Regulating Working Memory In Emotionally-Laden Contexts

by

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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 be predictive of differences in the ability to regulate attention in emotional contexts. To address this hypothesis, a complex-span working memory task (symmetry span) 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. Additionally, in Experiment 3, both negative and arousing images captured attention and led to increased hit rates in a subsequent recognition task. 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. Implications for theories of working memory and attention control in emotional contexts will be discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Regulating Working Memory in Emotionally-Laden Contexts

Working memory is responsible for the transient registration, maintenance, and retrieval of novel and previously learned information in primary memory. Three important sources of variability in working memory are active maintenance of task goals in primary memory, primary memory capacity, and controlled retrieval of momentarily displaced goals from secondary memory (Unsworth & Engle, 2007; Unsworth, Brewer, & Spillers, 2012; Unsworth, Fukuda, Awh, & Vogel, 2014; Shipstead, Harrison, & Engle, 2015). Individual differences in working memory capacity partly arise from differences in 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 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). Working memory may be important for dealing with emotional distractions and the purpose of the present study is to determine whether individual differences in working memory capacity moderate the effect of distracting emotional content on attention when attempting to encode task-relevant information into primary memory.

Working Memory Capacity

Working memory capacity 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 *Figure* 1A for an illustration) participants remember the spatial locations of red squares presented in a 4x4 grid. Interspersed with the to-be-remembered spatial locations are patterns that the participant identifies as symmetrical or nonsymmetrical. Working memory capacity in a symmetry-span task is defined as the total number of spatial locations that can be recalled in the correct serial order. The symmetry judgment task serves as distracting information, and participants are asked to achieve at least 80% accuracy on the distraction task while still maintaining the locations of the squares in memory. According to Engle and Kane (2004), attention control is one theoretical mechanism responsible for active maintenance of the spatial locations while 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.

Working Memory Capacity and Attention

Variance in complex-span tasks is not only related to a diverse array of higher-order cognitive abilities (Daneman & Carpenter, 1980; Conway, Kane, & Engle, 2003) but it is also related to performance on tasks that measure lower-order abilities such as resisting prepotent responses. For example, working memory capacity predicts performance on the antisaccade task (Kane, Bleckley, Conway, & Engle, 2001). In this 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 they were not correlated with prosaccade performance. Specifically, in an antisaccade condition low working memory capacity participants made numerically higher errors at identifying the target and were slower in identifying the target on correct trials. Additionally, low working memory capacity participants were slower to make a correct saccade toward the target and made more incorrect saccades toward the flashing cue (Kane et al., 2001).

In voluntary saccades a cue is not directly informative about the location of the target, similar to the antisaccade condition in Kane et al. (2001). Similar to the prosaccade condition, automatic saccades occur when a cue provides direct information about the location of the target. Unsworth, Schrock, and Engle (2004) demonstrated that high and low working memory capacity participants' latencies differed in an antisaccade task when a voluntary saccade needed to be made. Engle and Kane (2004) posited that attention control is needed to maintain task goals and to resolve response competition by suppressing irrelevant content (e.g., the flashing cue). For example, in an antisaccade task a failure to maintain the task goal will result in an incorrect saccade toward the flashing cue. By contrast, issues resolving response competition by suppressing irrelevant content should lead to a slow but correct saccade away from the flashing cue (Engle & Kane, 2004). This view suggests that low working memory capacity participants have deficits in both goal maintenance and resolving response competition by suppressing irrelevant content. In the present study we aim to evaluate whether working memory capacity is similarly related to the ability to suppress the tendency to look at distracting images containing emotional content.

