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The Role of Attention and Relatedness in Emotionally Enhanced Memory

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Examining the positive and negative pictures separately revealed that emotionally enhanced memory (EEM) for positive pictures was mediated by attention, with no significant influence of emotional arousal, whereas the reverse was true of negative pictures. Consistent with this finding, in Experiment 2 EEM for negative pictures was found even when task emphasis was manipulated so that equivalent attention was allocated to negative and neutral pictures. The results show that attention and semantic relatedness contribute to EEM, with the extent varying with emotional valence. Negative emotion can influence memory independently of these 2 factors.

Keywords: emotion, memory, attention, divided attention, semantic relatedness

Emotionally arousing events are remembered better than neutral events, a fact attested to anecdotally and confirmed empirically (Cahill & McGaugh, 1998; Dolan, 2002). This phenomenon, which we term *emotionally enhanced memory* (EEM), has been demonstrated for recall and recognition of emotional words, pictures, and stories (e.g., Bradley, Greenwald, Petry, & Lang, 1992, with pictorial stimuli; Cahill & McGaugh, 1995, with stories; and LaBar & Phelps, 1998, with taboo words). The means by which emotion influences memory are not well understood. Emotion may exert its influence on memory directly or indirectly, via other processes, with different processes possibly operating immediately than at prolonged delays. In this study, we focused on the immediate effect of emotion on memory to determine whether it is mediated by attention and semantic relatedness.

It is important to distinguish between the immediate and the delayed effects emotion has on memory because each is believed to depend on different processes. Prolonged effects are explained by the influence of emotion on modulating neurobiological processes involved in the consolidation of memory traces. According to the modulation hypothesis, activation of the amygdala during encoding leads to better consolidation of emotional memory traces (for reviews, see Cahill & McGaugh, 1998; Hamann, 2001; McGaugh, 2004). Because the postulated neurobiological consolidation processes take hours or even days (McGaugh, 2004), the modulation hypothesis can account for EEM when memory is tested at long delays, but does not apply when memory is tested immediately or at relatively short delays. Although the modulation hypothesis readily explained the correlation between amygdala activation and delayed recognition (Hamann, Ely, Grafton, & Kilts, 1999), it could not account for the immediate EEM in that study, which did not correlate with amygdala activation, nor could it account for robust immediate EEM reported by many other investigators (Blake, Varnhagen, & Parent, 2001; Bradley et al., 1992; Dolcos, LaBar, & Cabeza, 2004a, 2004b; Hamann, Cahill, McGaugh, & Squire, 1997; Kensinger, Brierly, Medford, Growdon, & Corkin, 2002; LaBar & Phelps, 1998; MacKay et al., 2004; Phelps, LaBar, & Spencer, 1997; Palomba, Angrilli, & Mini, 1997). Moreover, patients with unilateral surgical resection of the temporal lobes that included the amygdala, as well as a bilateral amygdala-lesioned patient, have shown EEM when tested immediately (Phelps et al., 1998, 1997; LaBar & Phelps, 1998). Because these patients exhibited EEM despite their amygdala lesions—the site responsible for the modulatory effect—the modulation hypothesis likely does not account fully for immediate EEM.

The present study examines two cognitive processes that may account for EEM in immediate memory tests, namely the influence of emotion on attention and differences in semantic relatedness between emotional and nonemotional stimuli (see Figure 1, top panel). Ample evidence has shown that emotional stimuli attract more attention than neutral ones during encoding (e.g. Fox, Russon, Bowles, & Dutton, 2001; MacKay et al., 2004; Öhman, Flykt, & Esteves, 2001; Schimmack, 2005; Williams, Mathews, & MacLeod, 1996). The increased activation in anterior temporal and extrastriate visual cortex while viewing emotional pictures is attributed to increased attentional and perceptual processing of the emotional material (e.g. Bradley et al., 2003; Lane, Chua, & Dolan, 1999; Mourao-Miranda et al., 2003). Because allocation of attention during encoding is known to be an important determinant of memory (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Smith, 1895), emotional stimuli may be remembered better because they attract more attention during the encoding phase (Hamann, 2001; Kensinger & Corkin, 2003). Indirect support for this hypothesis stems from studies showing parallel effects of emotional stimuli on attentional tasks (e.g., the emotional Stroop test) and memory tasks (e.g., MacKay et al., 2004; Pratto & John, 1991). Recent reports that arousal is a better predictor than valence of the effect of emotional stimuli on attention (Kensinger & Corkin, 2004; Schimmack, 2005) and memory (Bradley et al., 1992; Kensinger & Corkin, 2004; Ochsner, 2000) are consistent

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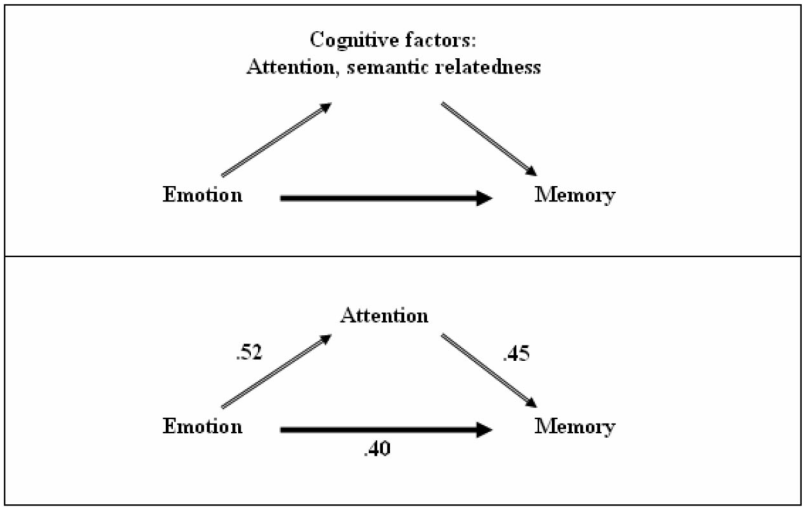

Figure 1. Cognitive mediation mechanism as an explanation of emotionally enhanced memory. The top panel shows the theoretical model. The bold arrow represents the direct path from emotion to memory postulated by the modulation hypothesis. The double-line arrows represent the alternative cognitive mediation mechanism. The arrow from emotion to attention and semantic relatedness represents the suggestion that emotional items are more attended to and semantically interrelated than are neutral items. The arrow from those cognitive factors to memory represents the suggestion that the change in cognitive attributes for emotional items is the reason for their mnemonic advantage. The bottom panel shows data from Experiment 1 of a structural equation model linking emotion, attention, and memory. The values represent standardized path coefficients.

with the idea that arousal influences memory via attention. In sum, prior research has suggested that emotional stimuli tend to be more arousing than neutral stimuli, arousing stimuli attract more attention than other stimuli, and arousing stimuli are more memorable. Thus, it is possible that EEM is mediated by attention. It is also possible that it is not. Although emotion may capture attention, it does not follow that it exerts its effects on memory via this route, or even that the attention that it captures contributes to EEM. Attentional capture by emotion may serve an alerting and orienting purpose independently of emotion's effect on memory. In this study, we test these alternative hypotheses more directly than they have been in the past.

Previous tests of the role of attention in EEM have been inconclusive. A few studies used number of eye fixations as measures of attention and found that they did not predict EEM (Christianson, Loftus, Hoffman, & Loftus, 1991; Wessel, van der Kooy, & Merckelbach, 2000). One problem with these studies is that eye fixations are poor indicators of attention (Posner, 1980). Other studies have tried to minimize differences in attention toward emotional and neutral items by presenting the items for a brief duration (Christianson et al., 1991; Sharot & Phelps, 2004a). The main problem with these studies is a lack of a manipulation check that reveals how much attention was allocated to neutral and emotional stimuli. Differences in the effectiveness of the manipulation may account for the inconsistent results.

Recently, Kensinger and Corkin (2004) showed that memory for negative arousing words was enhanced even under conditions of divided attention, but memory for negative nonarousing words was reduced under these conditions and resembled memory for neutral words. These authors suggested that the arousing items were better remembered because they automatically attracted attentional resources to themselves. However, they did not test whether the effect of arousing words on attention mediated the effect of arousing words on memory. Thus, although enhanced attention was associated with emotion, it remains possible that EEM in that study was not mediated by attention.

