, $MSE = 0.018$, $p > 0.05$, partial $\eta^2 = 0.003$, and List Length did not differentially interact with Valence and Arousal, $F(3, 531) = 0.032$, $MSE = 0.020$, $p > 0.05$, partial $\eta^2 < 0.001$ (see Fig. 5). Additionally, Span Factor Score did not interact with 1) List Length and Valence, $F(3, 531) = 2.026$, $MSE = 0.020$, $p > 0.05$, partial $\eta^2 = 0.011$, 2) List Length and Arousal, $F(3, 531) = 0.666$, $MSE = 0.018$, $p > 0.05$, partial $\eta^2 = 0.004$, 3) or with List Length, Valence and Arousal, $F(3, 531) = 1.712$, $MSE = 0.020$, $p > 0.05$, partial $\eta^2 = 0.010$. Taken together, this indicates that Valence and Arousal have similar effects on proportional partial-unit span scores across list lengths. Additionally, WMC does not moderate the effect of Valence or Arousal on proportional partial-unit span scores across list lengths despite preexisting differences in how high and low WMC participants deal with interference across list lengths on average.

8. General discussion

The results of the present study indicate that emotional content can disrupt working memory encoding processes when the emotional content consists of negative and arousing images. Although WMC is needed to maintain task goals and suppress reflexive responding in attention control tasks like the antisaccade, the results of Experiments 2 and 3 indicate that this may not be the case when distracting content is emotional. Across two large-scale experiments, reported Bayes factors indicated that the data were more likely under a model excluding WMC as a predictor of the effect of emotion on attention control at encoding in a symmetry span task. The marginal interaction between Emotion and List Length in Experiment 1 indicated that emotion primarily impacted performance at a list length of three, and the interaction between Emotion and List Length in Experiment 2 with means adjusted on the Span Factor Score covariate was driven by an effect of emotion that was largest for a list length of five. Although this may have been an indication that working memory capacity does relate to the effect of emotion when considering an individual's capacity, it is unlikely that the marginal interaction in Experiment 1 represents a true effect given

---

[10] Replicating Experiment 2, follow-up paired-samples *t*-tests on these proportional partial-unit span scores confirmed a significant decrease for each list length increasing from two to five, all $ps < 0.001$.

that the studies conducted on larger samples should have revealed that interaction.

These data are consistent with the notion that emotional content may influence and be influenced by different attention components or processes within the executive control attention network (Cohen et al., 2011; Redick & Engle, 2006). That is, emotion may affect attention components outside of the boundary of the relation between WMC and attention (for an example of a task that requires executive control but does not relate to WMC see the findings of Kane, Poole, Tuholski, & Engle, 2006). Failing to find an interaction between WMC and emotion is consistent with research indicating high and low WMC participants should not differ when automatic processing is needed (Barrett et al., 2004; Unsworth, Heitz, & Engle, 2005) and emotional content is automatically processed despite the conscious volition of the participant to focus on task goals.

Along these lines, Cohen et al. (2011) reported that emotional content had an effect on task performance in congruent trials (which contain no conflict) but not on incongruent trials (when conflict is present) in a flanker task embedded in a modified Attention Network Test (Fan et al., 2002). By contrast, Redick and Engle (2006) found that WMC was related to performance on incongruent trials. Therefore, while Emotion interacts with the part of the executive control attention network that can be automatically processed (i.e., no conflict), WMC interacts with the part of the executive control attention network that is processed in a controlled manner (i.e., conflict). Thus, WMC may not moderate the effect of emotion on attention allocation at encoding because emotion influences attention processes not under top-down control of working memory functions (e.g., Fukuda & Vogel, 2011; Shipstead et al., 2014). In the present study, it is likely that individual differences in WMC were not predictive of the effect of emotion on attention allocation at encoding because the images were presented simultaneously with the information being encoded. This is consistent with research demonstrating that high and low WMC participants are equally captured by distracting stimuli and perform filtering tasks similarly (Fukuda & Vogel, 2011; Shipstead et al., 2014).

