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Emotion Strengthens High-Priority Memory Traces but Weakens Low-Priority Memory Traces

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Abstract
When people encounter emotional events, their memory for those events is typically enhanced. But it has been unclear how emotionally arousing events influence memory for preceding information. Does emotional arousal induce retrograde amnesia or retrograde enhancement? The current study revealed that this depends on the top-down goal relevance of the preceding information. Across three studies, we found that emotional arousal induced by one image facilitated memory for the preceding neutral item when people prioritized that neutral item. In contrast, an emotionally arousing image impaired memory for the preceding neutral item when people did not prioritize that neutral item. Emotional arousal elicited by both negative and positive pictures showed this pattern of enhancing or impairing memory for the preceding stimulus depending on its priority. These results indicate that emotional arousal amplifies the effects of top-down priority in memory formation.

Keywords
emotional arousal, memory, arousal-biased competition, goal relevance, top-down attention

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Decades of research have indicated that emotionally arousing events or items are more likely to be remembered than neutral events or items (for a review, see LaBar & Cabeza, 2006). But there is surprisingly little consensus about another important aspect of emotional memory: How do arousing stimuli influence memory for neutral stimuli around them?

For instance, animal research has revealed that emotional arousal after training enhances memory of the training experiences (for reviews, see McGaugh, 2000, 2004). Studies in humans have also demonstrated enhanced memory for neutral stimuli preceding emotionally arousing items (Anderson, Wais, & Gabrieli, 2006; Finn & Roediger, 2011; Knight & Mather, 2009; Nielson & Arentsen, 2012; Nielson & Powless, 2007; Nielson, Yee, & Erickson, 2005). However, other studies have revealed the opposite pattern: impaired memory for neutral stimuli preceding emotionally arousing items (Bornstein, Liebel, & Scarberry, 1998; Hurlemann et al., 2005; Knight & Mather, 2009; Miu, Heilman, Opre, & Miclea, 2005; Strange, Hurlemann, & Dolan, 2003; Strange, Kroes, Fan, & Dolan, 2010).

How can the same types of emotionally arousing stimuli lead to opposite effects on memory for preceding neutral information in different contexts? Arousal-biased competition (ABC) theory (Mather & Sutherland, 2011) proposes a simple mechanism to explain these contradictory results. The theory posits that emotional arousal modulates the strength of competing mental representations, enhancing memory for high-priority items while inhibiting memory for low-priority items. The priority of an item can be determined by either its bottom-up perceptual salience or its top-down goal relevance (Fecteau & Munoz, 2006). Thus, according to ABC theory, experiencing emotional arousal should enhance later memory for stimuli that are currently the target of one's top-down goal or perceptually conspicuous, but should inhibit memory for other stimuli. Initial research testing ABC

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theory demonstrated that perceptual saliency helps determine whether emotional arousal enhances or impairs attention and perceptual learning of particular stimuli (Lee, Itti, & Mather, 2012; Sutherland & Mather, 2012).

In the current study, we examined the role of top-down goal relevance. In particular, we investigated whether goal relevance determines whether emotional arousal induces retrograde amnesia or enhancement. Following previous research (Hurlemann et al., 2005), we had participants learn image sequences that included several neutral objects and one perceptual oddball (either emotional or neutral). We manipulated participants' goal when encoding the image sequence; some participants were told to focus on objects that appeared right before the oddball (*oddball–1 objects*) in each sequence, whereas other participants were told to focus on another image. We predicted that memory for oddball–1 objects would be enhanced by the emotional arousal induced by oddball images when participants prioritized oddball–1 objects, but impaired by that same arousing content when participants prioritized other images. We tested this prediction with both negative and positive emotionally arousing oddball images.

The current study also examined the effects of goal relevance on memory for subsequent neutral stimuli: objects that followed oddball images (*oddball+1 objects*). One possibility is that top-down prioritizing modulates the effects of arousal similarly irrespective of whether arousal occurs before or after a to-be-prioritized stimulus is encountered. Thus, memory for oddball+1 objects should show emotion-induced impairment when they are not prioritized but show emotion-induced facilitation when they are prioritized. However, previous research has shown emotion-induced memory enhancement predominantly for items preceding arousing stimuli, but not for subsequent items (e.g., Knight & Mather, 2009). In addition, emotionally arousing stimuli can impair perceptual processing of stimuli presented in the same modality immediately afterward (Bocanegra & Zeelenberg, 2009). Thus, an alternative possibility is that emotional arousal interferes with the encoding of representations of subsequent stimuli, hindering the execution of goals about which items to prioritize and thus leading to weaker interactions between priority and arousal on memory for subsequent items.

Study 1

In Study 1, we tested our hypothesis that top-down goal relevance can determine whether emotionally negative oddballs lead to retrograde amnesia or enhancement. Some participants were asked to prioritize oddball–1 objects (*prioritize-oddball–1 condition*), whereas the other participants were asked to prioritize oddball images (*prioritize-oddball condition*). We predicted that memory for oddball–1 objects would be enhanced by negative oddballs when those objects were prioritized but impaired by the same oddballs when the oddballs were prioritized.

