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"Hot" Facilitation of "Cool" Processing: Emotional Distraction Can Enhance Priming of Visual Search

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Emotional stimuli often capture attention and disrupt effortful cognitive processing. However, cognitive processes vary in the degree to which they require effort. We investigated the impact of emotional pictures on visual search and on automatic priming of search. Observers performed visual search after task-irrelevant neutral or emotionally evocative photographs. Search performance was generally impaired after emotional pictures, but improvement (measured both with inverse efficiency and sensitivity to briefly presented targets) as a function of incremental between-trial target-color repetition was strongest after emotional pictures. For observers showing the largest general effect of emotional pictures, there was a reversal, with performance becoming better after neutral pictures than after four or more trials containing the same search target. This suggests that although emotional pictures disrupt effortful attention, this detriment can be overcome—to the point where performance is enhanced by emotional stimuli—when the task involves prepotent task priorities.

Keywords: priming of pop-out, attention, emotional blink, dual task, attentional rubbernecking

Interactions between cognition and emotion have sometimes been characterized as an interplay between "cool" executive and "hot" affective processes, which sometimes—although not always—work in opposition (e.g., Flykt, 2006; Metcalfe & Mischel, 1999). There have been suggestions in the literature that emotion can facilitate cognition and perception (e.g., Becker, 2009; Bocanegra & Zeelenberg, 2009; Gray, 2004; Phelps, Ling, & Carrasco, 2006; Mather & Sutherland, 2011), but many studies have shown that processing of emotional information disrupts the maintenance and manipulation of spatiotemporal and episodic representations (e.g., Dolcos & McCarthy, 2006; Johnson et al., 2006; Metcalfe & Mischel, 1999; Most et al., 2005). For example, in an experiment demonstrating the deleterious effects of emotional distraction on working memory, participants viewed three simultaneously presented faces on each trial, which they then tried to keep in mind during a retention interval. After each retention interval, a probe face appeared, and participants reported whether it had been part of the initial set of three faces (Dolcos & McCarthy, 2006). Critically, if task-irrelevant emotional pictures briefly appeared during the retention interval, working memory performance was worse than if emotionally neutral pictures appeared, and this was accompanied by decreases in BOLD activity in neural regions involved with working memory.

Such studies could suggest that emotional distraction uniformly interferes with short-term memory (STM) for nonemotional information. However, not all forms of STM demand equal levels of effortful processing. Indeed, some forms of STM, such as priming of visual search (often referred to as "priming of pop-out"), operate relatively automatically (e.g., Maljkovic & Nakayama, 1994; see Kristjánsson, 2008, for review) and play a vital role in visual exploration (Brascamp, Blake, & Kristjánsson, 2011). When participants search for a target that contains a unique—but response-independent—feature on each trial, performance is faster and more accurate if the same target feature or target position is repeated from one trial to the next (Geyer et al., 2006; Kristjánsson et al., 2005; Kristjánsson, Ingvarsdóttir & Teitsdóttir, 2008; Maljkovic & Nakayama, 1994, 1996; Sigurdardottir et al., 2008). What is notable about such priming is that it is not under voluntary control. Participants show such priming effects no matter what their intentions are (Maljkovic & Nakayama, 1994; Kristjánsson & Nakayama, 2003), and it has been shown to reflect the simultaneous, but distinct, operation of both short-lived and long-lasting implicit memory traces (Brascamp, Pels & Kristjánsson, 2011; Martini, 2010).

Priming of visual search thus provides an informative means for increased understanding of the nature of emotion's impact on "cold" cognitive processing. If emotional distraction interferes generally with the short-term retention of visual information, then the presentation of task-irrelevant emotional pictures between trials should reduce priming. But emotional distraction may disrupt only the effortful retention of visual information, in which case priming should remain robust despite the presentation of emotional distractors. A third, intriguing possibility is that—in contrast to their disruptive impact on ongoing effortful processes—emotional distractors might facilitate more reflexive operations, leading to an

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enhancement of priming. The latter possibility would be consistent with suggestions that emotion serves to shift the balance between cognitive functions (e.g., Gray, 2004), in this case shifting priority to automatic, prepotent functions over effortful ones. Priming of visual search has, indeed, been thought to reflect a relatively low-level perceptual facilitation (Ásgeirsson & Kristjánsson, 2011; Becker & Horstmann, 2009; Kristjánsson, 2006; Maljkovic & Nakayama, 1994).