Presenting emotional content simultaneously with information being encoded may have artificially ensured that the present study primarily measured capture of attention and the allocation of attentional resources rather than the ability to disengage attention from emotional content in favor of task goals. As stated in the introduction, Schmeichel et al. (2008) demonstrated that high WMC participants appraise emotional stimuli differently than low WMC participants. Kleider, Parrott, and King (2010) further demonstrated that when low WMC participants are shown negative arousing stimuli they are more likely to subsequently shoot unarmed targets and not shoot armed targets in a shoot-don't shoot task. In the current study, emotional stimuli were presented simultaneously with to-be-remembered stimuli at encoding. Therefore, the failure to find a moderating effect of working memory on emotional impacts on attention allocation during encoding is not necessarily inconsistent with prior research.

While Kleider et al. (2010) and Schmeichel et al. (2008) demonstrate emotion and WMC interactions, these studies primarily consider how emotional information is managed and how it impacts *subsequent* task performance. By contrast, we presented images at the same time as the task-relevant information, and high and low WMC participants may be no more likely to differ in overt attentional capture in the present study than they are when the capturing stimuli are not emotional in nature (e.g., Fukuda & Vogel, 2011). Therefore, it is possible that the critical difference determining when WMC will moderate the effect of emotion on task performance is whether the emotion manipulation occurs simultaneously with task-relevant information (emotional capture/bias) or occurs and then task-relevant information is presented (disengagement). Future research should assess individual differences in emotional capture/bias versus disengagement to better clarify relations with WMC.

An alternative explanation for the results of the present study is that an entire block of negative, high arousal images may have placed participants in a negative mood which made it more difficult to suppress intrusive thoughts about the images. Brewin and Smart (2005) demonstrated that participants in a negative mood were more likely to experience unwanted and intrusive thoughts during thought suppression. Furthermore, although they also found evidence that people with higher WMC are more able to suppress these intrusive thoughts than people with lower WMC, WMC was uncorrelated with negative mood. These results indicate that both high and low spans may be susceptible to intrusive thoughts about the emotional images if they are in a negative mood. As a result, the fact that WMC did not moderate the effect of emotion on attention allocation at encoding in the present study could potentially be due to the fact that the entire block of negative, high arousal images placed participants in a negative mood. However, this interpretation of the results of the present study is inconsistent with both the results of Schmeichel et al. (2008) and Kleider et al. (2010).

In the present study we were interested in how the presence of emotional content influences the ability to encode information into memory. To examine this, we selected images across conditions that were matched in content and only varied in valence and arousal. If presenting these distracting images in the background at encoding made the images impossible to ignore, there would not have been an effect of emotion because neutral, low arousal trials also contained images. While both sets of images do appear to capture overt attention and reduce performance compared to traditional trials, it is the negative, high arousal condition specifically that leads to the largest reduction in symmetry span task performance. The images in the present study were presented during the encoding phase because attending to these distracting stimuli should have the largest impact on performance. If a square location in symmetry span is not encoded it cannot be retrieved. By contrast, it is possible to retrieve an encoded stimulus from secondary memory even if it is displaced from primary memory by the onset of an emotional image during the distracting phase of the symmetry span task (during or in place of the symmetry judgments).

Future research should assess the interaction between emotion and WMC within the executive control attention network. For example, in a symmetry span task the symmetry judgments serve as distracting information that must be suppressed in order to encode the locations of the squares in the 4 × 4 grid. Thus, there is a direct match between the type of suppression required to perform a traditional symmetry span task and the type of suppression required to perform an emotional version of the task when the images are presented during the distracting phase (during or in place of the symmetry judgments). This manipulation should primarily affect the conflict component of the executive control attention network and may yet reveal a relation between WMC and the ability to suppress reflexive evaluation of emotional content rather than content relevant to task goals. Additionally, future research should try to better segregate attention capture/bias from attention disengagement as these factors likely differentially correlate with WMC.

The results of the present study indicate that both valence and arousal impact attention control processes at encoding relatively automatically despite evidence from Kensinger and Corkin (2004) showing that valence is processed in a controlled manner. This pattern of results should only be expected if emotion impacted earlier stages of information processing that are not under prefrontal cortex control. If this is the case, then differences in dorsolateral prefrontal cortex integrity observed between high and low WMC participants (Kane & Engle, 2002) should not predict attentional capture by and allocation to emotional content. The present study manipulated emotional content at encoding where competing information (i.e., the picture and the to-be-remembered square location) may impact attentional processes that are unrelated to WMC. Future studies manipulating emotion during the distracting phase may allow us to study if and how emotion interacts with WMC when controlled processing of emotion is required.

Appendix A

Table A
IAPS image numbers for Experiments 1–3.