We also examined memory for oddball+1 objects. Because the oddball+1 objects were not relevant to participants' goals in either priority condition, we expected that memory for oddball+1 objects following negative, as opposed to neutral, oddballs would be impaired in both conditions.

Method

Participants. Participants were 146 volunteers who found our study on lists of online psychology experiments (mean age = 24.12 years, *SD* = 6.27, age range 18–59 years; 62 males, 84 females). They were randomly assigned to the prioritize-oddball–1 condition (n = 77) or the prioritize-oddball condition (n = 69). To ensure data quality, we had several exclusion criteria: Participants whose false-alarm rates in a memory test were 100% or were defined as outliers within their condition (more than three times the interquartile range higher than the third quartile; Tukey, 1977), participants who used only one option for all "old" responses during the memory test (see the Procedure section for details), participants who took part in the study more than once, and those who came from the same organization as another participant and participated at the same time as or within 30 min of that participant. Seven participants were excluded, resulting in a sample of 139 people (mean age = 24.30 years, *SD* = 6.27, age range = 18–59 years; 59 males, 80 females; prioritize-oddball–1: n = 74; prioritize-oddball: n = 65).

Stimuli. We constructed six lists of ten semantically different items. Each list comprised nine nonoddball stimuli (photo objects with black labels and no frame) and one perceptual oddball (photo pictures with white labels and a thick black frame) that appeared at the fourth, fifth, or sixth position in the list; the serial position of the oddball was randomly determined for each list.

Oddball stimuli consisted of six pairs of pictures obtained from a previous study (Mather & Nesmith, 2008); in each pair, a negative picture was yoked with a less arousing neutral picture that was similar in appearance, complexity, content, and focus of interest and had the same verbal label (see Table S1 in the Supplemental Material available online for the normative arousal and valence ratings for the pictures). Each participant was shown one of the pictures from each pair; whether they saw the negative or neutral version was counterbalanced across participants.

Photographs of neutral objects obtained from previous research (Kensinger, Garoff-Eaton, & Schacter, 2006) were used as nonoddball items.

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Eighteen pairs of photo objects were used as oddball–1 and oddball+1 objects. Each pair consisted of two photo objects that shared the same verbal label but had different perceptual features (e.g., color, orientation, and shape). One third of the pairs were used as oddball–1 objects, another third were used as oddball+1 objects, and the remaining third were used as distractors in the final memory test. The assignment of object pairs to the three item types and to negative and neutral conditions was counterbalanced across participants.

From each pair assigned to oddball–1 and oddball+1 objects, one of the two photo objects was randomly chosen and shown during the encoding phase; the one not chosen served as the foil shown with the old item in the memory test. An additional 42 photo objects were shown in the remaining list positions during the encoding phase.

Procedure. Participants first completed the encoding phase, in which they viewed six lists of 10 images (each shown with its title for 1 s). Prior to the encoding phase, they were told to remember as many images as possible for a later memory test while focusing especially on one image. Participants in the prioritize-oddball condition were told to focus on the oddball picture, whereas participants in the prioritize-oddball–1 condition were told to focus on the oddball–1 object. To ensure that participants focused on the to-be-prioritized items, after the presentation of each list, we prompted participants to type the name of the target picture (Fig. 1).

After the encoding phase, participants completed a demographic questionnaire and then a memory test. On each memory-test trial, participants saw two different photographs of the same object: one labeled "A" and the other labeled "B." Which version was shown as "A" was randomized. Participants' task was to indicate if both images were new or, if not, which of the two images they had seen during the encoding phase (Fig. 2). The memory test included oddball–1 objects, oddball+1 objects, and new objects (distractors).

Response coding. The memory test was designed to elicit more detailed information about participants' memory than a standard old-new recognition memory test would. Following past studies (Kensinger, Garoff-Eaton,