In contrast to the previous study, MacKay et al. (2004) reported EEM to taboo words over neutral words studied in a lexical decision task despite equal reaction times for encoding both word types. According to this finding, the memory enhancement is independent of attentional differences. MacKay et al.'s findings, however, can be interpreted differently. For example, it is possible that lexical decision tasks can be performed with a minimum of attention or that participants could use the interstimulus interval to dwell on the word they have seen (Pashler, 1998, pp. 343–344), a process more likely for emotional items, which are known to increase attentional "dwell time" (Fox et al., 2001). As a result, reaction times in this task may not have been an ideal measure of allocation of attention.

The present study was designed to provide a more stringent test of the hypothesis that EEM is mediated through attention by means of mediator analysis in Experiment 1 (Baron & Kenny, 1986) as well as by experimentally controlling allocation of attention during encoding in Experiment 2.

In addition to attention, we also investigated the effects of semantic relatedness on EEM. Like attention, semantic relatedness is higher for emotional relative to neutral items; emotional items share category membership and a thematic relationship (a gun and a dead body vs. a bowl and a fire hydrant). As semantic relatedness enhances memory on its own (Mandler, 1967), independent of emotionality, it also may mediate immediate EEM (Maratos & Rugg, 2001; Phelps et al., 1997). Our study with verbal material was the first to control for semantic relatedness of words, which eliminated the EEM effect that was evident in the comparison with random neutral words (Talmi & Moscovitch, 2004). Previous studies with more arousing pictorial stimuli failed to control relatedness. Thus, it remains possible that emotional items are remembered better because they are more related semantically. It is also possible that attention and semantic relatedness can interact with one another because impoverished attentional resources may reduce the role of relatedness in memory (Park, Smith, Dudley, & Lafronza, 1989). The advantage of emotional over neutral items, stemming from enhanced attentional allocation and enhanced semantic relatedness, might be stronger still if participants can use the extra attention associated with processing emotional stimuli to organize and connect studied items better. Thus, the second goal of the present study was to examine whether semantic relatedness associated with emotional pictures is a contributing factor to immediate EEM by comparing emotional to equally related neutral pictures (Experiment 1) and to both equally related and randomly selected neutral pictures (Experiment 2).

Experiment 1

We used a divided attention (DA) manipulation to examine the role of attention in EEM. The divided attention manipulation was necessary to obtain a direct measure of attention allocation. If the greater allocation of attention to emotional stimuli is voluntary and the auditory discrimination task is primary, then the divided attention conditions would leave participants fewer attentional resources to allocate to processing of emotional and neutral stimuli (Craik et al., 1996). Under divided attention, participants would attempt to ignore all item types equally, and the same concurrent task cost (errors and delayed responses) should be obtained for all item types. Thus, voluntary effects predict that attentionally mediated EEM would decrease under divided attention because under these conditions participants would no longer attend to emotional pictures more than neutral ones. If attention does not contribute to EEM, however, even if attention allocation to emotional stimuli is completely voluntary, EEM would not change in magnitude. If attention is allocated involuntarily to emotional pictures, then the opposite predictions hold. Involuntary attention allocation to emotional pictures would manifest as increased cost to the primary task when participants view emotional pictures, and those could be used to measure the amount of attention allocated to the secondary stimuli (MacKay et al., 2004; Pratto & John, 1991; Schimmack, 2005). As a result, under divided attention processing of neutral items would suffer more than processing of emotional items. Thus, involuntary effects predict that EEM would be larger in the divided attention condition than in the full attention (FA) condition because the relative difference between attention to emotional and to neutral stimuli will increase (N. D. Anderson, Craik, & Naveh-Benjamin, 1998). This prediction about the magnitude of EEM when attention to emotional pictures is allocated involuntarily holds for both attentionally mediated and nonmediated EEM. Thus, by using a concurrent task and measuring concurrent task costs, we hoped to determine whether divided attention reduces or increases EEM and whether EEM is mediated by attention. We investigated the latter by conducting a mediator analysis (Baron & Kenny, 1986). A mediator analysis answers two questions: (a) Does emotion influence memory indirectly via attention and (b) does emotion still have a significant, possibly "direct" influence on memory once the indirect effect of attention has been taken into account statistically? (By *direct*, we mean an influence of emotion on memory by any route other than by attention.)

We predicted that emotional pictures would be recalled better than neutral pictures and that concurrent task costs would be higher when participants viewed emotional pictures than when they viewed neutral ones. If enhanced attention to emotional stimuli has mnemonic consequences, EEM would be larger under divided attention and the mediator analysis will reveal a significant mediated path from emotion to memory via attention. If the effect of emotion on attention completely accounts for EEM, only the mediated path through attention will be significant, not the direct path from emotion to memory. If, however, emotion enhances memory in other ways, in addition to its influence on memory via attention and relatedness, the direct path between emotion and memory will be significant as well.

In this experiment, we also tested memory immediately (20-s delay) and after a 50-min retention interval. There is evidence that the amygdala can modulate memory traces of emotional items even with a retention interval as short as 45–60 min (Dolcos et al., 2004a, 2004b; LaBar & Phelps, 1998). If emotion can modulate picture-memory consolidation within this time frame, then according to the modulation hypothesis, delay would result in more forgetting of neutral than emotional items, so that a larger EEM should be obtained in the delayed test. By contrast, attentionally mediated EEM should not be affected by the delay.

Method

Participants

Forty-eight University of Toronto undergraduates (32 women, 16 men; mean age = 19.02 years, $SD = 1.9$) completed the study for course credit. The same number of men and women participated in each condition. All participants gave informed consent.

Material

The picture set included 10 positive pictures, 10 negative pictures, and 10 related neutral pictures, which depicted domestic scenes. The negative pictures were drawn from the IAPS (International Affective Picture System; Lang, Bradley, & Cuthbert, 1999), the related neutral pictures from the Internet, and the positive pictures from both sources. All pictures were resized to 400×500 pixels (which sometimes required cropping). We equated emotional and neutral pictures with the presence of people, an important control that was frequently absent in previous studies (see Charles, Mather, & Carstensen, 2003; Dolcos et al., 2004a, 2004b). A separate group of 12 participants rated all experimental pictures as well as additional pictures on valence and arousal using the computerized Self-Assessment Manikin (SAM) scales (Bradley & Lang, 1994). Agreement among raters was high (standardized item $\alpha > .90$). We attempted to minimize the differences in semantic relatedness between picture types by choosing distinct pictures. For example, we avoided using pictures with repeated content (e.g., we included only one picture with a gun). However, a pilot rating study showed that matching emotional and random neutral pictures for relatedness was impossible. Therefore, we selected neutral pictures that all depicted domestic scenes and had an additional group of 12 participants rate all possible picture pairs in the set for relatedness on a 7-point Likert scale. Agreement among raters was high (standardized item $\alpha > .90$). Picture scores for valence, arousal, and relatedness were computed across participants and analyzed with separate analyses of variance (ANOVAs). The effects of valence, $F(2, 27) = 372.24$, $p < .001$, and arousal, $F(2, 27) = 197.42$, $p < .001$, were significant. Planned contrasts showed that positive pictures had more positive valence ($p < .001$) and negative pictures had more negative valence ($p < .001$) relative to neutral pictures (see Table 1). Positive and negative pictures were equally arousing ($p > .10$) and more arousing relative to the neutral pictures ($p > .001$). All picture types were equally related, $F(2, 27) = 1.76$, $p > .10$. Picture presentation was pseudorandomized for each participant, with the constraint that two pictures of the same type could not be presented consecutively.

The pictures were presented centrally on a white computer screen with a resolution of 768 × 1,024 pixels. The stimuli for the auditory discrimination task were 250, 750, and 2,250 Hz pure tones, respectively, presented for 1 s. The 750-Hz tone served as the target tone. E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) was used for presentation and data collection.