Experiment	Image numbers			
	Negative, high arousal	Negative, low arousal	Neutral, high arousal	Neutral, low arousal
1 & 2	2352.2			1602
	2691			1670
	3000			2010
	3001			2026
	3005.1			2038
	3015			2101
	3030			2102
	3059			2190
	3063			2191
	3069			2235
	3071			2270
	3102			2271
	3103			2273
	3110			2305
	3130			2308
	3168			2320
	3170			2374
	3213			2384
	3400			2393
	3530			2394
	3550			2397
	4664.2			2411
	5961			2435
	6021			2445
	6212			2446
	6213			2480
	6220			2489
	6300			2491
	6315			2493
	6370			2500
	6410			2506
	6550			2511
	6563			2518
	6821			2560
	6834			2570
	9050			2620
	9075			2745.1
	9183			2749
	9252			2870
	9254			4500
	9321			4605
	9325			5020
	9400			5471
	9412			5731
	9424			5875
	9570			7039
	9600			7512
	9630			7513
	9800			7546
	9903			7550
	9908			8311
	9911			9070
	9920			9190
	9921			9210
	9930			9360
	9940			9700

3	1051	2312	1303	1616
	1205	2400	1560	2308
	1301	2490	1820	2359
	2661	2491	3302	2372
	3022	2520	3310	2394
	3211	2525	5920	2435
	5973	2590	5950	2487
	6211	6010	6910	2489
	6244	7013	7240	4605
	6555	7023	7600	7033
	6840	7078	7640	7081
	9042	9001	8065	7190
	9160	9010	8160	7242
	9621	9220	8191	7283
	9623	9390	8192	7495
	9930	9469	8475	7550

References

Barrett, L. F., & Russell, J. A. (1999). The structure of current affect controversies and emerging consensus. *Current Directions in Psychological Science, 8*(1), 10–14. http://dx.doi.org/10.1111/1467-8721.00003.

Barrett, L. F., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin, 130*(4), 553–573. http://dx.doi.org/10.1037/0033-2909.130.4.553.

Brewin, C. R., & Smart, L. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of Behavior Therapy and Experimental Psychiatry, 36*(1), 61–68. http://dx.doi.org/10.1016/j.jbtep.2004.11.006.

Cohen, N., Henik, A., & Mor, N. (2011). Can emotion modulate attention? Evidence for reciprocal links in the attentional network test. *Experimental Psychology, 58*(3), 171–179. http://dx.doi.org/10.1027/1618-3169/a000083.

Conway, A. R., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786. http://dx.doi.org/10.3758/BF03196772.

Conway, A. R. A., Kane, M. J., & Engle, R. W. (2003). Working memory capacity and its relation to general intelligence. *Trends in Cognitive Sciences, 7*(12), 547–552. http://dx.doi.org/10.1016/j.tics.2003.10.005.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450–466. http://dx.doi.org/10.1016/S0022-5371(80)90312-6.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *Psychology of Learning and Motivation, 44*, 145–200. http://dx.doi.org/10.1016/S0079-7421(03)44005-X.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340–347. http://dx.doi.org/10.1162/089892902317361886.

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2014). Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition, 43*(2), 226–236. http://dx.doi.org/10.3758/s13421-014-0461-7.

Fukuda, K., & Vogel, E. K. (2011). Individual differences in recovery time from attentional capture. *Psychological Science, 22*(3), 361–368. http://dx.doi.org/10.1177/0956797611398493.

Jarosz, A. F., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting Bayes factors. *The Journal of Problem Solving, 7*(1), 2–9. http://dx.doi.org/10.7771/1932-6246.1167.

Kane, M. J., Bleckley, M. K., Conway, A. R., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130*(2), 169–183. http://dx.doi.org/10.1037/0096-3445.130.2.169.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9*(4), 637–671. http://dx.doi.org/10.3758/BF03196323.

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention". *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(4), 749–777. http://dx.doi.org/10.1037/0278-7393.32.4.749.

Kensinger, E. A., & Corkin, S. (2004). Two routes to emotional memory: Distinct neural processes for valence and arousal. *Proceedings of the National Academy of Sciences of the United States of America, 101*(9), 3310–3315. http://dx.doi.org/10.1073/pnas.0306408101.