In the following experiments we combined visual search tasks with interleaved presentation of emotional and neutral distractors to investigate the impact of emotional distraction on an automatic variant of STM.

General Method

All three experiments involved presentations of picture distractors between trials of visual search. In Experiments 1 and 2, participants searched for a uniquely colored target diamond among 2 distractors of another color (e.g., red vs. green), and then performed a discrimination judgment on the target, a task introduced by Bravo and Nakayama (1992) and used by others since to study priming of visual search (e.g., Maljkovic & Nakayama, 1994; see Kristjánsson, 2008, for review). In Experiment 3, participants searched for a square of odd size and color (a "conjunction" search) and judged whether a smaller square within it was shifted up, down, left, or right relative to the middle of the larger square. Further details will be introduced in the methods sections for each respective experiment.

Between consecutive search trials, a single photograph—either a neutral picture, emotionally evocative picture, or an inverted version of one of the neutral pictures (in Experiments 1 and 2)—appeared, requiring no response from the participant. The inverted neutral pictures appeared with the same frequency as emotional pictures and were included to control for the fact that the upright neutral and emotional pictures themselves differed in how frequently they appeared (emotional picture presentations were limited to avoid habituation, with the frequent neutral pictures constituting a baseline against which emotion effects were measured). Pictures were drawn mostly from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2001), a database of images rated for their emotionality, and were supplemented by similar pictures culled from publicly available sources. The images included 58 neutral and 58 emotional color pictures that portrayed people or animals, with the negative set including depictions of violence, distress, and medical trauma; using nine-point scales, a separate group of six men and six women had rated the negative pictures as more unpleasant and emotionally arousing than the neutral pictures (ps $< .001$).[1]

Experiment 1

The first experiment involved search for an odd-colored diamond among distractor diamonds of another color. After each search trial, a photograph appeared that was emotionally neutral five of seven times, emotionally evocative one of seven times, and an inverted neutral picture one of seven times.

Method

Observers. Twenty observers (14 females, six males) participated in 407 trials each. All had normal, or corrected to normal, vision.

Equipment. The experimental display was programmed in C using 16-bit graphics mode to accurately display the full-color images in high color resolution and was presented on a 75-Hz CRT display controlled by a 400-MHz G4 Apple computer.

Stimuli and procedure. Each trial started with the presentation of a white (56.6 cdm^{-2}) fixation cross for 1200–1700 ms (randomly determined) on a dark background (0.5 cdm^{-2}). A picture followed, presented for 1175 ms, and after a brief (78 ms) blank screen a search display was presented that contained three diamond shapes (each sized 2.0° by 2.0°, at 5.71° from screen center; see Figure 1A) on the same dark background. Note that before the first trial, no picture was presented, so 406 trials were analyzed for each observer. Participants searched for the oddly colored diamond, either a red (12 cdm^{-2}) target among two green distractors (25 cdm^{-2}) or a green target among two red distractors. Target color varied randomly across trials and was not known ahead of time by the participants. Participants indicated via key press whether the singleton diamond had a notch at the top or the bottom (see Kristjánsson, Sigurjónsdóttir & Driver, 2010). Viewing distance was 60 cm. A chin rest was used to ensure stable fixation and constant viewing distance.

Response times were recorded separately for the first and second consecutive presentations of a particular target color and then pooled over third or higher consecutive presentations of the same target color (there were relatively few trials with more than two trials of the same target color preceding it) and plotted as a function of the type of picture that had preceded the last of the consecutive trials. To provide a measure that incorporated effects both upon speed and accuracy, we calculated inverse efficiency (each participant's mean response time divided by their proportion correct responses), a standard method for combining response times and error rates into a single meaningful index (see Townsend & Ashby, 1983).

Note that repetition is independent of picture type in the analysis, so if target color repetition on a given trial (n) is, say, 3 and the picture type is neutral, the picture type on trial $n - 1$ could be any of the three picture types. The paucity of trials that followed emotional or inverted distractors prevented analyses of the effects of sequences of consecutive trials separately for emotional or inverted pictures.

