Distractor devaluation requires visual working memory

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Visual stimuli seen previously as distractors in a visual search task are subsequently evaluated more negatively than those seen as targets. An attentional inhibition account for this distractor-devaluation effect posits that associative links between attentional inhibition and to-be-ignored stimuli are established during search, stored, and then later reinstated, implying that distractor devaluation may require visual working memory (WM) resources. To assess this, we measured distractor devaluation with and without a concurrent visual WM load. Participants viewed a memory array, performed a simple search task, evaluated one of the search items (or a novel item), and then viewed a memory test array. Although distractor devaluation was observed with low (and no) WM load, it was absent when WM load was increased. This result supports the notions that active association of current attentional states with stimuli requires WM and that memory for these associations plays a role in affective response.

The conventional view of selective attention is that it serves to control action by facilitating responding to task-relevant objects and inhibiting responding to task-irrelevant objects. However, in a series of recent studies, it has been suggested that selective attention may also play a role in the genesis and control of affective response (see Fenske & Raymond, 2006, for a review). Raymond, Fenske, and Tavassoli (2003) used a simple two-item visual search task to control attention during initial exposure to images and then, a few seconds later, had participants evaluate either the just previously seen target or distractor or a novel item on an affective scale. Prior distractors were rated more negatively than novel or prior targets. To explain this distractor-devaluation effect, Raymond et al. (2003) proposed that when distractors attract attentional inhibition (to ameliorate response conflict), the inhibition becomes persistently associated with to-be-ignored stimulus features. When stimuli with these features are subsequently encountered, an inhibitory state is reinstated, leading to affective devaluation (Goolsby et al., in press). Other behavioral (Fenske, Raymond, & Kunar, 2004; Raymond, Fenske, & Westoby, 2005) and electrophysiological (Kiss et al., 2007) data support the notion that distractor devaluation is specifically mediated by inhibition applied to distractors. A key component of this theoretical view is that the inhibitory attentional state becomes associated in memory with the to-be-ignored feature (Tipper, Grison, & Kessler, 2003), a process that presumably requires visual working memory (WM) resources. This view predicts that if visual WM, as a limited-capacity resource (Cowan, 2001), was loaded prior to a selective-attention task, distractor-devaluation effects should be reduced or absent.

The inhibition account of distractor devaluation can be contrasted with the notion of perceptual fluency, in which changes in evaluative responses to stimuli can be brought about by prior exposure that passively produces changes in the ease or fluency of perceptual processing (Reber, Winkielman, & Schwarz, 1998). If a reduction in perceptual fluency could account for distractor devaluation (Griffiths & Mitchell, 2007), carrying a concurrent visual WM load should either enhance or have no effect on distractor-devaluation effects, because fluency alterations (at least enhancements) are typically larger when participants are unaware of prior exposure (Bornstein & D'Agostino, 1992, 1994).

To test the role of WM in distractor devaluation, we sandwiched the search-then-evaluate procedure of Raymond et al. (2003) between the study and test phases of a simple visual WM task. (See Figure 1A.) The number of items presented for study (load) was varied, and the effect of this manipulation on distractor devaluation was assessed. At the beginning of each trial, participants were shown a WM study array, and at the very end of the trial, they were shown the array either as it was or with one item changed. The WM task was to judge whether the two arrays were the same or different. During the WM retention interval, participants performed a search-then-evaluate task sequence. In Experiments 1 and 2, the WM items were faces and houses, respectively. In both experiments, the search-then-evaluate sequence involved faces (as in Goolsby et al., in press). We predicted that in conditions with no WM load, faces seen as distractors in the search task would later be rated as less trustworthy than faces encountered as targets (a conventional distractor-

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Figure 1. (A) The main elements of a sample trial from Experiment 1 with a working memory (WM) load of two. Fixation displays (not shown) were blank white screens with a single fixation cross at the center. Each trial had the following sequence: a 1,000-msec fixation display; a 2,000-msec WM study array; a 1,000-msec fixation display; a 200-msec search array; a fixation display that remained visible until response, whereupon the cross was replaced by a question mark, and the otherwise empty screen remained for a further 1,130 msec; the evaluate display; a fixation display for 500 msec; the words “Rate Now” for 3,000 msec; and, finally, the WM test array (displayed until response). The search display contained two grayscale faces, one of each gender with a blue or yellow tint. The participants indicated the color of the face with the target gender in response to the search display. The evaluation display contained a single grayscale face, and the participants rated this face for trustworthiness using a 5-point scale during the interval in which the “Rate Now” display was available. The response to the WM test array was whether it was the same as or different from the WM study array. (B) Examples of the main display elements used for the WM load-1 and load-0 conditions of Experiment 1. RT, response time.

devaluation effect). When visual WM was loaded (with either face or house images), we predicted, on the basis of the associated-inhibition account of distractor devaluation, that differences in ratings between targets and distractors would diminish or disappear.