Procedure

The study began with practice on all tasks. Specifically, participants practiced the auditory discrimination task alone (until they reached an 80% accuracy criterion); the picture task alone (picture task—encoding phase, FA conditions; distractor task; picture task—retrieval phase); and the DA task, which combined the picture task and the auditory discrimination task. Then the experiment, consisting of longer versions of the same tasks, began. Participants first performed the auditory discrimination task alone. They then encoded a single set of pictures (picture task—encoding phase), according to the condition to which they were assigned: Half of the participants performed the picture task alone, and the other half performed the DA task. A 20-s distractor task separated picture encoding and memory test (picture task—retrieval phase). Participants then performed the auditory discrimination task alone for the second time to examine effects of practice on that task. After a 50-min filled interval, they received a surprise delayed free recall test on the same pictures seen earlier and rated all the pictures for arousal and valence on SAM scales.

Auditory discrimination task alone. The auditory discrimination task that we used as a concurrent task required participants to discriminate between a target tone (fixed for the duration of the experiment) and two distractor tones. The screen was blank during the tone presentation. Ninety tones, 30 of each frequency, were randomly presented at the rate of 1 every 2 s. Six buffer tones were presented before the presentation of the first experimental tone. Participants classified the tones as target or nontarget by pressing one of two marked keys with their dominant hand. Participants always pressed the "target" key with their index finger and the "nontarget" key with their middle finger.

Picture task—encoding phase, FA condition. Picture encoding was intentional. Each picture was presented for 2 s, followed by a 4-s blank interstimulus interval, which was included to reduce carry-over effects. Following picture presentation, participants counted down out loud in decrements of three for 20 s, starting from a three-digit number presented on the screen. They then recalled the pictures for 3 min.

Picture task—retrieval phase. We tested memory with a free recall procedure that closely followed Bradley et al. (1992). The free recall paradigm allowed us to test memory immediately, when recognition memory might be at ceiling. The free recall measure is also more akin to real-life recall of visually experienced scenes and is in this sense more ecologically valid. Participants were asked to describe verbally the pictures they remembered (deviating from Bradley et al., who asked for written descriptions). The recall instructions emphasized a succinct, yet informative description (e.g., "a car accident," "a man sweeping"). The exact instructions for this task, for both immediate and delayed testing, were as follows:

> Please recall all the pictures you can remember in any order. The experimenter will tape your recall. Try not to describe each picture in detail (1–4 words are usually enough). If the experimenter isn't sure which picture you have in mind, she will ask you about it at the end. The experimenter will tell you when time is up.

The experimenter coded the responses as matches or nonmatches of study pictures and asked participants to elaborate on any ambiguous descriptions at the end of the recall period, to overcome potential confusions mentioned in Bradley et al. (1992). Just as in Bradley et al., we found that in almost all cases matching the descriptions to pictures was clear and straightforward, as was evident from the high interrater agreement. The surprise delayed recall test followed a 50-min filled interval during which participants were engaged in an unrelated face-processing task, which was optimal for preventing rehearsal of the pictures. The delayed recall test was 5 min long.

DA task. The tone and encoding phases of the picture task were performed together. Again, participants were told that the auditory discrimination task was the primary task. To ensure the auditory discrimination task was demanding enough when performed concurrently with the picture task, we paired three tones with each picture. The first tone sounded simultaneously with picture presentation, a stimulus-onset asynchrony (SOA) of 0 s. The second tone sounded at picture offset (SOA = 2 s). The third tone sounded during the interstimulus interval, 2 s after picture offset and 2 s before the onset of the next picture (SOA = 4 s). The

Table 1
Mean Arousal and Valence Ratings of Pictures Used in Experiments 1 and 2

	Arousal		Valence	
Experiment	*M*	*SD*	*M*	*SD*
1				
Related neutral	3.33	0.36	4.97	0.28
Negative	6.76	0.58	2.4	0.46
Positive	6.42	0.26	6.92	0.35
2				
Related neutral	2.54	0.52	4.95	0.35
Negative	5.65	0.72	2.83	0.57
Random neutral	2.78	0.56	4.97	0.40

retrieval phase of the picture task was identical in the FA and the DA conditions.

Results

Picture Memory

We counted the number of correctly recalled pictures of each type for each participant. Descriptions limited to one thematic element in a picture were counted as correct recall to prevent potential confounds between emotional and neutral pictures in the number of recallable details (e.g., the description “child running” without mentioning a soldier in the background was counted as correct). A second rater, unaware of the goals of the study, listened to the taped recall of 25% of the participants.[1] The two raters agreed on 98% of the cases. Discrepancies were resolved through discussion.

We analyzed memory performance with a 2 (memory delay: 20 s, 50 min) × 3 (picture type) repeated measures ANOVA with task as a between-subjects factor. As shown in Figure 2, picture memory was better under FA than under DA, $F(1, 46) = 23.13$, $p < .001$, partial $\eta^2 = .33$. Picture memory was better in immediate testing than after a delay, $F(1, 46) = 6.95$, $p < .05$, partial $\eta^2 = .13$. The effect of picture type on memory was also significant, $F(2, 92) = 56.64$, $p < .001$, partial $\eta^2 = .54$. Participants recalled the positive, $F(1, 46) = 41.88$, $p < .001$, partial $\eta^2 = .48$, and the negative, $F(1, 46) = 138.52$, $p < .001$, $\eta^2 = .75$, pictures better than the neutral pictures. The effect of picture type and the advantage of both positive and negative items over neutral pictures were still significant when analyzing each task separately. More important, the interaction of task and picture type was significant, $F(2, 92) = 9.44$, $p < .001$, partial $\eta^2 = .17$ (see below for delay effects). To explore the Task × Type interaction, we analyzed memory cost, calculated as the difference between recall scores of yoked participants in the FA and DA conditions in the immediate memory test. Participants were yoked according to their assignment to counterbalancing variables. Planned contrasts showed that relative to neutral pictures, memory cost was smaller for positive pictures, $F(1, 23) = 6.93$, $p < .05$, partial $\eta^2 = .23$, and negative pictures, $F(1, 23) = 24.40$, $p < .001$, partial $\eta^2 = .51$. One-sample

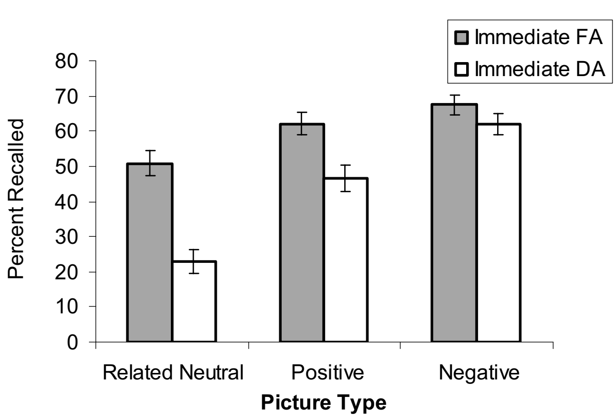

Figure 2. Memory performance in Experiment 1 as a function of picture type and attention condition in immediate testing. Error bars represent standard error. FA = Full attention; DA = divided attention.

t tests showed that memory costs were significantly different from zero for both positive and neutral pictures in both immediate and delayed testing: positive immediate $t(23) = 7.00$, $p < .001$; positive delayed $t(23) = 1.70$, marginally significant at $p = .10$; neutral immediate $t(23) = 3.06$, $p < .001$; and neutral delayed $t(23) = 9.14$, $p < .001$. Memory cost was not significant for negative pictures, $p > .10$.

Effect of study-test delay. The three-way interaction between delay, picture type, and task was significant, $F(2, 92) = 3.518$, $p < .05$, partial $\eta^2 = .07$. This high-order interaction did not qualify the Task × Type interaction; the main effects and the interaction remained significant in two separate repeated measures ANOVAs for each delay condition. Bonferroni-corrected *t* tests between immediate and delayed memory for each picture type under FA and DA showed that only neutral pictures under divided attention conditions significantly suffered from the delay, $t(23) = 3.11$, $p = .005$. Delay also increased the correlation between arousal and free recall of individual pictures (immediate FA, $r = .43$, $p < .05$; immediate DA, $r = .69$, $p < .01$; delayed FA, $r = .38$, $p < .05$; delayed DA, $r = .74$, $p < .001$). Although the difference between these correlations was not significant in the immediate test ($Z = -1.42$, $p > .10$), it was larger and significant in the delayed test ($Z = -2.06$, $p < .05$). In summary, we found attenuated forgetting of emotional pictures, but only when participants encoded pictures under DA.