Results

Figure 1B shows inverse efficiency (reaction time (RT)/proportion correct) as a function of picture type and repetition. Table 1 shows the RTs and proportion correct. A 3-by-3 ANOVA revealed a large main effect of picture type, in that inverse efficiency was lower after emotional pictures than after upright or inverted neutral ones, $F(2, 38) = 27.1$, $p < .001$. This effect upon search after emotional stimuli is not unexpected given previous

[1] The neutral set included one IAPS picture that had not been rated by these 12 participants. However, within the IAPS, this picture was rated as emotionally neutral ($M = 4.87$) and of low arousal ($M = 2.93$).

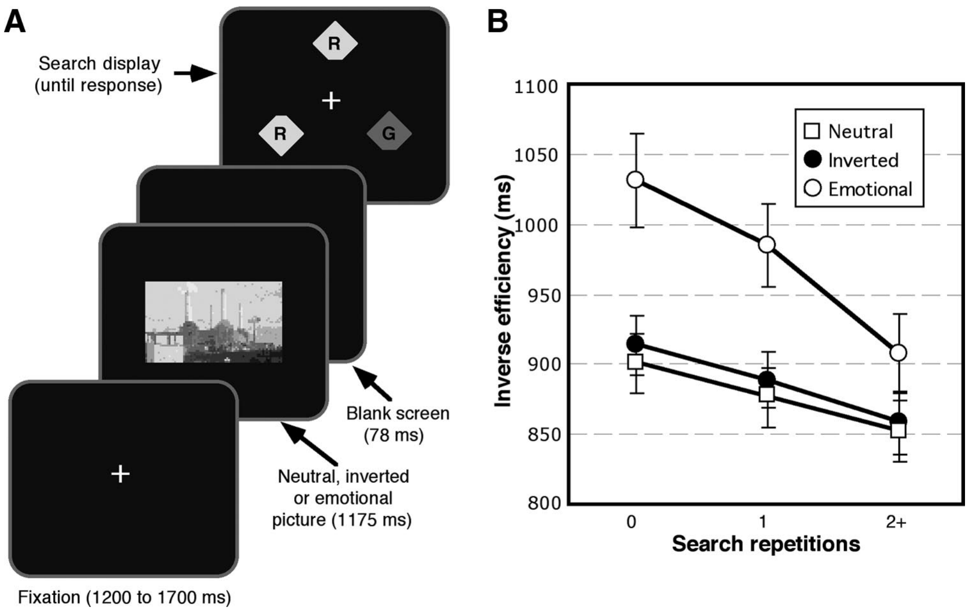

Figure 1. The design and results of Experiment 1. A shows the task in Experiment 1. Observers passively viewed a picture (neutral, inverted or emotional), which was followed by a search display (with a 78-ms blank screen in between). Their task was to locate the oddly colored diamond and judge whether there was a notch at its top or bottom. B shows the results plotted as inverse efficiency (RT/proportion correct, see text, indicated on the ordinate) as a function of picture type (separate lines) and repetition of the same search task (target and distractor color), 0, 1, or 2 or more times (denoted on the abscissa).

findings that emotional stimuli tend to disrupt ongoing perceptual and cognitive processing (Dolcos & McCarthy, 2006; Most et al., 2006; Most & Wang, 2011; Smith et al., 2006). There was also a strong main effect of repetition of search type, $F(2, 38) = 48.5$, $p < .001$, as expected from previous results (Maljkovic & Nakayama. 1994; Lamy et al., 2010; Goolsby & Suzuki, 2001; Kristjánsson et al., 2008), where inverse efficiency increased upon repetitions of target properties. The novel and most interesting finding is the significant interaction between picture type and repetition of search, $F(4, 76) = 6.48$, $p < .001$, which indicates that the repetition effect varies depending on the type of picture that preceded the last consecutive visual search trial. As the graph shows, the priming effect is significantly larger after the emotional pictures.

What this indicates is that the more often the same search repeats, the more easily observers "override" the disruptive effect of the emotional pictures upon the search. This may be because the emotional pictures facilitate well-practiced or prepotent attentional priorities. In other words, after emotional stimuli, the prepotent prioritization dominates, in this case facilitating a search in which the target characteristics are the same as on the previous trial. The flipside of this is, of course, that when the colors switch (0 on the abscissa in Figure 1B) performance is particularly inefficient after presentation of emotion inducing pictures. Note that the presence or absence of an emotion effect doesn't wholly depend on whether the trial involves a task set reconfiguration, as the emotion-induced disruption is still present when the target properties have undergone a single repetition (*t* tests between effects of emotional pictures and effects of neutral or inverted pictures, *p*s $< .01$). Instead, whereas emotional pictures disrupt a search that involves the reconfiguration of a task set, their impact diminishes as the task set configuration stabilizes. There was no hint of any speed–accuracy trade-offs in the error data (see Table 1) which are additionally guarded against via the inverse efficiency measure.

