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Enhanced Memory for Negatively Emotionally Charged Pictures Without Selective Rumination

Christine R. Harris and Harold Pashler
University of California, San Diego

Emotionally charged materials have been found to elicit higher levels of recall in many studies. However, the use of slow presentations and/or uncontrolled retention intervals may have allowed subjects to rehearse emotional materials preferentially. The authors presented a series of 5 pictures (1 emotionally charged) at a rate of 4 pictures per second, precluding selective rehearsal. In Experiment 1, subjects recalled the pictures immediately or after performing an arithmetic task for 20 s. In Experiment 2, the pictures were described as to-be-ignored distractors, and the memory test was unexpected. Stimulus emotionality greatly enhanced recall in all conditions. The speed of the presentations and the fact that enhancement did not spread to temporally adjacent items argues against some widely discussed mechanisms for emotional enhancement.

Comparisons of memory for emotionally charged stimuli or events versus more neutral stimuli or events have been carried out for over a 100 years using a diverse range of stimuli, tasks, and measures. With some notable exceptions, the typical finding has been better memory for emotionally charged materials. One potential mechanism for this is that people ruminate on and rehearse emotionally significant materials more than they do for neutral materials. Previous studies have not clearly demonstrated whether enhanced memory will occur for emotionally charged materials when the conditions preclude selective rumination and rehearsal. The present study attempted to do so by using very rapid presentations of pictures (neutral vs. emotional in character) and filled retention intervals, providing no "free time" for selective rumination. An additional goal in this study was to determine whether, in the context of such rapid presentations, emotional enhancement can be temporally isolated to just a single emotionally charged item or whether the enhancement will encompass neutral materials that appear immediately before and after the emotionally charged item. If, under these circumstances, an individual emotionally charged item is better remembered than are neutral materials, it would suggest that the memory enhancement triggered by stimulus emotionality cannot be wholly dependent on any slow-acting emotional, neural, and/or cognitive processes. As described in the introduction, this may provide useful constraints on theorizing about how emotion affects memory.

Christine R. Harris and Harold Pashler, Department of Psychology, University of California, San Diego.

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Correspondence concerning this article should be addressed to Christine R. Harris, Department of Psychology, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0109. E-mail: charris@ucsd.edu

Enhanced Memory for Emotional Words and Pictures

The majority of studies of enhanced memory for emotionally charged stimuli have focused on the most convenient form of stimulus, namely, words. Several dozen papers from the 1930s and 1940s compared memory for emotional (mostly negative, but sometimes positive) and neutral words (e.g., Rapaport, 1942; Silverman & Cason, 1934). Most found better memory for the emotionally charged words compared with neutral words. More recently, Rubin and Friendly (1986) examined numerous factors potentially affecting word recall and concluded that emotionality has a "persistent effect over different experiments and different samples of words" (p. 86), an effect not attributable to the other factors predicting recall.

Common sense would suggest that emotionally charged pictures often produce more intense emotional reactions than do words (De Houwer & Hermans, 1994), and emotional content has been found to enhance picture memory as well. Bradley, Greenwald, Petry, and Lang (1992) showed subjects color photographs of neutral scenes, positive scenes (e.g., ski jumper, strawberry pie) and negative scenes (e.g., mutilated face). Subjects were given an immediate recall test (attempting to produce a word or phrase that would describe each picture) and another similar test 1 year later. Both highly pleasant and highly unpleasant slides (based on subjects' ratings) were remembered better than were the neutral slides. Similar advantages for emotional materials have been observed for film clips (Guy & Cahill, 1999) and slides that are accompanied by narratives creating an emotional context (Burke, Heuer, & Reisberg, 1992; Christianson & Loftus, 1991; Heuer & Reisberg, 1990, 1992).