Emotion, Attention, and Working Memory Capacity

Emotional content obligatorily captures attention in order to orient organisms toward salient information that may be relevant for survival (Mather, 2007; Öhman, Flykt, and Lundqvist, 2000). There are three networks of attention that can interact with emotion: 1) alerting, 2) orienting, and 3) executive control. The Attentional Network Test was developed to measure efficiency in each of these networks (Fan, McCandliss, Sommer, Raz, & Posner, 2002). In this task participants must respond quickly to the direction of the arrow in the center of a display of arrows. In the version of the Attention Network Test used by Cohen, Henik, and Mor (2011) the surrounding arrows can either be pointing in the same direction as the center arrow (congruent; →→→→→) or the opposite direction as the center arrow (incongruent; →→←→→). These arrow displays can occur on the top or bottom of the screen, and are preceded by a valid cue (occurs on the same half of the screen) or an invalid cue (occurs on the opposite half of the screen). Prior to the display of a cue and arrows participants either hear an alerting tone or do not hear an alerting tone. The difference in response times for tone vs. no tone trials is considered an index of alerting efficiency. The difference in response times for cue vs. no cue trials is considered an index of orienting efficiency. Finally, the difference in response times for congruent vs. incongruent trials is considered an index of executive control efficiency. Therefore, the presence of emotional (vs. neutral) content as a cue in the Attention Network Task could impact performance measures for any of these networks (though emotion is unlikely to affect alerting efficiency in this case).

Cohen et al. (2011) argued that attention and emotion interact in only the executive control network of attention. Specifically, response times for congruent trials were slower following negative cues compared to neutral cues. On incongruent trials emotion did not influence response times. Cohen et al. (2011) argued that the use of top-down inhibition on incongruent trials suppressed the effect that emotion had on response times. Similarly, Redick and Engle (2006) reported that high and low working memory capacity participants differed in this executive control attention network. Thus, individual differences in working memory capacity and attention control processes may predict who is able to suppress the tendency to look at distracting emotional images.

However, Redick and Engle (2006) found that low working memory capacity participants were slower on incongruent trials than high working memory capacity participants. There were no differences between high and low working memory capacity participants on congruent trials. In contrast, an alternative way to explain the interaction between emotion and the executive control attention network in Cohen et al. (2011) is by restating the results to illustrate that the effect of emotional content on response times was primarily driven by longer response times in the congruent condition for trials cued by negative arousing content. Therefore, it remains possible that emotional content affects different attention components than working memory capacity. If this is indeed the case, then working memory capacity may not moderate the effect of emotional content on attention processes at encoding. Rather, high and low working memory capacity participants may similarly be affected by the distracting emotional content.

The research reviewed thus far has primarily treated emotion as a one-dimensional 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 are confounded. It is not known whether the interaction between emotion and the executive control component of the attention network described above is 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, working memory capacity may be differentially related to the ability to suppress distracting information containing valenced or arousing content. Specifically, when controlled processing is needed individuals with high working memory capacity should be better at suppressing 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 working memory capacity participants (Kane and Engle, 2002) should lead to individual differences in regulating attention in emotionally evocative contexts.

Unsworth et al. (2005) argue that low working memory capacity participants should not differ from high working memory capacity participants for automatic processing, but should differ when controlled processing is needed for goal completion. They further suggest that high working memory capacity participants should be better at resisting attentional capture by salient information. Thus, low working memory capacity participants should be worse at suppressing emotional distractions in their environment in favor of focusing on their task goals. Unsworth et al. (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 working memory capacity participants are better able to suppress reactions to negative emotional content than low working memory capacity participants (Schmeichel, Volokhov, & Demaree, 2008). However, the different routes that valence and arousal take may lead to differential effects on attention at encoding in a symmetry span task and may be differentially sensitive to individual differences in working memory.

In the present study we were interested in how valence and arousal independently and interactively impact attention processes during working memory encoding. To investigate this issue we selected images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) database that served as distractors during the encoding phase of a symmetry span task. In Experiment 1 we selected high valence, high arousal (HH) images and low valence, low arousal (LL) images to serve as distractors (similar to Cohen et al., 2011). Experiment 1 was designed to first evaluate whether emotional content captures attention leading to reduced working memory capacity estimates in a symmetry span task. Experiment 2 was designed to replicate and extend the findings of Experiment 1 by testing the hypothesis that working memory capacity would moderate the deleterious effect of emotional content on attention during working memory encoding. Experiment 3 was designed to separate the valence and arousal dimensions of emotion in order to further evaluate whether individual differences in working memory capacity predict whether valenced but not arousing content captures attention to the detriment of task goals. To accomplish this, an additional subset of high valence, low arousal (HL) images and low valence, high arousal (LH) images from the IAPS database were selected in addition to the HH and LL images used in Experiments 1 and 2. Additionally, a recognition task was administered at the end of Experiment 3 to provide evidence that attention was captured by high arousal images.