Experiment 2

Experiment 2 was motivated by a pilot experiment in which we observed large effects of emotional pictures on search performance as measured with d', indicating lowered sensitivity to search

Table 1
Mean Response Time (RT) and Error Rates (in Percentages) From Experiment 1 as a Function of Picture Type and Search Repetition

	Neutral			Inverted			Emotional		
	0	1	2+	0	1	2+	0	1	2+
RT	868.1	840.3	818.6	876.0	858.9	829.1	996.1	948.1	875.5
Error rate (%)	3.6	4.2	3.9	4.0	3.4	3.3	3.3	3.8	3.5

targets after emotion-inducing stimuli. If the emotional effect is stronger upon briefly presented displays, any consequences upon priming might become even more prominent. In Experiment 2 we assessed whether emotional pictures reduce sensitivity in a visual search task and whether such reductions can be overcome via repetitions of target properties. The use of brief displays was also incorporated to help eliminate concerns about speed/accuracy trade-offs, as d' constitutes a response-bias free measure. Although there was no hint of such trade-offs in Experiment 1, the power to detect such trade-offs in that experiment was limited, as accuracy levels were very high. Importantly, Sigurdardottir, Kristjánsson, and Driver (2008) and Lamy and Yashar (2010) have reported strong priming of visual search for brief displays.

Method

Observers. Ten observers (six female, aged 22 to 53, mean age 27 years) participated.

Stimuli and procedure. As in Experiment 1, participants engaged in feature search (an odd-diamond-out task) and judged whether the cut-off on the odd-one-out diamond was at top or bottom. The display was presented for 450 ms, followed by a multicolor random-dot mask (dot size = 13 arc min). Pilot tests had indicated that 450-ms presentations resulted in acceptable accuracy levels for the application of signal detection theory measures. As in Experiment 1, neutral, inverted, and emotional pictures were presented in between each of the search trials using the same frequency ratios (5/7, 1/7, 1/7, respectively). We measured d'_{FC}, a version of d' for forced choice experiments, which takes into account the presence of more bits of information in a 2AFC experiment than is typically present in a simple detection experiment (see, e.g., Wickens, 2002).[2] To increase the number of longer "streaks" of repetition of the same search, the likelihood of target repetition was set by the function $100 - (20 * \sqrt{N})$ where N denotes the number of previous presentations of the same target color. If the target color on trial N was green, the likelihood of the target being green on trial $N+1$ was 80%, on trial $N+2$ the likelihood of a green target was 71.7% and so on, such that the likelihood of target color repetition decreased by a negative square root law. By $N = 7$, this likelihood was less than 50%. For the first trial in each block the probability was 50% for each color. Similar procedures have in previous experiments not influenced priming patterns while increasing the efficiency of the data collection (see, e.g., Kristjánsson & Nakayama, 2003). The observers participated in 407 trials each as in Experiment 1, with the first trial not preceded by a picture. In other respects, methods were similar to Experiment 1.

Results

The results from Experiment 2 are shown in Figure 2B.[3] As in Experiment 1, performance was generally worse after presentation of emotional pictures. Increased repetition of the same search task improved performance overall, and this improvement was greater after the presentation of emotional pictures relative to neutral or inverted pictures.

This was confirmed with a 3 (picture type) by 4 (repetition) repeated-measures ANOVA on the d'_{FC} scores, which revealed a main effect of picture type, $F(2, 18) = 3.5$, $p = .051$, a main effect of repetition, $F(3, 27) = 18.2$, $p < .001$, and a strong interaction between the two factors, $F(6, 54) = 4.47$, $p = .001$, suggesting that the effect of repetition varies depending upon the picture type. As in Experiment 1, this interaction was driven by the steep slope in the emotional-picture condition. The pictures with emotional content not only affected RT and accuracy but also target sensitivity. Furthermore, sensitivity was most heavily modulated by repetition after the emotional pictures, a pattern that converges with Experiment 1 to suggest that emotional distraction leads to stronger reliance on the participant's previously established attentional priorities (i.e., from the preceding search trials).