Additional Analyses of Picture Memory

Semantic clustering. To examine how grouping was influenced by the divided attention and the delay manipulation, we looked at semantic clustering, using the list-based semantic clustering index (Stricker, Brown, Wixted, Baldo, & Delis, 2002). This index is a per-list measure of participants’ tendency to recall items consecutively from the same category. Here we treated the three picture types as categories. Clustering was reduced under DA relative to FA, $F(1, 45) = 9.61$, $p < .001$, partial $\eta^2 = .18$, replicating previous findings (Park et al., 1989). Reliance on clustering increased at the delayed test, $F(1, 45) = 9.92$, $p < .01$, partial $\eta^2 = .18$. The interaction between the level of attention and the study-test delay was not significant. The clustering analysis thus serves as another indication of the mnemonic effects of the divided attention and the delay manipulations.

Number of words used in recall. The second rater also transcribed these data and counted the number of words used to describe each picture for 25% of the participants. The number of words used to describe neutral pictures ($M = 5.73$, $SD = 2.79$) was smaller than the number of words used to describe positive ($M = 6.04$, $SD = 2.20$) and negative ($M = 7.24$, $SD = 2.25$) pictures, a marginally significant effect, $F(2, 78) = 2.92$, $p = .06$, partial $\eta^2 = .07$.

Effect of output order. Because we measured memory with free recall, it is possible that participants were biased to recall emotional items first, which could then have interfered with memory for the neutral items and led to reduced memory for them for motivational or strategic reasons rather than for mnemonic ones. In

[1] A pilot study, similar to Experiment 1 but with random neutral pictures, had the second rater code 75% of the recall output and showed a similarly high agreement rate.

an analysis limited to the first 10 output positions, we did not find evidence for this alternative as manifested in a nonsignificant Type × Output Order interaction ($F < 1$) and no significant three-way interactions with output order.

Auditory Discrimination Task

Participants' mean accuracy and median latency were computed for each condition (all the following latency analyses use the median to minimize outlier influence). There were no significant differences between the two times DA participants performed the auditory discrimination task on its own (accuracy, $p > .10$; latency, $p = .07$). We therefore collapsed participants' performance and compared it with their performance of this task under DA conditions (see Table 2). Performance was worse under DA than under FA both in terms of accuracy, $t(24) = 6.41$, $p < .001$, and latency, $t(24) = 8.85$, $p < .001$. The accuracy and latency of participants' performance on the auditory discrimination task under DA were analyzed with two 3 (picture type: neutral, negative, positive) × 3 (SOA: 0 s, 2 s, 4 s) repeated measures ANOVAs. Participants performed the concurrent task less accurately when they viewed emotional pictures relative to when they viewed neutral pictures. Picture type had a significant effect on accuracy, $F(2, 46) = 3.93$, $p < .05$, partial $\eta^2 = .14$. Planned contrasts showed that compared with neutral pictures, accuracy was lower for positive pictures, $F(1, 23) = 6.67$, $p < .001$, partial $\eta^2 = .225$, and negative pictures, $F(1, 23) = 4.40$, $p < .001$, partial $\eta^2 = .16$. The difference between positive and negative pictures was not significant ($t < 1$). SOA only affected latency, $F(2, 46) = 5.42$, $p < .01$, partial $\eta^2 = .19$. Bonferroni-corrected pairwise comparisons showed that participants responded more slowly at an SOA of 2 than at an SOA of 4 ($p < .01$). This pattern possibly reflected an increase in concurrent task cost after picture content was fully comprehended, followed by a return back to baseline speed. None of the other effects was significant.

Mediator analysis. Mediation in immediate EEM was tested in an analysis across stimuli (the same results were obtained in the analysis of delayed EEM). Valence and arousal ratings of participants in the two attention conditions were highly correlated ($r > .90$). Therefore, we averaged ratings across conditions to obtain the most reliable estimates of pictures' arousal and valence. Attention is reflected both in more errors and in delayed responses. To obtain a single measure of attention, we standardized and averaged the cost scores to indicators. As expected, arousal was significantly correlated with immediate recall in the divided and FA conditions ($r = .64$, $p < .05$, and $r = .42$, $p < .001$, respectively). In contrast, valence was not significantly related to memory in the FA condition ($r = .21$, $p > .10$) but had a marginal effect on memory in the divided attention condition ($r = .31$, $p = .06$; see separate analyses below). Also expected was a significant correlation between arousal and attention ($r = .52$, $p < .01$), and attention was a significant predictor of divided attention memory, ($r = .66$, $p < .001$). A regression analysis revealed that arousal and attention uniquely contributed to memory ($\beta = .41$, $p = .01$, and $\beta = .45$, $p < .01$, respectively). The bootstrapped ratio (1,000 bootstraps) for indirect effects (Preacher & Hayes, 2004), a test comparable to the Sobel test (Sobel, 1982) but specialized for use with relatively small sample sizes, showed that the reduction in the effect of arousal on memory from .64 to .41 when attentional mediation was included in the model was significantly different from zero with 95% confidence ($p < .05$). These results support the hypothesis that attention partially mediates the effect of arousal on memory but does not completely account for it (see Figure 1, bottom panel).

Separate regression analyses for positive and neutral pictures revealed that attention was a significant mediator for positive pictures ($\beta = .74$, $p < .001$), but arousal did not contribute to memory beyond its effect on attention ($\beta = .16$, $p > .10$). By contrast, a regression analysis for negative and neutral pictures revealed that only arousal significantly contributed to memory ($\beta = .75$, $p < .001$), but attention did not ($\beta = .19$, $p > .10$). The conclusion was supported by a bootstrapped ratio for indirect effects that was significantly different from zero with 95% confidence ($p < .05$). This finding suggests that attention may be sufficient to account for EEM for positive pictures, but not for EEM for negative pictures.

Table 2
Mean Accuracy and Latency of Auditory Discrimination Task Performance: Experiment 1

Picture type and tone onset asynchrony	Accuracy (%) *M*	Accuracy (%) *SE*	Latency (milliseconds) *M*	Latency (milliseconds) *SE*
Positive				
0	87.08	2.21	621	34
2	87.50	2.71	673	39
4	91.67	2.06	600	36
Negative				
0	90	2.09	687	50
2	87.08	2.85	683	31
4	89.17	2.32	604	35
Related neutral				
0	92.92	1.85	657	34
2	90	2.48	645	37
4	94.58	1.47	600	36
FA	90	1	446	16

Note. FA = full attention.

Discussion

Experiment 1 showed a typical EEM effect in both FA and DA conditions. EEM was stronger for negative than for positive pictures but was significant for both of these picture types, under both attention conditions. Below we discuss the contribution of semantic relatedness and attention, in turn.

Role of Semantic Relatedness in EEM

The FA results in Experiment 1 ruled out the possibility that differences between memory for emotional and neutral items were due to differences in semantic relatedness—an important aspect of participants' memory for the pictures, as attested to by the semantic clustering of their free recall—because all picture types were equally related. This presence of EEM over and above the effects of semantic relatedness with pictoral stimuli is different from our earlier finding with verbal stimuli. There, EEM was eliminated when semantic relatedness was equated across emotional and neutral words (Talmi & Moscovitch, 2004). It is possible that differences in arousal between words and pictures (viewing the word *rape* vs. a picture of a dead rape victim) accounts for the discrepancy. For emotionality to affect memory over and above the effects of relatedness, it may be necessary to use more arousing stimuli, such as pictures; single words that are not taboo may just not be arousing enough (Buchanan, Etzel, Adolphs, & Tranel, in press; Talmi & Moscovitch, 2004).