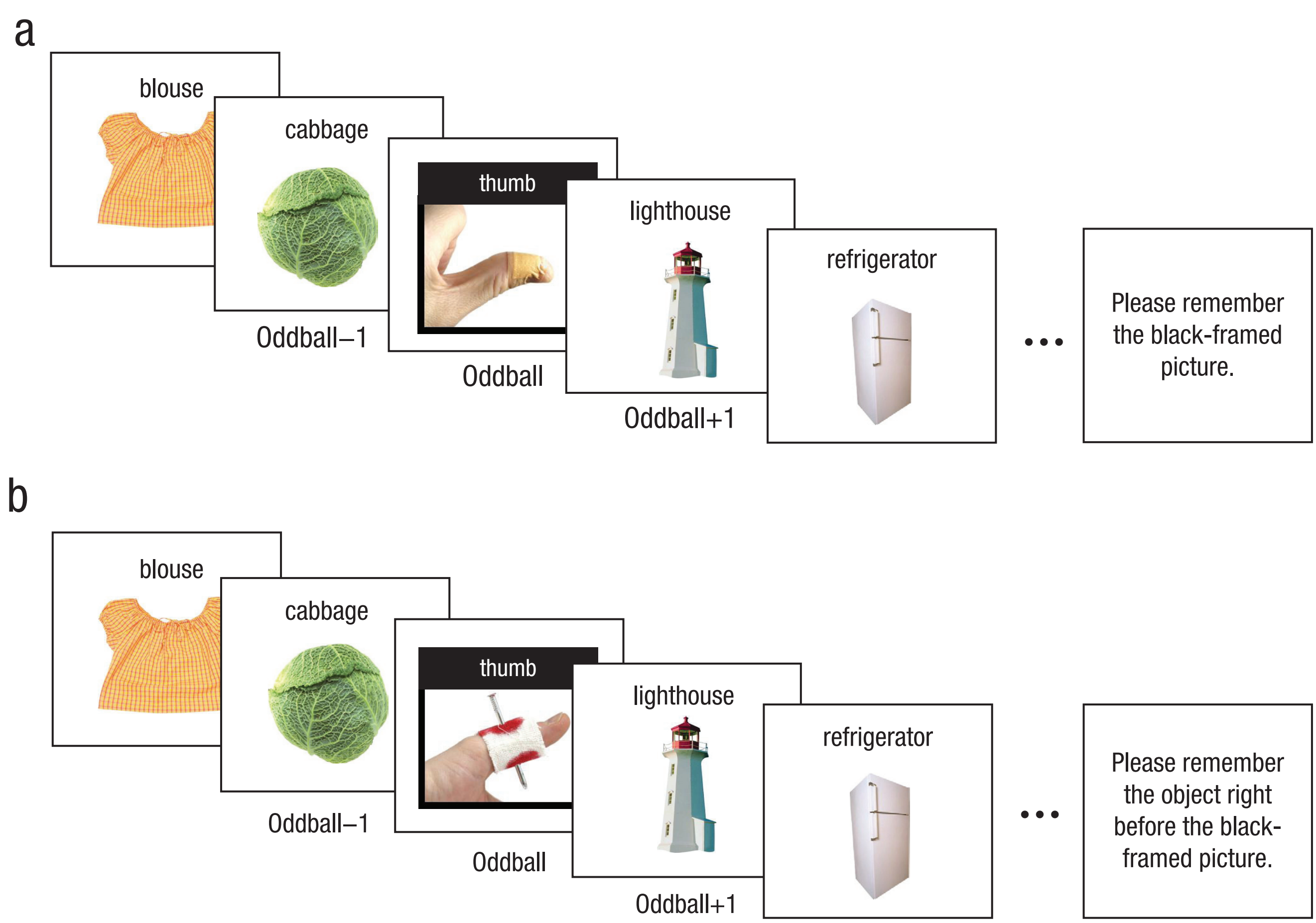

Fig. 1. Schematic representations of (a) a neutral trial in the prioritize-oddball condition and (b) a negative trial in the prioritize-oddball–1 condition. See text for details.

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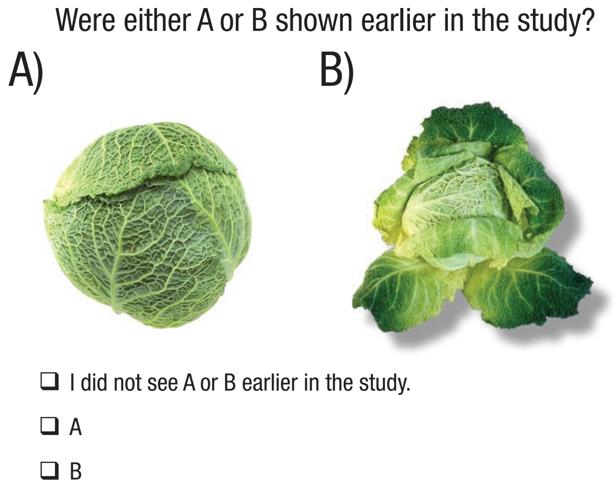

Fig. 2. Schematic representation of the memory test.

& Schacter, 2007), we coded each "old" response for objects as a correct response for specific recognition when the participants selected the same object that had been shown during the encoding phase. "Old" responses given to either the identical or the other version of the same object were also obtained as a measure for the general memory of an item. However, performance was at ceiling in this measure; for example, the rate of accurate general recognition for oddball–1 objects in the prioritize-oddball–1 condition was .98, .97, and .96 in Studies 1, 2, and 3, respectively. Therefore, we focused on the specific-recognition measure. To control for false-alarm rates, we analyzed the corrected recognition rate (correct specific-recognition rate – false-alarm rate).

Results and discussion

Encoding phase. Performance was better in the prioritize-oddball condition ($M_{negative}$ = .98, $M_{neutral}$ = .98) than in the prioritize-oddball–1 condition ($M_{negative}$ = .95, $M_{neutral}$ = .94), $F(1, 137) = 6.82$, $\eta_p^2 = .05$, $p < .05$. There were no other significant effects (ps > .60).