Experiment 3

One striking detail of the data from Experiment 2 was that when the same target feature was repeated four or more times consecutively, performance after emotional pictures not only became equivalent to performance following neutral pictures but also showed a trend toward enhanced performance. This trend did not reach significance, but the number of repetitions may simply have been too low to achieve strong prepotency of search priorities. With enough repetitions, the two functions might "cross-over," with participants becoming faster and more accurate after emotional relative to neutral pictures. With Experiment 3 we address this possibility by combining a higher number of consecutive repetitions with a more difficult search task, which has previously been shown to result in strong priming effects (Wang, Kristjánsson & Nakayama, 2005).

We had two main aims with Experiment 3. First, we aimed to replicate the interaction between priming and distractor emotionality with a conjunction search, which is typically more difficult than the feature search tasks used in Experiments 1 and 2. Such tasks have previously been shown to elicit particularly strong priming effects (Kristjánsson, Wang & Nakayama, 2002; Wang et al., 2005). Second, we tested the a priori prediction that performance after emotional pictures would gradually improve to the point where it *surpassed* performance after neutral pictures. Whether such a pattern emerges would be key to understanding the results from the first two experiments, which so far can only be interpreted as diminished interference from emotional pictures with increased repetitions rather than facilitation of automatic processing. Based on previous findings of strong priming effects in a comparable task, participants were required to search for a square characterized by a unique conjunction of color (red vs. green) and size (small vs. large; Wang et al., 2005, Experiment 4). These previous findings had revealed priming effects as large as 400–500 ms within about six search repetitions, thereby providing substan-

[2] d'_{FC} denotes the difference between two distributions (in this case of response to each possibility: notch at top or bottom) as with the more traditional d'. It is, of course, arbitrary in this case which distribution is considered to be "signal" and which one "noise" but d'_{FC} measures essentially the psychophysical distance between perception of notch at top or bottom. Note that $d'_{FC} = 2Z(p_c)$, so that $d'_{FC} = (\sqrt{2})^{*}d'$, where p_c denotes the proportion correct.

[3] An ANOVA confirmed that there was no difference between proportions of leftwards and rightwards responses as a function of picture type or repetition; neither was there an interaction (all ps $> .6$).

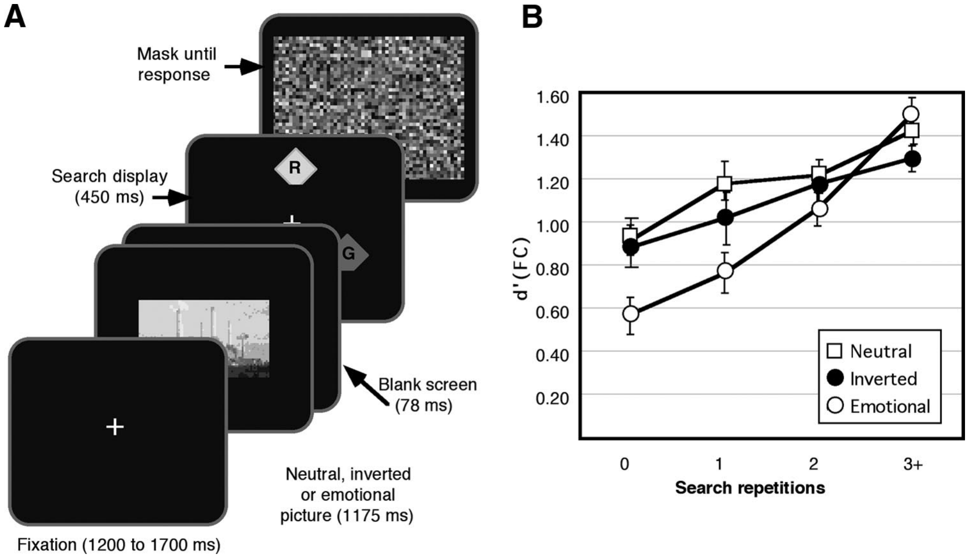

Figure 2. The design and results of Experiment 2. A shows the task, where participants had to indicate the location of a notch on the odd-colored diamond (now presented for 450 ms, and masked). B shows performance in d'_{FC} for the three different picture types (separate lines) and as a function of repetition of the same search (on abscissa).

tial potential for uncovering a repetition-driven crossover of performance after emotional versus neutral pictures.

Method

Observers. Twelve new naïve observers (eight female) participated in 1160 trials in four blocks of 290 trials.