Experiment 1 Methods

Participants

A total of 50 participants were recruited from the introductory psychology research participation pool at Arizona State University. Two participants were excluded from analyses due to extreme performance (i.e., mean +/- 1.5 X the interquartile range). An additional three participants left the study before completing the task because they were unable to cope with the HH images, and one participant was unable to complete the task because the program crashed. Thus, data from the remaining 44 participants were analyzed.

Materials and Procedure

All participants consented to participate in accordance with the standards of the 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 HH images in one block and LL images in the second block. The presentation 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.

Modified symmetry span task. In the present study we modified the traditional version of the symmetry span task described earlier. Specifically, HH and LL images were obtained from the IAPS database (Lang et al., 1999). Efforts were made in the selection of images to ensure that HH and LL images contained similar content (if a selected HH image contained a face, a LL image was selected from the database that also contained a face). HH and LL images differed in valence means (HH: $M = 2.22$, $SD = 0.56$ vs. LL: $M = 5.38$, $SD = 0.64$), $t(110) = 27.881$, $p < .001$, and in arousal means (HH: $M = 6.35$, $SD = 0.44$ vs. LL: $M = 3.35$, $SD = 0.40$), $t(110) = 37.806$, $p < .001$; 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 percent transparency and superimposed over the image. All other aspects of the symmetry span task remained identical to the symmetry span task discussed previously. *Figure* 1B & 1C 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 in this modified symmetry span task varied from two to five similar to the symmetry span task usually used in the literature (see *Figure* 1A). However, instead of presenting three of each list length as is commonly done in the symmetry span task, participants completed four of each list length. Presentation of each list length was randomized, and the HH and LL images were presented in blocks that were counterbalanced. For this version of the modified symmetry span task, one image was presented for each of the 112 possible square locations (56 images for the HH condition, and another 56 images for the LL condition) and the location of the to-be-remembered spatial location was presented randomly.

Experiment 1 Results and Discussion

The partial-unit span scores were submitted to a one-factor repeated measures analysis of variance (ANOVA) with Emotion as a within-subjects factor. As expected, partial-unit span scores were lower when HH images served as distractors (HH: M = 37.45, SD = 11.12 vs. LL: M = 39.64, SD = 9.42), $F(1, 43) = 4.112$, $MSE = 25.471$, $p < .05$, partial $\eta^2 = .087$ (see *Table* 2). Thus, relative to LL images, HH 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 working memory capacity is consistent with the interpretation that when emotional content is present it captures attention (see Mather, 2007). Experiment 2 aimed to replicate this effect and further address whether individual differences in working memory capacity moderate this effect of Emotion on attention at encoding of information into working memory. Specifically, we hypothesized that individual differences in goal maintenance and the ability to suppress irrelevant content would predict whether attention is captured and maintained on task-irrelevant emotional content.

Experiment 2 Methods

Participants

A total of 213 participants were recruited from the introductory psychology research participation pool at Arizona State University. 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). An additional two participants were excluded because they were classified as multivariate outliers[1]. Three participants were excluded because they were unable to cope with the HH images, and one participant was excluded because one of the complex span tasks crashed. Data from the remaining 206 participants were analyzed.

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 shortened versions of the operation span, reading span, and symmetry span tasks (Foster et al., 2014). Following the shortened version of the traditional symmetry span task, participants completed the modified symmetry span task described in Experiment 1.

[1] Multivariate outliers were assessed via mahalanobis distance outlier detection based on three complex-span tasks.

Complex span tasks.

Operation span. In 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 second. 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. The dependent variable was the total number of memoranda recalled in the correct serial order (i.e., partial-unit span scoring).

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 second. 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 in this experiment and the dependent variable was the total number of memoranda recalled in the correct serial order.

Symmetry span. The symmetry span task is as it was described in the introduction. Participants first determined if an image of an 8 x 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 and the dependent variable was the total number of memoranda recalled in the correct serial order. 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.

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 partial-unit span scores were submitted to a one-factor repeated measures analysis of covariance (ANCOVA) with Emotion as a within-subjects factor and Span Factor Score as a covariate. Replicating Experiment 1, partial-unit span scores were lower when HH images served as distractors (HH: $M = 33.04$, $SD = 12.09$ vs. LL: $M =$

37.89, *SD* = 11.25), *F*(1, 204) = 76.711, *MSE* = 31.641, *p* < .001, partial η^2 = .273 (see *Table* 2). To evaluate the main effect in more detail, the partial-unit span scores for the HH and LL conditions as well as the partial-unit span scores for the traditional symmetry span were converted to proportions (because HH and LL 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 Type (HH vs. LL vs. Traditional) as a within-subjects factor. This analysis was conducted to discriminate between two opposing predictions: (1) partial-unit span scores in the LL condition were the same as the Traditional condition vs. (2) partial-unit span scores in the LL condition were lower than the Traditional condition. In either case it was predicted that partial-unit span scores in the HH 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 possibility that LL images improve task performance.