Memory for oddball–1 objects. A 2 (valence: negative vs. neutral) × 2 (priority: oddball–1 vs. oddball) analysis of variance (ANOVA) on the corrected recognition rate for oddball–1 objects revealed better memory in the prioritize-oddball–1 condition than the prioritize-oddball condition, $F(1, 137) = 11.75$, $\eta_p^2 = .08$, $p < .01$. This indicates that participants prioritized oddball–1 objects more in the prioritize-oddball–1 condition, as expected. In addition, we found a significant valence-by-priority interaction (Fig. 3a), $F(1, 137) = 10.16$, $\eta_p^2 = .07$, $p < .01$. Consistent with our prediction, results showed that when participants prioritized oddball–1 objects, their memory for oddball–1 objects was more accurate in the negative condition than in the neutral condition ($M_{negative}$ = .71, $M_{neutral}$ = .64), $F(1, 137) = 4.43$, $p < .05$. Also as predicted, the prioritize-oddball condition showed the opposite pattern: worse memory for oddball–1 objects in the negative condition than in the neutral condition ($M_{negative}$ = .54, $M_{neutral}$ = .46), $F(1, 137) = 5.74$, $p < .05$. Thus, depending on the top-down goal, seeing negative pictures produced

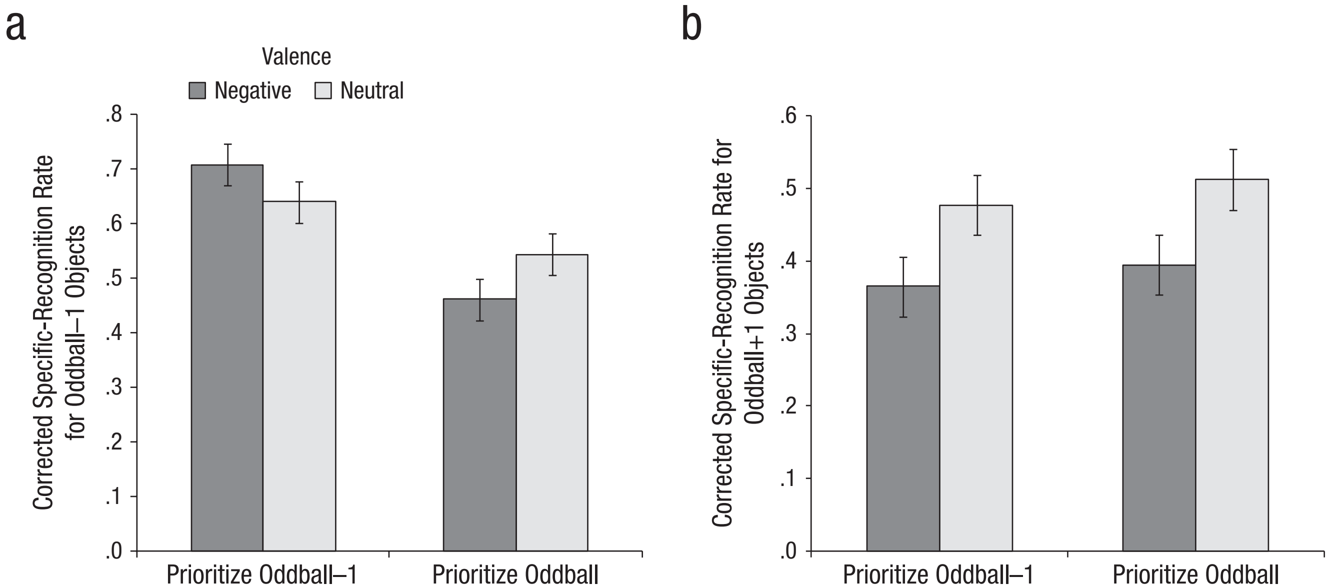

Fig. 3. Mean corrected specific-recognition rate as a function of priority condition and oddball valence in the memory test in Study 1. Results are shown separately for (a) oddball–1 objects and (b) oddball+1 objects. Error bars represent standard errors.

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either retrograde amnesia or retrograde enhancement for preceding neutral information.

Memory for oddball+1 objects. The corrected recognition rates for oddball+1 objects revealed a significant effect of valence, $F(1, 137) = 10.63$, $\eta_p^2 = .07$, $p < .01$, with no other significant effects (ps > .50). As expected, in both conditions, participants showed worse memory for oddball+1 objects when the objects followed negative pictures than when they followed neutral pictures (Fig. 3b; oddball–1: $M_{negative} = .36$, $M_{neutral} = .48$; oddball: $M_{negative} = .39$, $M_{neutral} = .51$).

Study 2

Study 2 extended Study 1 in two ways. First, we examined whether similar effects were obtained with positively valenced oddballs. Second, we added a condition in which participants prioritized oddball+1 objects (prioritize-oddball+1 condition). Thus, we manipulated the goal relevance of oddball+1 objects as well, to examine the role of top-down priority on memory for subsequent information.