Stimuli and procedure. In contrast to the task used by Wang et al. (2005), participants' responses did not involve a present/absent judgment, which would eliminate the usefulness of half of the trials. Instead, participants judged whether a small square contained within the target square was positioned left, right, above, or below the center of the target square (see Figure 3A). To increase power, we used fewer neutral picture trials than in Experiments 1 and 2 (ratio: 4:1, instead of 5:1) and no inverted pictures, as the inclusion of inverted pictures in Experiments 1 and 2 revealed that the effect of emotional pictures was not due to their rarity of presentation. As in Experiment 2 we manipulated the likelihood of target repetition using the function $100 - (20 * \sqrt{N})$. The search items were red or green squares either large (side length = 1.12 deg) or small (side length = 0.63 deg). The size of the small squares was 0.25 deg, and they were displaced by 0.12 deg up, down, right, or left with respect to the center of the square. A target appeared among 15 distractors on each trial. Participants responded by pressing keys on the numeric keypad of a standard keyboard (the keys corresponded spatially to the four response options). The search array was visible until response. Otherwise methods were similar to those described for previous experiments.

Results

The results from Experiment 3 are shown in Figure 3B to 3D and Table 2. There was an overall effect of picture type upon inverse efficiency, such that performance after emotional pictures was less efficient than after neutral ones: $F(1, 11) = 6.37$, $p = .028$. There was also a main effect of repetition, $F(4, 44) = 57.98$, $p < .001$. The interaction between repetition and picture type was strong and significant: $F(4, 44) = 10.76$, $p < .001$. This pattern of results is similar to those in the preceding experiments.

When collapsed across all participants (Figure 3B), there was little evidence of any reversal pattern, which would have indicated facilitated priming after emotion-inducing pictures. However, further analyses revealed notable individual differences in the effect of the emotional pictures upon inverse efficiency in this group of observers. We therefore examined whether repetition-driven enhancement of automatic processing might have specifically been apparent among those individuals who had initially exhibited the most robust emotion-induced impairment. To do this, we created a median split and examined the effects separately among the six observers with the smallest initial impact of emotional pictures and the six observers with the largest initial impact of emotional pictures.

Results for participants with a small initial effect of emotional pictures. The results for the six observers showing a small effect of picture type are shown on the left in Figure 3C. The main effect of picture type was not significant, $F(1, 5) = 1.64$, $p = .256$, but there was a significant main effect of repetition, $F(4, 20) = 25.15$, $p < .001$. In contrast with the collapsed results, the interaction between type and repetition in this group was not significant, $F(4, 20) = .695$, $p = .604$.

Results for participants with a large initial effect of emotional pictures. The results for the six observers showing a large initial effect of picture type are shown on the right in Figure 3C. The main effect of picture type was marginal, $F(1, 5) = 4.91$, $p = .078$, but there was a significant main effect of repetition of the search task, $F(4, 20) = 39.72$, $p < .001$. As in the collapsed