METHOD

Participants

In exchange for course credit or money, 34 adults (19 female, mean age = 26.1 years) participated in Experiment 1; another 37 adults (26 female, mean age = 24.3 years) took part in Experiment 2. All were recruited through Bangor University and gave informed consent.

Apparatus and Stimuli

A Pentium IV computer with a 33-cm color monitor (100 Hz, 1,024 × 768 pixel resolution) running E-Prime 1.1 software (Schneider, Eschman, & Zuccolotto, 2002) was used. Participants viewed the display at a distance of approximately 75 cm in a quiet, dimly lit room.

The stimuli used in the WM task in Experiment 1 were 24 face images (Ekman & Friesen, 1976; 50% female) with neutral expressions and visible hair (see Figure 1B). In Experiment 2, these stimuli were replaced by 12 grayscale house images. Two items (4.1° × 6.0° of visual angle each), positioned 2.7° to the left and right of fixation, comprised each WM study and test array. Set-appropriate scrambled images (created by dividing images from each set into a 20 × 20 grid and randomly reconfiguring the panels) served as placeholders when WM load was less than two (see Figure 1B). The number of

faces/houses and their locations remained unchanged between the study and test phases.

The stimuli in the search-then-evaluate sequence were 336 (50% female; an additional 40 were presented during practice trials) computer-generated faces (GenHead 1.2; Genemation, Inc.) made using a prototype face with a randomness setting of 6.5, an age setting of 20s and 30s, and an ethnicity setting of Caucasian. All had a neutral expression and were viewed frontally with neither teeth nor hair visible. Image processing produced grayscale faces (150 × 150 pixels) with a transparent yellow (hue = 40, saturation = 75) or blue (hue = 140, saturation = 75) tint on a square black frame (3.1 deg²). Each face was used in one trial only. For the search task, 2 tinted faces were presented 2.1° to the left and right of a central fixation cross; for evaluation, a single untinted face was presented centrally. A uniform white background field was used in both cases.

Procedure

Each trial consisted of three main tasks: WM, visual search, and evaluation. The sequence of events is shown in Figure 1A. The WM display, to be memorized by the participant, was 2,000 msec in duration (ample for encoding two faces; Jackson & Raymond, 2008) and was followed by an uneventful 1,000-msec retention period. Next, a search display, composed of one male and one female face, each tinted blue or yellow, was briefly (200 msec) presented; the participant's task was to report the color of the face with the prespecified target gender as quickly as possible (by depressing either the “k” or “l” key on the keyboard). A single grayscale face (prior target, prior distractor, or a novel face) was presented 1,130 msec after this response (for 300 msec) for evaluation. This involved rating (unspeeded) the face for trustworthiness using a 5-point scale (5 meaning *very trustworthy*, 1 meaning *not at all trustworthy*) via the number keys. Rating

responses were not permitted during stimulus presentation nor during a 500-msec wait interval imposed after stimulus offset. This was used to provide sufficient opportunity to decide on a scale value. The words "Rate Now" were presented (for 3,000 msec) to indicate when a rate response would be accepted. Immediately after rating, a WM test array appeared. The participants indicated (unspeeded) whether this display was the same (no-change trials) or different (change trials) from the study array seen at the beginning of the trial (using either the "p" or "o" key). (The mean retention interval was 6,200 msec.) In addition to the WM, search, and evaluate tasks, the participants were required to repeat the days of the week aloud throughout the trial (until the WM test) to minimize the possibility of verbal WM supporting visual WM (Besner, Davies, & Daniels, 1981). All of the participants complied with this minimal verbal-suppression task on every trial, as monitored by the experimenter. The session began with instructions and a practice block of 16 trials. Four blocks of 36 trials each were then completed.