Method

Participants. Participants were 227 volunteers recruited via lists of online psychology experiments (mean age = 26.41 years, *SD* = 8.94, age range 18–62 years; 62 males, 165 females). None of their IP addresses matched those of participants in Study 1. They were randomly assigned to the prioritize-oddball–1 condition ($n = 68$), the prioritize-oddball condition ($n = 75$), or the prioritize-oddball+1 condition ($n = 84$). We applied the same exclusion criteria used in Study 1. In addition, we excluded 3 participants in the prioritize-oddball+1 condition who typed the names of not only the oddball+1 objects but also all other objects following oddballs during the encoding phase. The remaining participants comprised 205 people (mean age = 26.78 years, *SD* = 9.23, age range 18–62; 52 males, 153 females; prioritize-oddball–1: $n = 64$; prioritize-oddball: $n = 67$; prioritize-oddball+1: $n = 74$).

Stimuli and procedure. The procedures were identical to those in Study 1, except for two modifications. First, oddball pictures were replaced by six positive pictures and their yoked visually similar, but less arousing neutral pictures with the same labels (see Table S1 for the normative arousal and valence ratings; Mather & Nesmith, 2008). Second, we included a prioritize-oddball+1 condition, in which participants were told to focus on the oddball+1 object and type its name after the presentation of each list.

Results and discussion

Encoding phase. Neither the priority condition nor valence influenced performance in the encoding phase (ps > .10; prioritize-oddball: $M_{positive} = .97$, $M_{neutral} = .97$; prioritize-oddball–1: $M_{positive} = .93$, $M_{neutral} = .94$; prioritize-oddball+1: $M_{positive} = .94$, $M_{neutral} = .97$).

Memory for oddball–1 objects. Oddball–1 objects were not relevant to participants' goals in either the prioritize-oddball+1 or the prioritize-oddball condition, and, as expected, we found a similar effect of valence in these two conditions without any interaction ($p > .30$). Therefore, these two conditions were combined into one *prioritize-another-item* group. A 2 (valence: positive vs. neutral) × 2 (priority: oddball–1 vs. another item) ANOVA was performed on the corrected recognition rate. This ANOVA revealed a significant effect of priority, $F(1, 203) = 7.58$, $\eta_p^2 = .04$, $p < .01$, and a significant valence-by-priority interaction (Fig. 4a), $F(1, 203) = 8.91$, $\eta_p^2 = .04$, $p < .01$. Consistent with our prediction, memory for oddball–1 objects was enhanced by positive oddballs in the prioritize-oddball–1 condition ($M_{positive} = .72$, $M_{neutral} = .64$), $F(1, 203) = 4.20$, $p < .05$, but impaired by positive oddballs in the prioritize-another-item group ($M_{positive} = .53$, $M_{neutral} = .59$), $F(1, 203) = 5.29$, $p < .05$.

Memory for oddball+1 objects. Next, we examined memory for oddball+1 objects. Because oddball+1 objects were not relevant to participants' goals in either the prioritize-oddball–1 condition or the prioritize-oddball condition, these two conditions were combined into one group (the prioritize-another-item group); indeed, these two conditions showed a similar effect of valence without any interaction ($p > .20$). The corrected recognition rate was then submitted to a 2 (valence: positive vs. neutral) × 2 (priority: oddball+1 vs. another item) ANOVA. This ANOVA revealed a significant effect of priority, $F(1, 203) = 39.00$, $\eta_p^2 = .16$, $p < .01$, and a valence-by-priority interaction (Fig. 4b), $F(1, 203) = 4.43$, $\eta_p^2 = .02$, $p < .05$. Replicating the findings of Study 1, results showed that positive oddballs impaired memory for subsequent objects when participants did not prioritize those objects ($M_{positive} = .45$, $M_{neutral} = .54$), $F(1, 203) = 8.41$, $p < .01$. In contrast, this emotion-induced impairment did not occur in the prioritize-oddball+1 condition ($p > .60$; $M_{positive} = .75$, $M_{neutral} = .73$), although we did not see the emotion-induced memory facilitation.

Study 3

We had three objectives in Study 3. The first goal was to confirm our results from Studies 1 and 2 showing the effects of emotionally arousing stimuli on memory for