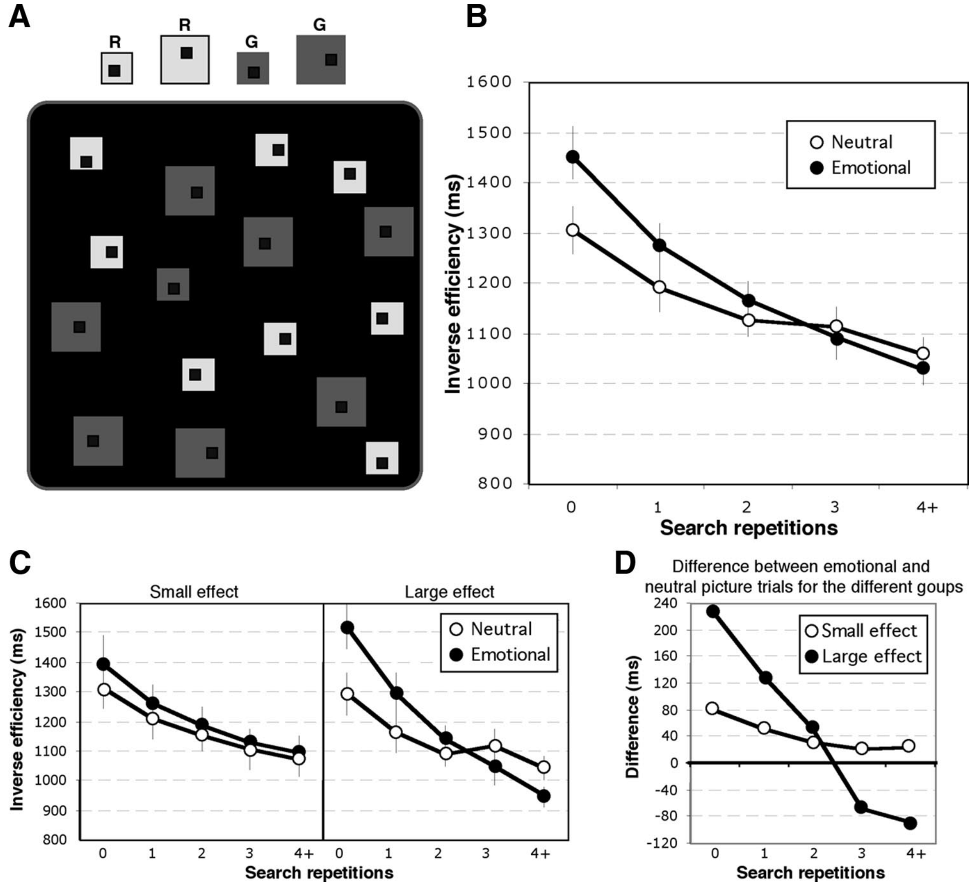

Figure 3. The search task and results of experiment 3. A shows the task which was to find the odd-one-out target (which was different in size and color from the other items on the screen) and respond whether the small dark square within it was shifted up, down, left, or right relative to the center of the larger square. B shows the overall results. C compares the repetition effect for the groups with large versus small initial effects of the emotional pictures, whereas D shows the difference between the performance for the different picture types (emotional minus neutral) for the two groups (small initial effect of emotional pictures versus large initial effect of emotional pictures) as a function of repetition of target identity. In all graphs (B–D), the abscissa shows consecutive repetitions of the same target of the visual search task. The error bars denote the SEM for each data point.

results (but in contrast to the group with a small initial impact of emotional pictures), the interaction between picture type and repetition was significant, $F(4, 20) = 48.66$, $p < .001$. Importantly, and consistent with our a priori prediction, a *t* test on the inverse efficiency score revealed that participants in this group were significantly faster after the emotional than the neutral pictures after four or more repetitions ($p = .01$).

To further cement this conclusion, we performed a mixed ANOVA with group (small vs. large initial impact of emotional pictures) as a between-subjects variable and picture type and

Table 2
Mean Response Time (RT) and Error Rates (in Percentages) From Experiment 3

	Neutral					Emotional				
Emotional effect	0	1	2	3	4+	0	1	2	3	4+
Small										
RT	1255	1148	1097	1067	1039	1323	1194	1126	1082	1041
Error (%)	4.5	5.0	4.85	3.42	3.05	5.07	5.22	4.92	4.08	4.48
Large										
RT	1203	1132	1024	1048	997	1435	1207	1090	999	925
Error (%)	7.02	2.83	6.15	5.77	4.2	5.55	6.73	4.62	4.35	2.7

repetition as within-subjects variables. This revealed a large three-way interaction between picture type, target repetition and group, $F(4, 40) = 7.26$, $p < .001$, suggesting that the interaction between repetition and picture type varied between the two groups. Figure 3D highlights this interaction by plotting the difference (inverse efficiency score after emotional pictures minus inverse efficiency score after neutral pictures) between the effects of the neutral versus emotional pictures as a function of repetition, separately for each group, showing how different the effects are for the two groups. Note that although the difference in priming patterns between groups might at first be construed as a regression to the mean for observers with a large initial effect, this is unlikely given that the crossover was significant, with emotional pictures eliciting better performance after four or more target repetitions ($p = .01$, as indicated above).

General Discussion

Our results demonstrate that although task-irrelevant emotional stimuli can disrupt visual search, this detrimental effect can be overcome if the task involves search criteria that have become prepotent over the course of several repetitions. This was shown here in three visual search experiments, and the pattern was the same in all cases: as the same task repeated, the detrimental effect of emotion-inducing stimuli decreased. This suggests that emotional stimuli are not uniformly disruptive to STM. Instead, STM processes that are relatively automatic—such as priming of visual search—are not strongly affected by emotional distraction.