Role of Attention in EEM

Participants performed worse on the concurrent tone task when they viewed the emotional pictures, even though the tone task was designated as primary, indicating that emotional capture of attention was involuntary. The coupling of reduced memory cost with increased attention cost for emotional pictures suggested a potential tradeoff. The mediator analysis supported this interpretation by showing that the mediated path from emotional arousal to memory via attention was significant. More important, breaking down this effect according to valence showed that negative and positive emotions operated differently. The mediated path completely accounts for the effect of positive emotion on memory. This is the first demonstration of which we are aware that attention mediates the effect of emotion on memory. By contrast, for negative pictures, the direct effect that negative emotion had on memory remained even when attentional effects were taken into account statistically.

We minimized strategic encoding effects by instructing participants to treat the auditory discrimination task as their primary task. Accordingly, the reduced semantic clustering under divided attention shows that participants used relational strategies less in these conditions. In fact, the influence of negative emotion on memory was not significantly mediated via attention. It is important to realize that concurrent task cost, therefore, not only serves as an operationalization of attention to pictures at the initial moment of encoding, but encompasses potential effects of strategic interitem elaboration and rehearsal during the interstimulus interval. Therefore, the direct path between negative emotion and memory is also independent of such encoding effects. This conclusion is in line with studies showing that negative EEM occurs even with incidental encoding instructions (e.g., Bradley et al., 1992; Buchanan & Lovallo, 2001; Ochsner, 2000).

Notably, the auditory discrimination task used in the DA condition was designed to be resource demanding but not resource exhausting. We wanted to allow participants to process the identity and the emotionality of the stimuli, but to a somewhat lesser or degraded degree. In other words, the concurrent task chosen was demanding enough to cause performance deficits, but not so demanding as to result in inattentional blindness (Pessoa, Kastner, & Ungerleider, 2002). The fact that participants viewed the pictures for 2 full seconds, and the fact that the concurrent task was taxing another modality, make it reasonable to assume that the emotional value of both positive and negative stimuli was registered in the amygdala (Hamann, Ely, Hoffman, & Kilts, 2002). The pathways of emotionally motivated attention following amygdala activation are not yet sufficiently understood, but the involuntary nature of the attentional capture in our task suggests reentrant amygdala feedback to sensory processing sites (Vuilleumier, 2005). Our results suggest that enhanced sensory processing that leads to enhanced memory is more critical for positive than for negative stimuli. For negative stimuli, enhanced sensory processing seems not to contribute to better memory, but may be important for perception and action. Taken together, our findings suggest that the mediation hypothesis accounts best for the positive EEM, whereas the modulation hypothesis accounts best for negative EEM.

Task instructions encouraged participants to ignore the pictures, to some extent. Raymond, Fenske, and colleagues (Raymond, Fenske, and Tavassoli, 2003; Fenske, Raymond, & Kunar, 2004) showed that ignored stimuli are evaluated more negatively. This would have led to reduced EEM under DA relative to FA because the negative pictures were less ignored than the neutral ones; however, the opposite occurred. Further research would be needed to test if devaluation also occurs with our markedly different paradigm and stimuli.

Additional Findings

In our study, a short (50-min) delay between study and test was not sufficient to reveal a strong differential forgetting effect; differential forgetting was only present when pictures were encoded under DA. This is in contrast to prior findings with words in which a delay of the same length was used (LaBar & Phelps, 1998). Under FA, the richer pictorial stimuli could support multiple retrieval routes so that a longer delay may be needed before differential forgetting can be seen. To probe this finding further, we showed that correlation with arousal is higher in DA and delayed tests relative to FA and immediate tests, possibly because when the memory trace of the rich pictorial stimulus is relatively degraded, arousal plays a larger role. Future research is needed to determine whether the difference in material type is the cause of this discrepancy.

Although we attempted to match emotional and neutral stimuli closely, emotional stimuli may have lent themselves to simpler description or an output bias, making it easier for participants to recall them than neutral pictures. Neither condition held. Analysis of number of words used in recall showed the opposite—more words were used to describe emotional than neutral pictures. As well, there was no evidence of bias in output order between emotional and neutral items. Thus, neither simplicity of description nor output bias accounted for EEM.

To summarize, semantic relatedness did not account for all of EEM for either positive or negative pictures. Experiment 1 showed that part of the effect of emotion on memory is mediated by its effects on attention. Mediation via attention completely accounted for positive EEM but did not contribute significantly to negative EEM, suggesting that negative emotion affects memory more directly. In Experiment 2, we wished to extend this latter finding by equating the amount of attention paid to negative and neutral items. In Experiment 2, we also tested the effect of semantic relatedness on emotion empirically by comparing negative pictures with both equally related and random neutral pictures.

Experiment 2

Because emotional items garner extra attention involuntarily, independent of participants' attempts to attend primarily to the concurrent task, it may seem that more attention will always be paid to the emotional items. One approach to equating the amount of attention to emotional and neutral items is to use neutral items that are especially interesting. Such a strategy runs aground on the finding that interesting neutral items are themselves arousing and, therefore, not really neutral (Hamann et al., 1999, 2002; Lang, Greenwald, Bradley, & Hamm, 1993; Mourao-Miranda et al., 2003).

To create a situation in which attention is allocated equally to neutral and emotional items, we manipulated task emphasis instructions. Participants in the DA condition were asked either to treat both the picture and the auditory discrimination task as equally important (50/50 emphasis instructions) or to treat the auditory discrimination task as the most important (tone emphasis instructions). The 50/50 emphasis should result in greater allocation of attention to the pictures relative to the tone emphasis. Although emotional pictures are likely to receive more attention in both conditions, the amount of attention devoted to neutral pictures under 50/50 emphasis may match the amount of attention devoted to emotional pictures when the auditory discrimination task is emphasized. Matching of attention allocation will be manifested in equivalent concurrent task cost for neutral pictures under 50/50 emphasis and for emotional pictures under tone emphasis. On the basis of the results of Experiment 1, we expected to find EEM in this critical comparison. If the effect of negative emotion on memory is independent of attention, then EEM should be evident even when attention is equated.

The second purpose of Experiment 2 was to test the contribution of semantic relatedness to EEM empirically, by comparing emotional items with an equally related set of pictures, as well as with a random set of pictures. For the FA condition, we predicted that EEM would be smaller in the comparison with equally related pictures relative to the comparison with randomly selected pictures. On the basis of the semantic clustering results in Experiment 1, we predicted that the difference between related and random neutral pictures would be smaller under DA than under FA. Finally, the third goal of Experiment 2 was to replicate Experiment 1 with a new set of pictures and slightly modified instructions (emphasizing accuracy over latency).

Method

Participants

Forty-eight University of Toronto undergraduates (20 men, 28 women; mean age = 21.19 years, *SD* = 3.35) completed the study for either course credit or a payment of $5. One participant had outlying results on the auditory discrimination task and was replaced. All participants gave informed consent.

Material

Two sets of pictures included 10 negative pictures, 10 related neutral pictures (domestic scenes), and 10 random neutral pictures. The negative pictures were drawn solely from the IAPS (Lang et al., 1999), whereas the neutral pictures were drawn from the IAPS and from the Internet. All pictures were resized to 400 × 500 pixels. The number of pictures depicting people was matched across picture types and sets. A separate group of 15 participants rated all pictures on valence and arousal on SAM scales. These participants also rated the pictures for visual complexity using a 7-point Likert scale. Complexity was defined as the number of objects in the picture and the complexity of each object (following Ochsner, 2000). One participant was replaced owing to a negative correlation with the others, and ratings were used from the remaining 14 participants who highly agreed with each other (standardized item $\alpha > .90$ for all three ratings). An additional group of 13 participants rated all possible picture pairs in each set for relatedness on a 7-point Likert scale. These ratings were then recoded (1–2 = low relatedness, 3–5 = medium relatedness, 6–7 = high relatedness). One participant was replaced owing to a low correlation (<.4) with the others, and ratings were used from the remaining 12 participants who highly agreed with each other (standardized item $\alpha = .87$).