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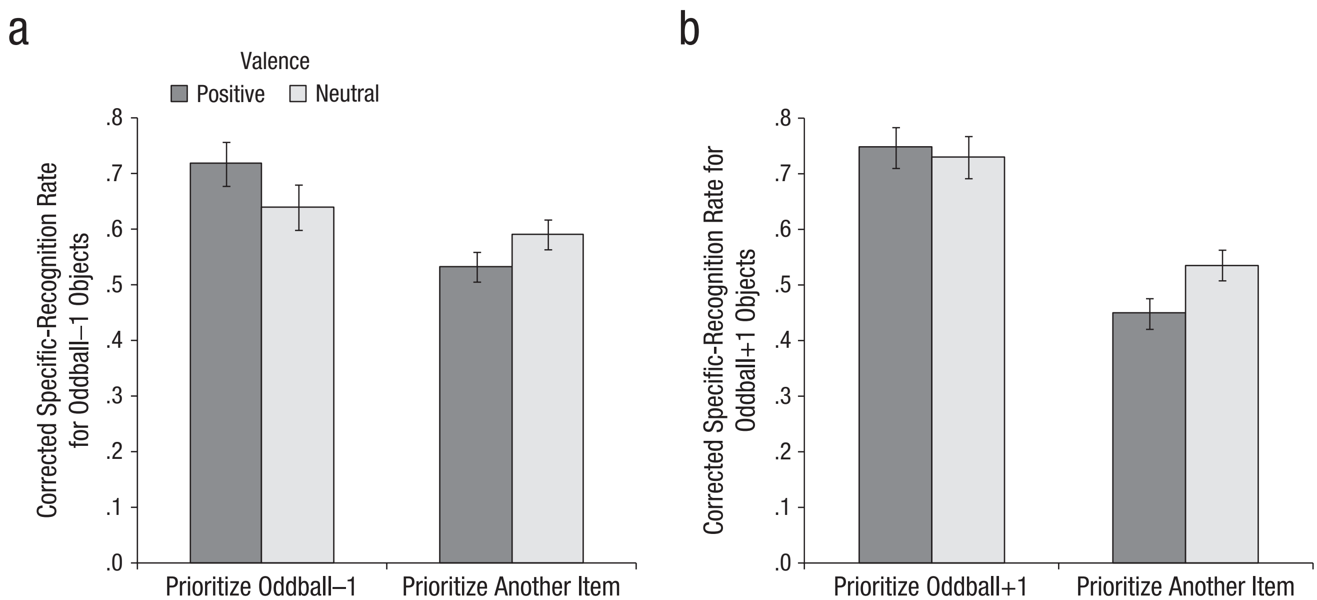

Fig. 4. Mean corrected specific-recognition rate as a function of priority condition and oddball valence in the memory test in Study 2. Results are shown separately for (a) oddball–1 objects and (b) oddball+1 objects. Error bars represent standard errors.

preceding information while including positive and negative emotionally arousing stimuli within a single study. We expected to replicate the finding that the goal relevance of preceding items determines whether emotionally arousing images (irrespective of valence) induce retrograde amnesia or enhancement. Second, we aimed to further examine the effects of goal relevance on memory for subsequent information. In Study 2, positive emotionally arousing oddballs enhanced memory for goal-relevant preceding information but not subsequent information. In Study 3, we examined whether this diminished effect occurred with negative emotionally arousing stimuli or was specific to positive emotionally arousing stimuli. Finally, we addressed whether the effects of emotionally arousing oddballs were attributable to arousal or to valence by using a trial-by-trial analysis.

Method

Participants. Sixty-four undergraduate and graduate students (mean age = 20.71 years, *SD* = 2.92, age range 18–34 years; 22 males, 42 females) were randomly assigned to the prioritize-oddball–1 condition (*n* = 32) or the prioritize-oddball+1 condition (*n* = 32).

Stimuli. We increased the number of lists from 6 to 42; each list included seven nonoddball objects and one oddball that appeared at the third, fourth, fifth, or sixth position. Oddballs were 42 pictures (14 positive, 14 negative, and 14 neutral) obtained from the International Affective Picture System (see Table S1 for the normative arousal and valence ratings; Lang, Bradley, & Cuthbert, 2008).

Nonoddballs were 112 pairs of photo objects obtained from previous research (Kensinger et al., 2006) and other resources (e.g., the Internet). They were randomly assigned to be oddball–1 or oddball+1 objects and further assigned to one of the four conditions (positive, negative, neutral, or distractors in a memory test); assignment was counterbalanced across participants. During the encoding phase, one of the photo objects was shown from each pair; which version was shown was counterbalanced across participants. The one not shown served as a foil in the memory test. An additional 210 photo objects were shown in the remaining list positions during the encoding phase.

Procedure. The procedure was based on that of Study 2 with several modifications. First, we had participants complete the study in the lab. Second, we omitted the prioritize-oddball condition. Third, we increased the total number of trials to 42 (14 trials per condition), divided into seven blocks of 6 trials each (2 positive, 2 negative, and 2 neutral).

In each block, participants first underwent the encoding phase, in which they saw six lists of seven images (each image was shown for 1.2 s, followed by a 500-ms blank screen, and each list was followed by a cue to retrieve the prioritized item).

After the encoding phase, participants were given a three-digit number and asked to count back from the number by 3s for 1 min. Participants then completed a

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memory test on oddball–1 and oddball+1 objects. To prevent participants from selectively remembering oddball–1 and oddball+1 objects, we included in the memory test other objects randomly chosen from half of the lists in each block (filler items). After all blocks, participants viewed each oddball picture and rated the degree to which it was arousing, using a scale from 1 (*least arousing*) to 9 (*most arousing*), and its valence, using a scale from 1 (*extremely negative*) to 9 (*extremely positive*).