Experimental Design

Within each block, a third of the trials tested each WM load (0, 1, or 2); half of the trials for each load condition were change trials (the side of the change was counterbalanced) and half were no-change trials. Half of the participants searched for male targets in the first two blocks and for female targets in the last two blocks; the remainder used the reverse order. Targets appeared to the left or right and were colored blue or yellow with equal frequency. Different color tints were presented in the search arrays on two thirds of the trials in each combination of WM load and change condition (change or no change); on the remaining (match) trials, both items were tinted similarly. Match trials were used to ensure that attention was directed at both items on mismatch trials (and to prevent a strategy of examining only one item in the display). However, because the location of attention could not be inferred on these trials, they were always followed by evaluation of novel stimuli (i.e., stimuli not presented in the search task). (See Goolsby et al., in press, for a detailed discussion of this procedural issue.) For each WM condition, the evaluation face was equally likely to be the target from the preceding search array, the preceding distractor, or a novel face. Novel faces were equally likely to be matched in gender to the preceding target or distractor. This design yielded 32 trials for each combination of WM load and previously seen item evaluation condition (16 each for prior target and distractor) and 16 trials for each WM load and novel item evaluation condition (8 male, 8 female).

Data Analysis

The logic of the experiment required the participant's visual WM to be demonstrably taxed by the WM load manipulation. However, 5 participants in Experiment 1 and 3 in Experiment 2 showed near-perfect (greater than 95% correct) WM performance at the maximum WM load (2), indicating a WM capacity of greater than two faces. Since they very likely had WM capacity remaining even at this load, making interpretation of the presence versus absence of distractor-devaluation effects meaningless within the context of the present experiments, we excluded their data from further analysis. We analyzed rating and response time (RT) data only on trials in which both WM and search task responses were correct, when the rating response was made within the required response window, and when the search RT fell within 4 SDs of the condition mean calculated for each participant. This excluded more than 40% of the trials for 1 participant in Experiment 1 and for 4 participants in Experiment 2, so their data were not analyzed further. For Experiment 1 (28 participants remaining), 22% of trials were excluded on average (58% for search response errors, 38% for WM errors, and 4% for rating RT errors). For Experiment 2 (30 participants remaining), 21% of trials were excluded (42% for search response errors, 55% for WM errors, and 3% for rating RT errors). Repeated measures ANOVAs were conducted on mean ratings of evaluation stimuli using attention (target or distractor), exposure (prior search images or new), and WM load (0, 1, or 2) as factors. Alpha levels were set to .05.

Table 1
Mean Reaction Time (RT, in Milliseconds) and Accuracy Rates (%) for Each Working Memory Load Condition in the Attention Task in Experiments 1 (Faces) and 2 (Houses)

Condition	RT		Accuracy	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Experiment 1				
Load 0	1,306	47	88.6	0.02
Load 1	1,314	50	85.0	0.02
Load 2	1,318	45	88.6	0.01
Experiment 2				
Load 0	1,296	44	89.2	0.01
Load 1	1,232	39	90.2	0.02
Load 2	1,221	34	86.3	0.01

RESULTS AND DISCUSSION

Experiment 1

WM task. Change-detection accuracy was significantly reduced by increasing WM load from one ($M = 93\%$) to two ($M = 82\%$) faces [$t(27) = 69.4, p < .001$].

Attention task. Although RT was not significantly affected by WM load [$F(2,54) = 0.245, p > .20, \eta_p^2 = .01$], a marginally significant but nonsystematic effect on accuracy was observed [$F(2,54) = 3.04, p = .06, \eta_p^2 = .107$]. Table 1 shows mean RT and accuracy for each WM load condition.

Evaluation task. Figure 2 plots the mean trustworthiness ratings for evaluation stimuli obtained under each WM load (0, 1, or 2), separately for when they matched the target or distractor gender and for when they were just previously seen images or novel faces. As expected, faces with the distractor gender were rated more negatively than were those with the target gender [$F(1,27) = 5.587, p < .05, \eta_p^2 = .171$], reflecting the presence of a distractor-devaluation effect (i.e., the difference between the mean rating for faces with the target gender and those with the to-be-ignored gender).