Picture scores were computed across participants, averaged for each of the three picture types within each set and analyzed with separate ANOVAs. The effects of valence, $F(2, 54) = 145.46$, $p < .001$; arousal, $F(2, 54) = 159.05$, $p < .001$; and relatedness, $F(2, 54) = 27.68$, $p < .001$, were significant, but the effects of visual complexity were not ($p > .10$). The main effect of set and the interaction were not significant ($p > .10$). Planned contrasts showed that negative pictures were rated as more negatively valenced ($p < .001$) and more arousing ($p < .001$) than related and neutral pictures, which did not differ in valence ($p > .10$) or in arousal ($p > .10$; see Table 1). Random neutral pictures had lower relatedness than categorized and negative pictures ($p < .001$), which did not differ in relatedness ($p > .10$).

The stimuli for the auditory discrimination task were the same as in Experiment 1.

Procedure

The procedure was equivalent to that of Experiment 1 except for the following. Because there was no significant order-dependent difference in performance on the auditory discrimination task in Experiment 1, participants in Experiment 2 always performed the auditory discrimination task before they received two trials of the picture task. This served effectively as practice on the auditory discrimination task, so worse performance on this task when it is later performed concurrently with picture encoding would be even more striking. Second, half of the participants performed the two picture task trials under FA, and the other half performed the two picture trials under DA. Third, DA participants studied one set of pictures under instructions to treat both picture and auditory discrimination tasks as equally important (50/50 emphasis) and one set of pictures under instructions to treat the auditory discrimination task as the more important task (tone emphasis). The order of the emphasis conditions and the allocation of picture set to each task were counterbalanced. Fourth, participants were instructed to emphasize accuracy over speed. This change should facilitate the comparison between the two emphasis conditions. Finally, only immediate recall was tested.

Results

Three manipulation checks were carried out. First, to ensure that our emphasis manipulation was meaningful, we needed to show that it succeeded in affecting both auditory task and picture memory performance. Because of the instructions to maximize accuracy, we expected that the effects of emphasis instructions would be manifested as changes in latency. As predicted, concurrent task performance latency was faster under tone emphasis instructions than under 50/50 emphasis instructions, $t(23) = -2.09$, $p < .05$, but accuracy did not differ ($p > .10$). In addition, picture memory was better under 50/50 emphasis than under tone emphasis, $t(23) = -2.58$, $p < .05$.

Second, we wanted to see whether, as in Experiment 1, auditory task performance under tone emphasis suffers when participants view emotional pictures. Only if it does would our critical cross-condition comparison be necessary. As predicted, latency in the tone emphasis condition was influenced significantly by picture type, $F(2, 46) = 3.69$, $p = .05$, partial $\eta^2 = .14$. The main effect on latency was a result of slower reaction times when participants viewed negative versus related neutral pictures, $F(1, 23) = 6.85$, $p < .05$, partial $\eta^2 = .23$, and a marginally significant effect when participants viewed negative versus random neutral pictures, $F(1, 23) = 4.08$, $p = .055$, partial $\eta^2 = .15$. There were no significant effects for accuracy ($p > .10$).

Third, we needed to show that performance on the auditory discrimination task when viewing emotional pictures under tone emphasis was equivalent to performance on this task when viewing neutral pictures under 50/50 emphasis. To examine the three conditions of interest, we collapsed across SOAs and analyzed accuracy and latency to respond to the tone as a function of picture type (even stronger effects were obtained at SOA = 0). More important, participants attended to related neutral or random neutral pictures under 50/50 emphasis instructions just as much as they attended to the emotional pictures under tone emphasis instructions, as shown in Figure 3. There were no latency differences, $F(2, 46) = .742$, $p = .48$, partial $\eta^2 = .03$. Numerically, reaction times were even slower when viewing neutral pictures relative to negative pictures in this cross-condition comparison. Similarly, the differences in accuracy between the three conditions of interest were not significant, $F(2, 46) = 1.83$, $p = .17$, partial $\eta^2 = .07$.

Next, having established that our manipulation succeeded in equating performance on the auditory discrimination task across the two emphasis conditions, the critical comparison would be between memory for the pictures studied in these conditions.

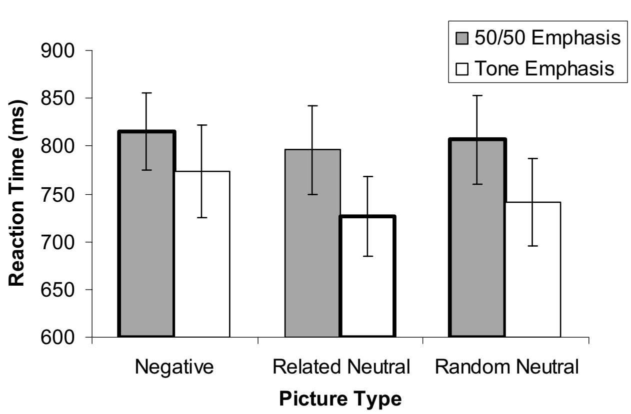

Figure 3. Concurrent task performance latency in Experiment 2 as a function of picture type and emphasis instructions. Boldface bar frames represent the three conditions of the critical comparison (see text). Error bars represent standard error.

Strikingly, despite the absence of difference in the indicators of attention across these conditions, memory performance differed, $F(2, 46) = 22.93$, $p < .001$, partial $\eta^2 = .50$. Figure 4 shows that although all picture types were attended to equally, memory for emotional pictures was still significantly better than memory for related pictures, $F(1, 23) = 27.48$, $p < .001$, partial $\eta^2 = .54$, or for the random neutral pictures, $F(1, 23) = 49.89$, $p < .001$, partial $\eta^2 = .68$.

The memory advantage of emotional over neutral pictures was larger in the comparison of negative to random pictures than in the comparison of negative to related neutral pictures, $t(23) = 2.35$, $p < .05$. Relatedness increased memory for neutral pictures under FA, $t(23) = 2.35$, $p < .05$, but not significantly so under DA, 50/50 emphasis $t(23) = .84$, $p > .10$, and tone emphasis $t(23) = 1.36$, $p > .10$.

Finally, we wanted to see whether the results of this experiment, with a new picture set and slightly modified auditory discrimination task instructions (emphasizing accuracy over speed), replicated the results of the previous experiments. For this purpose, we compared data from the tone emphasis instructions condition with half of the FA data, according to the counterbalancing conditions. Participants performed the auditory discrimination task worse under DA than under FA (see Table 3). This effect was statistically significant for latency, $F(2, 46) = 81.87$, $p < .001$, partial $\eta^2 = .78$, but not for accuracy ($p > .10$). There was a marginally significant effect of task on latency, $F(1, 23) = 3.47$, $p = .08$, partial $\eta^2 = .12$, and a main effect of SOA on both accuracy, $F(2, 46) = 4.89$, $p < .05$, partial $\eta^2 = .18$, and latency, $F(2, 46) = 17.02$, $p < .001$, partial $\eta^2 = .42$. On the basis of data from Experiment 1, we examined these effects with planned contrasts and found that responses were more accurate as well as faster at an SOA of 4 relative to an SOA of 0, accuracy $F(1, 23) = 9.73$, $p = .005$, partial $\eta^2 = .30$; latency $F(1, 23) = 32.36$, $p < .001$, partial $\eta^2 = .58$, or an SOA of 2, accuracy $F(1, 23) = 4.64$, $p < .05$, partial $\eta^2 = .17$; latency $F(1, 23) = 16.70$, $p < .001$, partial $\eta^2 = .42$.

As in Experiment 1, the cost of dividing attention at encoding was larger for the negative pictures. Participants in the FA condition had overall better memory than DA participants who received tone emphasis instructions, $F(1, 46) = 17.59$, $p < .001$, partial $\eta^2 = .28$. More important, there was a significant Task $\times$ Type interaction, $F(2, 92) = 3.97$, $p < .05$, partial $\eta^2 = .08$. Memory cost, calculated as in Experiment 1, was affected by picture type, $F(2, 46) = 4.45$, $p < .05$, partial $\eta^2 = .16$, and was higher for the emotional pictures, $F(1, 23) = 7.00$, $p < .05$, partial $\eta^2 = .23$, than for the random neutral or the related neutral pictures, which did not differ from each other ($p > .10$). One-sample t tests showed that memory cost was significant for related neutral pictures, $t(23) = 3.86$, $p < .001$, and random neutral pictures $t(23) = 3.11$, $p < .01$, but not for the negative pictures ($p > .10$). The advantage of emotional over related pictures, and of related pictures over random neutral pictures, remained when we analyzed each one of the tasks (FA and the two DA conditions) separately.