There was a main effect of Type on partial-unit span scores *F*(2, 410) = 46.228, *MSE* = .016, *p* < .001, partial η^2 = .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 LL (*M* = 0.68, *SD* = .20) and Traditional (*M* = 0.70, *SD* = 0.20) conditions, *t*(205) = 2.044, *p* = .042, *d* = .106.

Also, the partial-unit span scores were lower for the HH condition ($M = 0.59$, $SD = 0.22$) relative to both the Traditional condition, $t(205) = 8.310$, $p < .001$, $d = .580$, and the LL condition, $t(205) = 8.772$, $p < .001$, $d = .615$. Thus, presenting images in the background at encoding reduced working memory capacity estimates, and HH images had the strongest effect.

Returning to the initial analysis, there was no interaction between Emotion and Span Factor Score, $F < 1$. While the present study did not find an interaction between Emotion and Span Factor Score, this does not necessarily mean that working memory capacity does not moderate the effect of Emotion on attention at encoding. That is, the *p*-value does not demonstrate that the null is actually true. 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 LL - HH 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). This Bayes factor compares the fit of the data under the null hypothesis (i.e., that working memory capacity is unrelated to the effect of emotional content on attention at encoding) to the fit of the data under the alternative hypothesis (i.e., that working memory capacity moderates the effect of emotional content on attention at encoding). The estimated Bayes factor indicated that the data were 5.590:1 in favor of the null hypothesis. The data are 5.590 times more likely under a model that excludes working memory capacity as a predictor[2].

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 working memory capacity moderates the effect of emotional content on attention at encoding in a symmetry span task. In fact, we found support in favor of the null hypothesis that working memory capacity is unrelated to the ability to suppress emotional content in favor of task goals. 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 and memory processes (Kensinger & Corkin, 2004). In Experiment 3 we manipulated the distracting images' Valence and Arousal orthogonally to examine if individual differences in working memory capacity moderate the effect of Valence but not Arousal on partial-unit span scores and hit rates on a subsequent recognition memory task.

Experiment 3 Methods

Participants

A total of 195 participants were recruited from the introductory psychology research participation pool at Arizona State University. Six participants were excluded from analyses due to a failure to follow task instructions. An additional participant was excluded because they were classified as a multivariate outlier. Four participants were

[2] Reporting of the Bayes factor analysis was modeled after Jarosz and Wiley (2014).

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), one participant was excluded due to technical issues with the equipment, and one participant did not complete all of the complex span tasks. Data from the remaining 182 participants were analyzed.

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 (three of each list length). Following the traditional symmetry span task, participants completed an altered version of the modified symmetry span task split into four blocks containing HH images, HL images, LH images, and LL images. The presentation of the four Emotion blocks was counterbalanced across participants. 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 attentional capture by emotional content.

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 HL and LH images were selected from the IAPS database (Lang et al., 1999). Instead of a separate image being associated with the presentation of each square, an image remained on the screen for each encoding trial during a list length (16 images for the HH condition, 16 images for the HL condition, 16 images for the LH condition, and 16 images for the LL 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 HL and LH images in the IAPS database (low valence = neutral).