Figure 2. Mean trustworthiness ratings in Experiment 1 as a function of load, search relevance, and prior exposure. Error bars represent within-subjects standard errors of the means.

Our primary question concerned whether WM load modulates distractor devaluation. Unsurprisingly, the main effect of WM load on ratings was nonsignificant ($F < 1$), indicating that increasing load of the WM task did not, for example, bias participants to generally lower their ratings. However, consistent with our prediction that WM load might diminish distractor-devaluation effects, we observed a significant three-way interaction of load, exposure, and attention [$F(2,54) = 4.129, p < .05, \eta_p^2 = .133$]. With no concurrent memory load, planned comparisons confirmed a large and significant distractor-devaluation effect for just previously seen items [distractor devaluation = 0.23; $t(27) = 3.04, p < .01$] and for novel items [distractor devaluation = 0.18; $t(27) = 2.30, p < .05$]. The latter effect reflects the generalization of distractor devaluation found when categories are used to define the search target (Goolsby et al., in press; Raymond et al., 2003). All other comparisons of ratings for faces with target versus distractor gender for load 1 and load 2 were nonsignificant, indicating that the distractor-devaluation effect is abolished with a concurrent WM load. These findings support the supposition that visual WM resources are necessary if the association of attentional inhibition with the to-be-ignored feature is to have a persistent effect on evaluative responses.

However, it is possible that when WM was loaded, participants ceased to carefully consider face evaluations and arbitrarily chose rating values. If such a strategy were adopted, we should expect faster rating RTs and small *SD*s for each individual's rating responses. However, no evidence for this was found. An ANOVA of rating RT showed no main effect of WM load [$F(2,54) = 2.043, p > .10, \eta_p^2 = .70$] or attention [$F(2,54) = 1.496, p > .10, \eta_p^2 = .52$], nor their interaction [$F(4,108) = 1.380, p > .10, \eta_p^2 = .49$]. A similar ANOVA on the *SD* of each participant's rating response also showed nonsignificant main effects ($F < 1$, both cases) and a nonsignificant interaction [$F(2,540) = 1.212, p > .10, \eta_p^2 = .04$].

In this experiment, the items to be stored in visual WM (faces) were highly similar to those appearing in the selection and evaluation task (also faces). Perhaps this similarity led to abolition of the distractor-devaluation effect because of anchoring or biasing of face evaluations by the memory set faces. To replicate the results and test the robustness of WM effects on distractor devaluation, we repeated Experiment 1, this time using images of houses in the visual WM task.

Experiment 2

The method and procedure were the same as those used in Experiment 1 in all respects, except that images of houses were used instead of faces in the WM task.

WM task. Change-detection accuracy was significantly reduced by increasing WM load from one ($M = 87\%$) to two ($M = 77\%$) houses [$t(29) = 6.36, p < .001$] and was not different from that measured in Experiment 1 ($F < 1$).

Attention task. Table 1 shows mean RT and accuracy for each WM load condition. Mean RT decreased with

Figure 3. Mean trustworthiness ratings in Experiment 2 as a function of load, search relevance, and exposure. Error bars represent within-subjects standard errors of the means.

WM load [$F(2,58) = 11.99, p < .001, \eta_p^2 = .224$], but mean accuracy also decreased significantly [$F(2,58) = 4.41, p < .05, \eta_p^2 = .132$], indicating a speed-accuracy trade-off. Although this pattern of results suggests that loading WM with house images had the general effect of making the search task more effortful, the speed-accuracy trade-off makes it difficult to quantify.

Evaluation task. Figure 3 plots the mean trustworthiness ratings for evaluation stimuli obtained under each WM load, separately for when they matched the prior target or distractor in gender and for when they had or had not been previously seen. The results of Experiment 2 replicated those of Experiment 1: Faces with the to-be-ignored gender were rated more negatively than those with the target gender [$F(1,29) = 10.187, p < .01, \eta_p^2 = .260$], indicating a distractor-devaluation effect.