Discussion

Memory for negative pictures encoded under tone instructions was better than memory for neutral pictures encoded under 50/50 instructions, even though attention allocation was held constant in

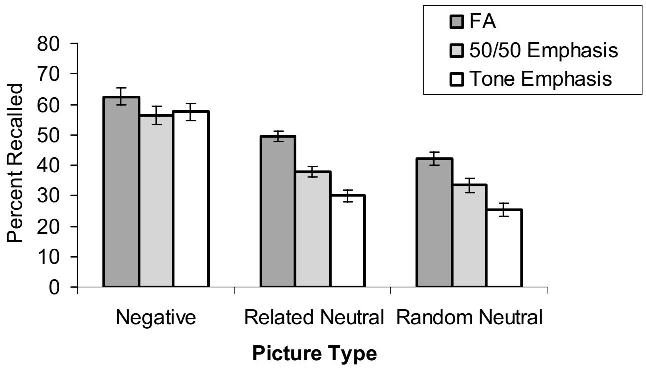

Figure 4. Memory performance in Experiment 2 as a function of picture type and attention condition (FA–DA with 50/50 emphasis instructions, DA with tone emphasis instructions). Error bars represent standard error. FA = Full attention; DA = divided attention.

these conditions. This result is a stronger demonstration of the principle that was already apparent in the mediator analysis of Experiment 1. Experiment 2 thus added converging empirical evidence to the demonstration in Experiment 1 that even though emotional picture content enhances both attention allocation at encoding and subsequent memory for these pictures, the benefit to memory is not dependent on the increased attention.

Like attention, relatedness accounted for part but not for all of EEM. The results showed that EEM was smaller in the comparison with related neutral pictures relative to the comparison with random neutral pictures but was still substantial and significant when relatedness was controlled. The DA manipulation was effective in reducing the role of relatedness in memory for neutral pictures; the advantage of related over random neutral pictures was only significant under FA, but not under DA. Because participants allocate more attention to emotional pictures under DA, the extra attention could help participants use the relatedness information so that emotional pictures would benefit more from relatedness than the neutral pictures, even when both types are equally related. The critical cross-condition comparison, in which both emotional and neutral pictures are attended to equally, removed the relatedness confound completely, but EEM remained.

Experiment 2 replicated all of the important findings of Experiment 1. As a consequence of the instruction to emphasize accuracy over latency, the effects of the attention manipulation were more apparent in the latency measure, and participants were more accurate but slower in this experiment relative to Experiment 1 (compare Tables 1 and 2).

General Discussion

Our goal in the current study was to understand why emotional items are remembered better than neutral ones when memory is probed shortly after study. Specifically, we wanted to know whether immediate EEM was mediated by the enhanced attention emotional items receive at encoding and by their higher semantic relatedness relative to neutral items (see Figure 1, top panel). The study documented these differences in attention and relatedness between emotional and neutral items in a typical encoding paradigm and showed that they account for some, but not all, of the effects of emotion on memory. Specifically, the study had three main findings. First, semantic relatedness partly accounts for EEM. Second, attention completely accounts for EEM for positive pictures. Third, negative emotion affects memory directly and independently of attention. We now discuss each of these findings in turn.

The Role of Semantic Relatedness

Semantic relatedness contributes to EEM but does not completely account for it. Experiment 2 showed that semantic relatedness accounted for part of the effect of negative emotion on memory, but not for all of it, and Experiment 1 showed that controlling semantic relatedness does not eliminate EEM for either positive or negative pictures. The importance of organization to

Table 3
Mean Accuracy and Latency of Auditory Discrimination Task Performance: Experiment 2

Picture type and tone onset asynchrony	Tone emphasis				50/50 Emphasis			
	Accuracy (%)		Latency (milliseconds)		Accuracy (%)		Latency (milliseconds)	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Related neutral								
0	94.58	1.47	734	41	95.00	2.00	814	47
2	96.67	1.30	744	34	94.58	1.90	797	43
4	96.67	2.14	668	35	97.08	0.95	707	37
Negative								
0	91.67	2.46	827	49	90.00	2.33	843	54
2	92.08	2.82	773	45	91.25	2.11	813	40
4	94.58	2.41	669	38	95.83	1.58	717	34
Random neutral								
0	95.83	1.69	779	46	94.58	1.47	822	43
2	95.00	1.47	776	52	95.83	1.58	815	49
4	94.58	1.59	646	38	97.08	1.27	694	35
FA	96.94	1.12	521	31	95.00	2.00		

Note. FA = full attention.

EEM for pictures is in line with similar findings with verbal stimuli (Buchanan et al., in press; Talmi & Moscovitch, 2004).

Semantic relatedness accounted for a larger portion of the EEM effect under FA and less under DA, possibly because DA reduces the ability to use organizing strategies (Park et al., 1989). This principle was manifested in Experiment 1 in that semantic clustering, an index of organization, was reduced under DA and in Experiment 2 in that related pictures were no longer recalled better than random neutral pictures under DA conditions.

The finding that a portion of the EEM effect is a consequence of the better organization of emotion relative to random neutral items is in line with evidence from neuroimaging research of a network of regions involved in encoding emotional items. The increased activation in prefrontal regions when encoding emotional relative to neutral items has been attributed to enhanced organization and elaboration (e.g. Dolcos et al., 2004a; Kensinger & Corkin, 2004). When activation in these regions was analyzed according to whether these items were subsequently remembered or forgotten, activation in the left inferior and dorsolateral prefrontal cortex was found to be correlated with memory for emotional items (Dolcos et al., 2004a; Kensinger & Corkin, 2004).

Mediation by Attention

We showed that emotional items garner extra attention and that this extra attention accounts for the effect of positive emotion on memory but does not contribute to EEM for negative emotion. Attentional capture by emotional pictures was manifested in participants' lower accuracy on the concurrent task when they viewed emotional pictures in Experiment 1. In Experiment 2, in which accurate performance was emphasized, we observed a differential effect of negative and neutral pictures on latency. Enhanced attention allocation to emotional stimuli under DA meant that participants' attention was less divided when they viewed these items. Divided attention resulted in a larger cost to memory for neutral than for emotional pictures. The overall pattern suggested a tradeoff between the larger EEM obtained under DA and the enhanced attention to emotional pictures in these conditions. Although the effect of emotion on attention and its effect on memory could be independent, the mediator analysis of data from Experiment 1 revealed a significant mediated path between emotion and memory via attention when the positive and negative stimuli were combined and overall emotional arousal was examined. Notably, when positive and negative emotional arousal were considered separately, the mediated effect on EEM via attention was only significant for positive pictures. In fact, the influence of positive emotion on memory was completely accounted for by the influence positive emotion had on attention. Therefore, the second important finding of the current study is that the differential attention allocation at encoding accounts for some of the advantages that emotional stimuli, particularly positive ones, have on memory. To our knowledge, this is the first demonstration that attention mediates the EEM effect.

Direct Effect of Emotion on Memory

The third important finding was that the effect of emotional arousal on memory cannot be attributed solely to its effect on attention. As we noted, although both positive and negative pictures captured attention involuntarily, mediation by attention did not significantly contribute to EEM for negative pictures. This finding is consistent with a recently published study (Kern, Libkuman, Otani, & Holmes, 2005) that found stronger adverse effects of divided attention on memory for neutral and positive pictures than for negative pictures. Experiment 2 supported this conclusion. By manipulating attention directly, we were able to equate the amount of attention devoted to the concurrent task while processing negative and neutral pictures. When we compared memory for equally attended negative and neutral pictures across emphasis conditions, EEM was still evident. Our data thus show that there is a direct memory enhancement associated with negative emotion that is not dependent on the differences in attention allocation or semantic relatedness. Involuntary attention allocation to emotional and neutral items likely serves alerting and orienting functions, but those have different consequences for memory for positive and negative information.