Efforts were made in the selection of images to ensure that all conditions contained similar content (i.e., if a HH image selected contained an outdoor scene, a HL, LH, and LL image were 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 HH ($M = 3.49$, $SD = 0.33$) and HL ($M = 3.70$, $SD = 0.55$) images ($t < 1.276$) or for LH ($M = 5.31$, $SD = 0.56$) and LL ($M = 5.51$, $SD = 0.24$) images ($t < 1.261$). Additionally, there were no differences in arousal means for HH ($M = 5.82$, $SD = 0.11$) and LH ($M = 5.94$, $SD = 0.48$) images ($t < 1.054$) or for HL ($M = 3.98$, $SD = 0.22$) and LL ($M = 3.91$, $SD = 0.09$) images ($t < 1.143$). There were differences in valence means for HH and LH images, $t(30) = 11.223$, $p < .001$, HH and LL images, $t(30) = 19.627$, $p < .001$, HL and LH images, $t(30) = 8.231$, $p < .001$, and for HL and LL images, $t(30) = 11.991$, $p < .001$. Additionally, there were differences in arousal means for HH and HL images, $t(30) = 29.954$, $p < .001$, HH and LL images, $t(30) = 54.696$, $p < .001$, HL and LH images, $t(30) = 14.913$, $p < .001$, and for LH and LL images, $t(30) = 16.701$, $p < .001$. Thus, the valence means were similar for high valence compared to other high valence and low valence compared to other low valence images, but differed when high valence was compared to low valence 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. All other aspects of this altered version of the task remained identical to the modified symmetry span task discussed previously.

Recognition task. A recognition task consisting of the 16 HH, 16 HL, 16 LH, and 16 LL 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 HH 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.

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 partial-unit span scores were submitted to a two-factor repeated measures analysis of covariance (ANCOVA) with Valence (High/Negative vs. Low/Neutral) and Arousal (High vs. Low) as within-subjects factors and Span Factor Score as a covariate. There were no main effects of Valence or Arousal on partial-unit span scores, Fs < 1.920. However, there was an interaction between Valence and Arousal, $F(1, 180) = 3.789$, $MSE = 25.461$, $p = .053$, partial $\eta^2 = .021$.

Follow-up paired-samples t-tests were conducted on the partial-unit span scores to assess the interaction in more detail. The replication effect comparing partial-unit span scores on HH trials ($M = 36.04$, $SD = 13.37$) to LL trials ($M = 36.96$, $SD = 13.18$) was marginally significant, $t(181) = 1.832$, $p = .069$, $d = .135$, with HH images leading to lower partial-unit span scores[3]. HH images also grabbed participants' attention more than LH images. That is, partial-unit span scores were marginally reduced when HH images ($M = 36.04$, $SD = 13.37$) served as distractors rather than LH images ($M = 37.12$, $SD = 13.96$), $t(181) = 1.847$, $p = .066$, $d = .137$. HH images also captured participants' attention more than HL images. Partial-unit span scores were lower when HH images ($M = 36.04$, $SD = 13.37$) served as distractors relative to HL images ($M = 37.34$, $SD = 13.29$), $t(181) = 2.494$, $p < .05$, $d = .186$. However, there were no differences between HL ($M = 37.34$, $SD = 13.29$) and LL ($M = 36.96$, $SD = 13.18$) images, HL ($M = 37.34$, $SD = 13.29$) and LH ($M = 37.12$, $SD = 13.96$) images, or LH ($M = 37.12$, $SD = 13.96$) and LL ($M = 36.96$, $SD = 13.18$) images, *t*s < 1. Thus, valence and arousal appear to have the strongest effect on attentional capture when the images are both negative and arousing. Returning to the initial analysis, working memory capacity did not moderate the effect of valence or arousal on attention at encoding, *F*s < 1. Additionally, working memory capacity did not differentially interact with valence or arousal, $F < 2.074$.

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

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[3] One participant was over 3 *SD* below the mean of LL – HH trials but their data did not otherwise meet exclusion criteria and thus were included in the analyses reported above. Removing this person from the analysis comparing HH ($M = 36.0221$, $SD = 13.40065$) to LL ($M = 37.0663$, $SD = 13.13926$) trials changes the marginal effect to a significant effect, $t(180) = 2.124$, $p = .035$, $d = .158$.