Results and discussion

Encoding phase. Performance was better in the prioritize-oddball–1 condition than in the prioritize-oddball+1 condition, $F(1, 62) = 4.72$, $\eta_p^2 = .05$, $p < .05$. In addition, the valence-by-priority interaction was significant, $F(1, 124) = 4.46$, $\eta_p^2 = .09$, $p < .05$; performance in the prioritize-oddball+1 condition was better in the negative condition than in the neutral condition ($M_{negative} = .98$, $M_{neutral} = .94$, $M_{positive} = .97$), $ts(62) = 2.75$, $ds = 0.54$, $p < .05$ (Tukey's range test), whereas the effect of valence was not significant in the prioritize-oddball–1 condition ($p > .50$; $M_{negative} = .97$, $M_{neutral} = .99$, $M_{positive} = .98$). Given this significant interaction and that our main interest was the effects of emotion on memory retention (rather than encoding performance), in subsequent analyses of memory tests, we focused on trials in which participants had made a correct response during the encoding phase. However, results were similar when we included items from incorrect encoding-phase trials.

Oddball picture rating. Negative pictures ($M = 2.14$) were rated more negatively than neutral pictures ($M = 5.09$), $t(124) = 25.67$, $d = 4.17$, $p < .01$ (Tukey's range test), and positive pictures ($M = 6.85$) were rated more positively than neutral pictures, $t(124) = 15.37$, $d = 2.04$, $p < .01$ (Tukey's range test). In addition, negative pictures ($M = 6.79$) were rated as more arousing than positive pictures ($M = 5.09$), $t(124) = 5.67$, $d = 0.97$, $p < .01$ (Tukey's range test), which were rated as more arousing than neutral pictures ($M = 2.10$), $t(124) = 15.05$, $d = 3.46$, $p < .01$ (Tukey's range test). The priority conditions did not significantly affect the valence or arousal ratings ($ps > .15$).

Memory for oddball–1 objects. A planned contrast test (Rosenthal & Rosnow, 1985) on the corrected recognition rates confirmed the results from Studies 1 and 2 (Fig. 5a), $F(1, 124) = 3.93$, $p < .05$: Memory for oddball–1 objects was enhanced by positive and negative oddballs in the prioritize-oddball–1 condition ($M_{negative} = .73$, $M_{neutral} = .69$, $M_{positive} = .72$) but impaired by positive and negative oddballs in the prioritize-oddball+1 condition ($M_{negative} = .54$, $M_{neutral} = .57$, $M_{positive} = .54$).

To examine the effects of arousal and valence, we performed a hierarchical generalized linear model analysis (Raudenbush & Bryk, 2002) with each trial as a Level-1 unit and each participant as a Level-2 unit. The dependent variable was specific-memory performance for an oddball–1 object from each trial (1 = correct, 0 = incorrect). Predictors consisted of the participant's arousal and

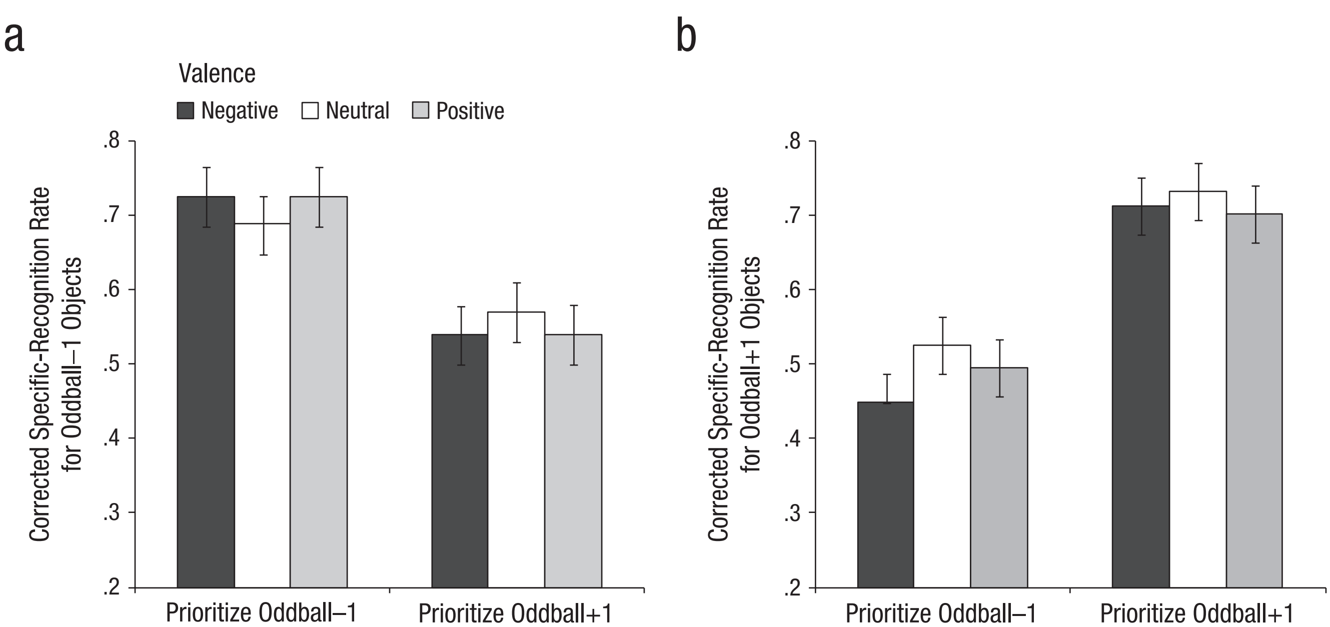

Fig. 5. Mean corrected specific-recognition rate as a function of priority condition and oddball valence in the memory test in Study 3. Results are shown separately for (a) memory for oddball–1 objects and (b) memory for oddball+1 objects. Error bars represent standard errors.