Kleider, H. M., Parrott, D. J., & King, T. Z. (2010). Shooting behaviour: How working memory and negative emotionality influence police officer shoot decisions. *Applied Cognitive Psychology, 24*(5), 707–717. http://dx.doi.org/10.1002/acp.1580.

Kuppens, P., Tuerlinckx, F., Russell, J. A., & Barrett, L. F. (2013). The relation between valence and arousal in subjective experience. *Psychological Bulletin, 139*(4), 917–940. http://dx.doi.org/10.1037/a0030811.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical report A-8.* Gainesville, FL: University of Florida.

Love, J., Selker, R., Marsman, M., Jamil, T., Dropmann, D., Verhagen, A. J., ... Wagenmakers, E.-J. (2015). *JASP (version 0.7) [computer software]*.

Mather, M. (2007). Emotional arousal and memory binding: An object-based framework. *Perspectives on Psychological Science, 2*(1), 33–52. http://dx.doi.org/10.1111/j.1745-6916.2007.00028.x.

Morey, R. D., Jan-Willem, R., & Rouder, J. N. (2016). The philosophy of Bayes factors and the quantification of statistical evidence. *Journal of Mathematical Psychology, 72*, 6–18. http://dx.doi.org/10.1016/j.jmp.2015.11.001.

Öhman, A., Flykt, A., & Lundqvist, D. (2000). Unconscious emotion: Evolutionary perspectives, psychophysiological data and neuropsychological mechanisms. In R. D. R. Lane, L. Nadel, & G. L. Ahern (Vol. Eds.), *Series in affective science: . Vol. 296–327*Oxford University Press.

Psychology Software Tools, Inc. [E-Prime 2.0] (2012). Retrieved from http://www.pstnet.com.

Redick, T. S., & Engle, R. W. (2006). Working memory capacity and attention network test performance. *Applied Cognitive Psychology, 20*(5), 713–721. http://dx.doi.org/10.1002/acp.1224.

Schmeichel, B. J., Volokhov, R. N., & Demaree, H. A. (2008). Working memory capacity and the self-regulation of emotional expression and experience. *Journal of Personality and Social Psychology, 95*(6), 1526–1540. http://dx.doi.org/10.1037/a0013345.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*(1), 4–27. http://dx.doi.org/10.1037/0096-3445.125.1.4.

Shipstead, Z., Harrison, T. L., & Engle, R. W. (2015). Working memory capacity and the scope and control of attention. *Attention, Perception, & Psychophysics, 77*(6), 1863–1880. http://dx.doi.org/10.3758/s13414-015-0899-0.

Shipstead, Z., Lindsey, D. R., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity: Primary memory, secondary memory, and attention control. *Journal of Memory and Language, 72*, 116–141. http://dx.doi.org/10.1016/j.jml.2014.01.004.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*(2), 127–154. http://dx.doi.org/10.1016/0749-596X(89)90040-5.

Unsworth, N., Brewer, G. A., & Spillers, G. J. (2012). Working memory capacity and retrieval from long-term memory: The role of controlled search. *Memory & Cognition, 41*(2), 242–254. http://dx.doi.org/10.3758/s13421-012-0261-x.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*(1), 104–132. http://dx.doi.org/10.1037/0033-295X.114.1.104.

Unsworth, N., Fukuda, K., Awh, E., & Vogel, E. K. (2014). Working memory and fluid intelligence: Capacity, attention control, and secondary memory retrieval. *Cognitive Psychology, 71*, 1–26. http://dx.doi.org/10.1016/j.cogpsych.2014.01.003.

Unsworth, N., Heitz, R. P., & Engle, R. W. (2005). Working memory capacity in hot and cold cognition. In R. W. Engle, G. Sedek, U. von Hecker, & D. N. McIntosh (Eds.). *Cognitive limitations in aging and psychopathology* (pp. 19–43). New York, NY: Cambridge University Press.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, 37*(3), 498–505. http://dx.doi.org/10.3758/BF03192720.

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635–654. http://dx.doi.org/10.1080/09658210902998047.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: Individual differences in voluntary saccade control. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(6), 1302–1321. http://dx.doi.org/10.1037/0278-7393.30.6.1302.

Wagenmakers, E. J., Verhagen, J., & Ly, A. (2015). How to quantify evidence for the absence of a correlation. *Behavior Research Methods, 48*(2), 413–426. http://dx.doi.org/10.3758/s13428-015-0593-0.