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 low valence conditions – the average of the partial-unit span scores in the two high valence 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 working memory capacity as a predictor of the effect of valence on attention at encoding. Similarly, an estimated Bayes factor indicated that the data were 5.438 times more likely under a model that excludes working memory capacity as a predictor of the effect of arousal on attention at encoding. Thus, the primary hypothesis that working memory capacity would moderate the effect of valence but not arousal on attention at encoding was not supported in Experiment 3. Attentional capture by valenced and arousing information was further examined in the analyses on hit rates from the recognition task. If an image captured a participant's 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 high valence images ($M = .491$, $SD = .220$) were higher than the average hit rates for low valence images ($M = .417$, $SD = .211$), $F(1, 180) = 54.654$, $MSE = 0.018$, $p < .001$, partial $\eta^2 = .233$. Additionally, the average hit rates for high arousal images ($M = .472$, $SD = .215$) were higher than the average hit rates for low arousal images ($M = .436$, $SD = .222$), $F(1, 180) = 10.314$, $MSE = 0.023$, $p < .01$, partial $\eta^2 = .054$. However, there was no interaction between Valence and Arousal, $F < 1$. Working memory capacity did not interact with valence or arousal, nor did working memory capacity differentially interact with valence or arousal, Fs < 1. In the present study participants were told to ignore these images. The fact that memory was better for high valence and arousal images (compared to low valence and arousal images, respectively) supports the assertion that these images were attended to despite the goal to ignore them and focus on the to-be-remembered location in the matrix. These results indicate that both valence and arousal capture attention.

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 working memory capacity is needed to maintain task goals and suppress task-irrelevant content in attention 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 working memory capacity as a predictor of the effect of emotion on attention at encoding. 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). Kensinger and Corkin (2004) indicated that arousing emotional content affects memory encoding automatically. Failing to find an interaction between working memory capacity and emotion is consistent with research indicating high and low working memory capacity participants should not differ when automatic processing is needed (Barrett et al., 2004; Unsworth et al., 2005).

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 modified Attention Network Test. Their interpretation of the results for incongruent trials was that use of executive control suppressed the effect of emotional content on task performance (i.e., response times). Redick and Engle (2006) found that working memory capacity was related to performance on incongruent trials in the Attention Network Test. Therefore, there are two potential reasons that working memory capacity does not moderate the effect of emotional content on attention processes in the present study. The first is that Emotion only interacts with the part of the executive control attention network that can be automatically processed (i.e., no conflict). By contrast, working memory capacity only interacts with the part of the executive control attention network that is processed in a controlled manner (i.e., conflict). Thus, working memory capacity may not moderate the effect of emotion on attentional capture because emotion influences information processing at a stage not under top-down control of working memory functions.

Arguably, participants that are performing a working memory task are using executive control to perform the task (Engle & Kane, 2004). However, in the present study we still observe an effect of emotion on attention processes (counter to what would be predicted based on the findings of Cohen et al., 2011). An alternative reason that we did not observe an interaction between Emotion and working memory capacity in the present study is that the emotional images may be affecting earlier attention networks such as alerting or orienting. According to Cohen et al. (2011), alerting refers to the effect of a cue on task performance, and orienting refers to shifts of attention. In the present study, emotional content may be influencing the orienting attention network. Said differently, these images may be accompanied by a shift in attention that keeps participants from encoding the to-be-remembered stimuli.

Future research should aim to assess the interaction between emotion and working memory capacity 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 x 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 the symmetry judgments). This manipulation should primarily affect the conflict component of the executive control attention network and may yet reveal a relation between working memory capacity and the ability to suppress emotional content in favor of task goals.

The results of the present study indicate that both valence and arousal impact attention 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 working memory capacity participants (Kane & Engle, 2002) should not predict attentional capture by 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 working memory capacity. Future studies manipulating emotion during the distracting phase may allow us to study if and how emotion interacts with working memory capacity when controlled processing of emotion is required.

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Tables

Table 1

Valence and Arousal Means for Experiments 1-3

Experiment	Dimension	Image Type	Mean (SD)
1 & 2	Valence	HH	2.22 (0.56)
		LL	5.38 (0.64)
	Arousal	HH	6.35 (0.44)
		LL	3.35 (0.40)
3	Valence	HH	3.49 (0.33)
		HL	3.70 (0.55)
		LH	5.31 (0.56)
		LL	5.51 (0.24)
	Arousal	HH	5.82 (0.11)
		HL	3.98 (0.22)
		LH	5.94 (0.48)
		LL	3.91 (0.09)

Note: HH = high valence, high arousal; HL = high valence, low arousal; LH = low valence, high arousal; LL = low valence, low arousal. The same images were used for Experiment 1 and Experiment 2.