As in Experiment 1, the main effect of WM load on face ratings was nonsignificant ($F < 1$). Although the three-way interaction of attention, WM, and exposure was nonsignificant ($F < 1$), planned comparisons showed that WM determined whether distractor-devaluation effects were present or absent. For load 0, distractor devaluation was evident for both previously seen [$t(29) = 2.69, p < .05$] and novel [$t(29) = 2.31, p < .05$] items. For load 1, a significant distractor-devaluation effect was evident only for previously seen items [$t(29) = 4.24, p < .001$]. All other comparisons of ratings for faces matched to the target versus distractor gender were nonsignificant ($p > .2$), replicating the general pattern of results found in Experiment 1. A mixed-design ANOVA, using experiment as a between-groups factor and attention (target or distractor), exposure, and WM load as within-subjects factors, showed that both the main effect of experiment and all interactions with it were nonsignificant ($F < 1$).

Analyses of rating RT and *SD* (paralleling those described in Experiment 1) showed that increasing WM load or manipulating attention had nonsignificant effects (all F s < 1).

GENERAL DISCUSSION

In two experiments measuring social-emotional evaluation of faces, we found robust devaluation of stimuli sharing a feature that had just been ignored in a previous search task, thus replicating prior reports using similar stimuli (Goolsby et al., in press; Kiss et al., 2007). Our goal in the present study was to determine whether this distractor-devaluation effect would be dependent on visual WM. To this end, we manipulated concurrent visual WM load and found that maintaining one face or two house images in visual WM was sufficient to eliminate distractor devaluation.

The attentional-inhibition theory of distractor devaluation posits that during visual search, attentional inhibition becomes associated with the task-defined, to-be-ignored feature present in the distractor, so that when this feature is subsequently encountered in an evaluation item, an inhibitory state is reinstated and applied to the evaluation task, thus leading to devaluation (Fenske & Raymond, 2006; Raymond et al., 2003). This notion suggests a dependency on the engagement of active associative processes that presumably involve WM (Baddeley, 2000). Our observation that distractor devaluation is eliminated when search is conducted with a concurrent visual WM load supports this idea. Insufficient WM resources could have interfered with associating inhibition with the to-be-ignored feature during search or with accessing this association during evaluation. An additional experiment in which the evaluation task was delayed until WM was emptied (after the test array) would be needed to distinguish these possibilities.

An alternate explanation for distractor devaluation (Griffiths & Mitchell, 2007) is based on a theory of perceptual fluency (Reber et al., 1998). Although fluency theory was derived to account for reports of up-valuations resulting from prior exposure (i.e., the mere-exposure effect; Zajonc, 2001), it could account for distractor-devaluation effects if the visual search task in our study somehow induced an unexpected lack of fluency for distractor or distractor-like stimuli (Griffiths & Mitchell, 2007). Although the mechanism by which this could be achieved is not obvious (inhibition being a candidate mechanism), fluency theories are clear in proposing that passive perceptual processes mediate alterations in evaluation. An important characteristic of mere-exposure effects is that they are greater when prior exposure is passive, subliminal (Kunst-Wilson & Zajonc, 1980), or not explicitly recalled (see Bornstein, 1989, for a review). In fact, explicit recall often abolishes mere-exposure effects (Bornstein & D'Agostino, 1992, 1994). These findings underpin the notion that fluency effects are passively induced and do not involve active associative memory processes. Our finding that distractor devaluation is eliminated when a concurrent visual WM load is being carried is clearly inconsistent with a fluency account of distractor devaluation.

Note that although visual WM load reduced the effect of attention on subsequent trustworthiness ratings, it did not impair performance on the selective-attention task. This finding is consistent with a previous report by Wood-

man, Vogel, and Luck (2001), who reported that maintaining objects in visual WM did not reduce search efficiency, but contrasts with other studies reporting reduced search efficiency and overall longer RTs with concurrent visual WM loads (Oh & Kim, 2004; Woodman & Luck, 2004). However, the latter studies had a spatial component to their WM tasks, a factor lacking in ours, which may account for the discrepancy in results. The lack of any observable effect of concurrent WM load on search performance in our task argues against the notion that processes mediating search, per se, such as distractor inhibition, were being modulated by the WM task. Rather, the present findings suggest that either maintenance of inhibition codes or active association of these codes with representation of the task-defined distracting feature was disrupted when visual WM load was high. Our observation that the categorical content of the images being held in visual WM (faces or houses) had little effect on the consequences of carrying a WM load for distractor devaluation further supports the idea that general WM resources are needed to support the genesis of affective responses that result from prior ignoring.

AUTHOR NOTE

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