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valence ratings for the oddball picture from that trial, the priority condition (oddball–1 vs. oddball+1), an arousal-by-priority interaction term, and a valence-by-priority interaction term. This analysis revealed a significant effect of priority, $z = 3.91$, $p < .01$, reflecting better memory for oddball–1 objects when these objects were prioritized than when oddball+1 objects were prioritized, as expected. In addition, there was a significant arousal-by-priority interaction, $z = 2.41$, $p < .05$. No other effects were significant (ps > .15). These results indicate that arousal, rather than valence, plays a crucial role in modulating the effects of priority on memory for preceding information.

Memory for oddball+1 objects. A planned contrast test on the corrected recognition rates did not show the pattern predicted by ABC theory ($p > .30$; Fig. 5b). To explore the results, we performed a separate contrast analysis for each priority condition. Replicating the findings from Study 2, results showed that memory for oddball+1 objects was impaired by positive and negative oddballs when the objects were not prioritized ($M_{negative}$ = .45, $M_{neutral}$ = .53, $M_{positive}$ = .49), $F(1, 124) = 5.72$, $p < .05$. In contrast, emotional oddballs did not enhance memory for oddball+1 objects when they were prioritized (p = .20; $M_{negative}$ = .71, $M_{neutral}$ = .73, $M_{positive}$ = .70).

To examine the role of arousal and valence, we performed a hierarchical generalized linear model analysis (equivalent to the one used for oddball–1 objects) on memory for oddball+1 objects. There was a significant effect of priority, $z = -5.65$, $p < .01$, reflecting better memory for oddball+1 objects when these objects were prioritized than when oddball–1 objects were prioritized, as expected. But neither the effects of arousal nor the arousal-by-priority interaction was significant (ps > .20). Instead, we found a valence-by-priority interaction, z = 1.94, p = .055. These results indicate that negative pictures, relative to positive pictures, impaired memory for the subsequent object less when that object was prioritized than when the preceding object was prioritized.

General Discussion

Previous research has presented a conflicting set of findings in which emotionally arousing stimuli sometimes enhance and sometimes impair memory for preceding neutral stimuli (for a review, see Mather & Sutherland, 2011). In the current study, we tested the hypothesis that top-down stimuli priority helps determine how arousal modulates memory. Consistent with this hypothesis, results showed that emotionally arousing images (both positively and negatively valenced) enhanced memory for preceding neutral objects when people prioritized those objects, but impaired memory for preceding objects when people did not prioritize the objects. Thus, depending on the focus of current goals, emotionally arousing images produced either retrograde amnesia or retrograde enhancement for preceding neutral information.

In contrast, memory for subsequent neutral information showed a weaker interaction between arousal and priority. Emotionally arousing images impaired memory for subsequent neutral objects when those objects were not prioritized. This emotion-induced impairment was diminished when people prioritized the subsequent objects, although we did not find emotion-induced memory enhancement for goal-relevant subsequent objects. Furthermore, the selective impairment for subsequent neutral objects appeared stronger for negative emotion than for positive emotion.

The weaker nature of the postarousal effects might be mediated by two different effects of emotion on perception. First, encountering emotionally arousing stimuli can impair perceptual processing of subsequent stimuli in the same modality for at least 500 ms (Bocanegra & Zeelenberg, 2009), making it harder to prioritize subsequent stimuli under arousal. Second, positive emotional arousal might broaden attentional focus (Fredrickson & Branigan, 2005) and enhance attention to subsequent stimuli even when they are not the target of goals (e.g., Waring & Kensinger, 2009). Because of these effects on perception (in addition to memory), emotional arousal may affect the processing of subsequent information in a more complex manner than that of preceding information.

Prioritizing goal-relevant information and ignoring irrelevant stimuli is crucial in human memory. This prioritization process is particularly important under emotional arousal; to increase future survival, one needs to learn the most important aspects of emotional events without being distracted by other details. The current findings indicate that emotional arousal amplifies the impact of top-down stimuli priority on memory, making it even more likely that people remember what was most important while forgetting the rest. These findings not only inform the basic mechanisms of emotion-memory interaction, but also have practical implications for eyewitness memory and students' learning in the classroom.

Author Contributions

M. Sakaki and M. Mather developed the study concept. All authors contributed to the study design. Data collection was performed by K. Fryer. M. Sakaki analyzed the data. M. Sakaki drafted the manuscript, and M. Mather and K. Fryer provided critical revisions. All authors approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

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