Table 2

Modified Complex Span and Recognition Task Performance as a Function of Emotion in Experiments 1-3

		Span Scores		Errors			
Experiment	Condition	Partial-Unit	Whole-List	Accuracy	Speed	Total	Hit Rate
1							
	HH	37.45 (11.12)	25.02 (13.48)	2.55 (2.08)	1.11 (3.13)	3.66 (3.70)	-
	LL	39.64 (9.418)	27.55 (12.85)	2.25 (1.93)	0.61 (0.89)	2.86 (2.06)	-
2	HH	33.04 (12.09)	20.76 (12.54)	3.44 (3.43)	1.29 (1.90)	4.73 (4.04)	-
	LL	37.89 (11.25)	25.58 (12.53)	3.17 (3.30)	1.03 (1.59)	4.19 (3.86)	-
3	HH	36.04 (13.37)	24.82 (14.44)	3.86 (3.81)	0.68 (1.34)	4.54 (4.32)	0.51 (0.24)
	HL	37.34 (13.29)	26.37 (14.53)	3.85 (4.21)	0.74 (1.09)	4.59 (4.50)	0.47 (0.24)
	LH	37.12 (13.96)	27.08 (14.85)	3.97 (4.03)	0.57 (1.04)	4.53 (4.42)	0.43 (0.23)
	LL	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). HH = high valence, high arousal; HL = high valence, low arousal; LH = low valence, high arousal; LL = low valence, low arousal.

Table 3

Complex Span Task Performance in Experiments 2 and 3

		Span Scores		Errors		
Experiment	Task	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 (0.77)	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.

Figures

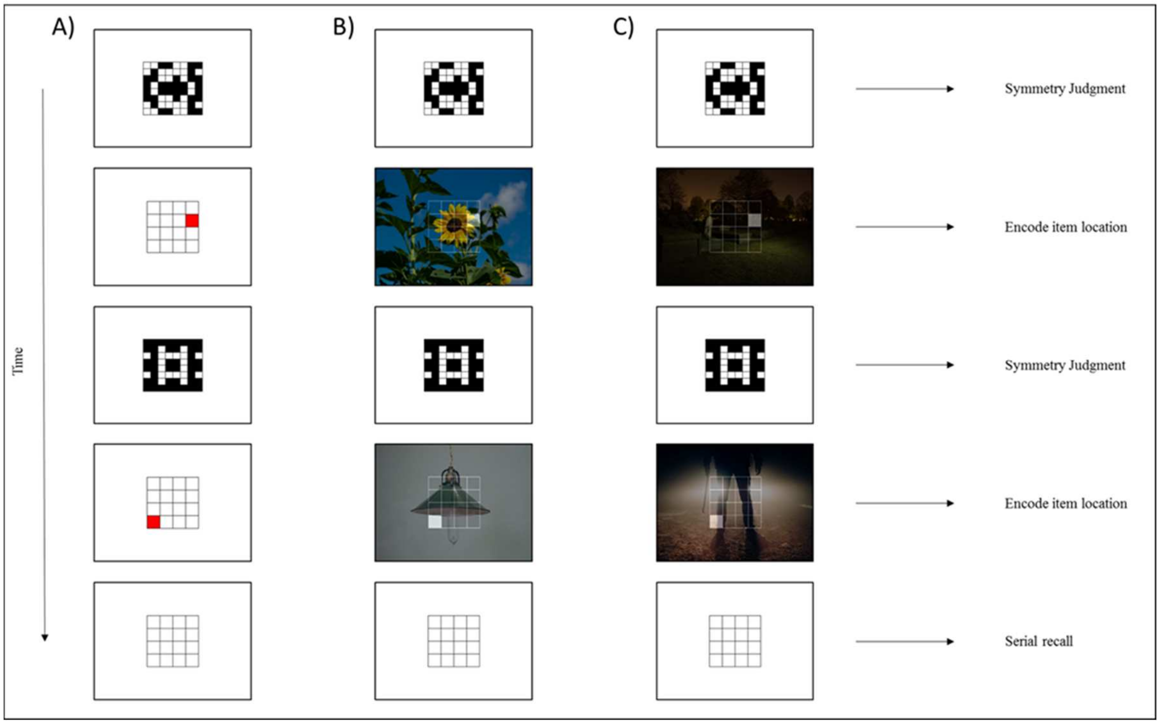

Figure 1. Sequence of events in a A) traditional, B) neutral, and C) emotional symmetry span task for a list length of two. Described in detail in the text. Photos in the figure were retrieved from https://www.pexels.com/ and are not included in the IAPS database.