The question that our study leaves open is what, in addition to attention and semantic relatedness, accounts for the direct immediate EEM. The modulation hypothesis in its current formulation cannot account for EEM when the study–test interval is short. Hamann (2001) proposed that immediate EEM may be attributed to attentional causes, whereas others suggested that the enhanced relatedness of emotional material underlies immediate EEM (LaBar & Phelps, 1998; Maratos & Rugg, 2001). Our data show that although differences in attentional allocation and in semantic relatedness between emotional and neutral pictures contribute to immediate EEM, they are not able to account for it completely. Indeed, for negative pictures, there is no significant mediated effect on EEM via attention. Given these results, we can think of three plausible accounts for immediate EEM, about which we now speculate briefly.

The first option is that some residual attention not measured by our procedures still mediates EEM. Specifically, concurrent task cost may not provide an adequate measure of attention for all picture types. For example, the concurrent task cost measure may not have included a unique component of attention to negative pictures but better measured attention to neutral and positive pictures. If that were the case, then the significant direct path between emotion and memory could reflect this unmeasured attention allocation to negative pictures, suggesting that immediate EEM is really the result of attentional differences at encoding. Similarly, that could mean that even though we equated attention allocation using concurrent cost measures in Experiment 2, the two emphasis conditions were still not completely matched for attention. Although the divided attention approach is an uncontroversial method of operationalizing attention (Craik et al., 1996), we cannot claim that it is a perfect measure. However, we see no reason to suppose that it is a better measure of attention for neutral and positive pictures than for negative pictures. Consequently, we consider this to be an unlikely interpretation of our results.

A second alternative is that EEM may be mediated by cognitive factors other than those we examined in our study. Notably, although studies with words routinely control for a host of factors that research has shown to have an effect on memory, there are no norms for any cognitive or perceptual factors for pictures, which are, therefore, rarely controlled for. We controlled for attention and relatedness and for people presence and visual complexity and also ruled out the possibility that the effect of emotionality on free recall was the result of an output bias or a shorter description of emotional pictures. Although our material was controlled more stringently than it had been in previous studies, we could not control for all possible variables (e.g., distinctiveness; Talmi, Luk, McGarry, & Moscovitch, 2007), leaving open the possibility that some as-yet unexamined factor acts as a mediator.

The third alternative is that arousal associated with negative emotions acts directly on memory, unmediated by any other factors. Emotional arousal can act as a glue to enhance the binding of item features (MacKay et al., 2004). MacKay and his colleagues suggested that the context of occurrence in the task is more strongly bound with emotional relative to neutral items, later facilitating their retrieval. The enhanced binding of emotional memory traces with other aspects of the experience could provide alternative retrieval routes and supports later memory. It is important to note, however, that not all aspects of the context are bound together, just those that pertain directly to the eliciting emotional stimulus (e.g., Loftus, Loftus, & Messo, 1987; MacKay & Ahmetzanov, 2005). Memory for incidental, unrelated aspects of the context may actually be worse for emotional than for neutral events.

Enhanced binding of items with their encoding context could explain why item memory is more strongly enhanced when the memory test is sensitive to the richness of the experience. EEM is found in recollection, a process particularly sensitive to trace cohesion, but there is less or no EEM in familiarity (Dewhurst & Parry, 2000, Experiment 1; Kensinger & Corking, 2003; Ochsner, 2000; Sharot & Phelps, 2004b). Similarly, emotionally enhanced binding of an individual item's features could explain why source memory for emotional items is also enhanced (Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; MacKay & Ahmetzanov, 2005; MacKay et al., 2004). Further research would be required to decide to what extent these effects depend on the direct influence of emotion on binding and to what extent they reflect cognitively mediated processes.

At a neurophysiological level, the direct effect on immediate EEM may also depend on the interaction between the amygdala and medial temporal lobe structures (Pitkanen, Pikkarainen, Nurminen, & Ylinen, 2000), although perhaps of a different sort than the hormonal effects on long-term consolidation (Bianchin, Mello e Souza, Medina, & Izquierdo, 1999). Such short-term interactions, for example, contribute to long-term potential, which some believe to reflect or underlay formation of memory traces (Ikegaya, Saito, & Abe, 1995). In humans, there are indications that the amygdala modulates memory formation for items that have just been encoded and may be in a labile short-term memory buffer (e.g., Anderson, Wais, & Gabrieli, 2006; Strange, Hurlemann, & Dolan, 2003). Activation in the amygdala is also associated with subsequent EEM with delays as short as 10 minutes (Kensinger & Corkin, 2004) and with delays of about 1 hr (Dolcos et al., 2004a, 2004b; LaBar & Phelps, 1998). Our findings with a 50-min delay showed modulated forgetting for emotional items only when those were studied under divided attention conditions, when their memory trace was presumably less rich than under full attention conditions. Differences in material complexity have implications for trace strength and could help account for the different time course of short-term emotional memory modulation, as McGaugh suggested (as cited in Walker, 1967, p. 231). Further research would be required to examine if these short-term modulatory effects are the result of the same process that supports long-term modulation in human and animal studies or a different process, possibly related to the amygdala's involvement in a parallel short-term consolidation process (Izquierdo et al., 1998, 2001).

The proposed phasic effect of emotional arousal on short-term consolidation or trace cohesion (Moscovitch, 1995) could help explain how arousal manages to enhance memory for the emotional item alone, without being carried over to adjacent items (Hamann, 2001; Cahill & Alkire, 2004). The riddle of EEM specificity arises because the mechanism postulated by the modulation hypothesis involves peripheral epinephrine release, which operates with a relatively prolonged time frame (Cahill, 2000; Christianson, Nilsson, Mjorndal, Perris, & Tjellden, 1986; McGaugh, 2004). The prolonged, systemic effects of arousal should enhance memory for all items the system encounters, not only the emotional ones; EEM, which reflects a unique advantage to emotional items, cannot be explained by such a mechanism because participants encounter both emotional and neutral items in quick succession in the usual course of human experiments. The specific modulatory influence of the amygdala could be explained more easily if at encoding memory traces of emotional items are already different—for example, more cohesive—from those of neutral items.

Our data suggest that the possible involvement of the amygdala in immediate EEM is unrelated to its downstream effects on the sensory processing of negative emotional items but that such downstream effects are important to EEM for positive emotional items. Under normal conditions, however, when all variables are not controlled for, the memory consequences of the direct effect of negative emotion on an item's memory trace could be complemented by the action of other indirect mechanisms recruited by emotional arousal. Involuntary attention capture would, for instance, increase the probability of noticing emotional events and lengthen the duration of focused attention on them. The better organization of real-life emotional events—for example, through their integration with the self-schema—would further improve their encoding and retrieval. Under normal conditions, therefore, the memory advantage of negative emotion may be a consequence of both the direct and the mediated effects of emotion. This immediate advantage, in turn, carries over to delayed testing situations when it is buttressed by an additional process of amygdalar modulation of long-term consolidation (Cahill & McGaugh, 1998; McGaugh, 2000, 2004). Delayed EEM, according to this framework, reflects three interactive processes: enhanced binding, indirect effects through other cognitive mechanisms, and modulated consolidation.

To conclude, our findings suggest that emotional arousal exerts an effect on memory over and above those mediated by attention and by semantic relatedness, which leads to better immediate memory for emotional relative to neutral items. The semantic relationship between individual emotional increases EEM for items of positive and negative valence. Although both positive and negative emotional stimuli capture attention, the effect of this attentional capture on memory varies with valence. Whereas the effect of positive emotion on EEM is mediated via attention allocation at encoding, that of negative emotion is not mediated by the attention it captures; rather, stimuli that elicit negative emotions seem to have an additional effect on memory either by influencing it directly or via other processes that have not yet been investigated. In real-life situations, when attentional resources are limited and the sources of emotional arousal are intimately interrelated, memory differences between emotional and neutral material would be exaggerated and influenced by mediated and unmediated factors.

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