Dramatically, in Experiment 3, participants who initially suffered the most disruption from emotional stimuli then exhibited emotion-induced *facilitation* of visual search upon consecutive repetitions of target properties. In other words, among those participants most sensitive to the impact of emotional distraction, the memory mechanisms driving priming of visual search were *enhanced* after viewing task-irrelevant emotional pictures. What this suggests is that emotion's impact on cognitive processing might be better characterized as a shifting balance between relatively effortful and automatic processing (or between competing cognitive control processes) rather than as a general emotion-induced impairment per se (see also Gray, Schaefer, Braver, & Most, 2005).

The emotion-induced disruption of effortful cognitive processing accords well with previous results. For example, when people actively search for a target embedded in a rapid stream of items, the task-irrelevant appearance of an emotional distractor in the stream disrupts target detection (Most et al., 2005; Most & Wang, 2011), an effect that has been called "emotion-induced blindness." Similarly, when people attempt to hold items in visual working memory, the presentation of an emotional distractor during the retention interval leads to impaired working memory performance (Dolcos & McCarthy, 2006). Meanwhile, the sparing and facilitation of relatively automatic cognitive processing is consistent with the notion that emotional arousal biases cognitive processing in favor of salient information. For example, a recently proposed framework suggests that emotional arousal reconfigures information processing so that "high priority" stimuli receive particularly preferential processing over less salient stimuli (Mather & Sutherland, 2011). According to this "arousal-biased competition" account, information can achieve high priority either through stimulus-driven salience or task-relevance. Our findings partially dovetail with this notion but suggest that the benefits of emotional arousal may be limited to prepotent or well-practiced search priorities.

Notes on Some Related Findings

In a recent study, Becker (2009) found that the presentation of an emotional face just before a search array increased the efficiency of target search, which might on the surface appear to be inconsistent with our finding of an emotion-induced slowing of search on unrepeated trials. However, in that study, participants always searched for a picture of a house among a heterogeneous collection of nonhouse images. Thus, the diagnostic features that determined the presence or absence of a target were the same from trial to trial, rendering the findings from that study consistent with ours.

In another recent, relevant study, Shen and Chun (2011) examined the effect of changes in expected reward upon priming of pop-out (see also Kristjánsson, Sigurjónsdóttir & Driver, 2010). They found that when the amount of an anticipated reward was increased, priming of pop-out was less robust than when low reward was expected. They suggested that the expectation of high reward increased participants' attentional flexibility, which in turn reduced trial-to-trial response time variation as a function of task repetition. Their study appears to complement our findings, as the emotion-induced shift toward an automatic mode of processing that our data suggest would entail diminished attentional flexibility. The result—as might be predicted from the findings of Shen and Chun (2011)—was an increase in priming of pop-out after emotional distractors.

Interestingly, although the emotional stimuli in our study were distracting, their impact on priming of visual search appeared to differ from that of distraction by other means. When participants are required to make antisaccades (i.e., eye movements made in a direction opposite a visual cue), they are faster when they perform a concurrent secondary task right before antisaccade execution (Kristjánsson et al., 2001, 2004). Antisaccades are thought to require the suppression of reflexive prosaccades (Kristjánsson, 2007; Munoz & Everling, 2004), and Kristjánsson and colleagues speculated that the secondary task interfered with reflexive prosaccade generation, thereby allowing faster volitional antisaccades. The inconsistency between those findings and our current ones raise the possibility that not all forms of distraction shift the balance between automatic and effortful modes of processing in the same way. The current findings might reflect an impact on information processing that is unique to emotion. Whether or not this is actually the case remains to be seen in future experiments, which will measure the effect of emotional pictures upon pro- and antisaccade performance.

Conclusions

Emotional stimuli are frequently found to disrupt cognitive functions such as STM, and resulting theoretical frameworks have tended to posit the relationship between cognition and emotion as a competition between "hot" and "cold" processing. The present findings contribute to a literature suggesting that the relationship between the two is subtler than this. Here, we found that whereas emotional stimuli did impair effortful aspects of cognitive processing, priming of visual search—a relatively automatic aspect of STM—was not only spared but appeared to be *enhanced* by the presentation of task-irrelevant emotional stimuli. In short, when it comes to the relationship between emotion and cognition, emotion may play a mediating role in the balance between different aspects of cognition (i.e., automatic vs. effortful) rather than a generally disruptive function.

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