Whereas memory enhancement for emotional materials is the rule, emotionally charged stimuli have sometimes been found to elicit reduced, rather than enhanced, memory. This usually seems to occur when the information that is later tested is peripheral or unrelated to the specific focus of the emotional context (for a discussion, see Burke et al., 1992). For example, seeing an armed mugger (or even a picture of one) may direct eye fixations and attention toward the weapon and away from other stimuli that

might be tested (e.g., the face of a perpetrator). This phenomenon of "weapon focus" remains controversial in the eyewitness memory literature (Cooper, Kennedy, Herve, & Yuille, 2002; Egeth, 1993; Steblay, 1992), but it seems likely that it occurs under some conditions (e.g., Loftus, Loftus, & Messo, 1987; Shaw & Skolnick, 1999). This effect does not negate the existence of emotional memory enhancement but merely suggests that under special conditions it may be overridden by changes in attention or eye fixations (cf. Christianson, 1992; Christianson, Loftus, Hoffman, & Loftus, 1991). It has also sometimes been found that the beneficial effects of emotion on memory are apparent only after relatively long retention intervals (Butter, 1970; Kleinsmith & Kaplan, 1964; LaBar & Phelps, 1998; Quevedo et al., 2003), although the conditions under which this is the case have not yet been delineated.

Explaining Emotionality Effects

What causes enhanced memory typically observed for emotionally charged inputs? As noted above, one factor that likely contributes to at least some memory enhancement for emotional material is an increased tendency for people to ruminate on emotionally charged stimuli (henceforth referred to as "selective rumination"[1]). The one area in which the role of selective rumination has been extensively discussed is in the literature on "flashbulb memories." This term refers to vivid memories people often report having of moments after they first learned about shocking public events (Brown & Kulik, 1977; Finkenauer et al., 1998; Neisser, Winograd, Shreiber, Palmer, & Weldon, 1996). In their pioneering study of flashbulb memories, Brown and Kulik (1977) (following Livingston, 1967) postulated a "Now-print!" mechanism producing enhanced storage when people are subject to intense emotions. However, they acknowledged that most people will later ruminate on such events. The fact that flashbulb memories can sometimes be shown to change over time, and to incorporate outright errors[2] (McCloskey, Wible, & Cohen, 1988; Neisser & Harsch, 1992), has been claimed to favor an important role for rumination in these kinds of memories (see Rime, Philippot, Boca, & Mesquita, 1992, for a discussion of rumination and its cognitive consequences). Retrospective reports of rehearsals also predict recollection independent of the intensity of the emotional reactions subjects report having had (Bohannon, 1988). Whereas some studies have concluded that rehearsal is insufficient to account for the memory advantage found for emotionally charged items based on subjects' reports of their own rehearsal patterns (Bohannon, 1988), recollections of rumination and rehearsal over periods of weeks and months may not be complete.

Selective rumination could potentially explain the enhanced recall of emotionally charged materials observed in laboratory studies. Some of the most convincing demonstrations of emotion-induced enhancement have involved relatively prolonged encoding, potentially permitting much more time to be devoted to rumination on emotionally charged events. For example, Bradley et al. (1992) presented slides at the rate of one slide per 21 s; Blake, Varnhagen, and Parent (2001) presented one slide every 16 s; Burke et al. (1992) presented one slide per 7 s, as did Libkuman, Nichols-Whitehead, Griffith, and Thomas (1999) and Christianson and Loftus (1991). Furthermore, most studies have used substantial and uncontrolled retention intervals; thus, subjects might have ruminated on the emotionally charged materials during these periods even if they did not anticipate a memory test. (Neither of these points represents criticisms of these investigators, whose goal was to demonstrate emotional enhancement, not to test the selective retrieval/elaboration hypothesis.)

One recent article by Kern, Libkuman, and Otani (2002) used sufficiently rapid presentations to make selective rehearsal somewhat less likely. They presented 23 slides (with all items in the sequence neutral or all items emotionally charged) at a rate of either 5 s or 1 s per item, followed by a 5-min filler task. Enhanced memory was observed at both presentation rates. Although brisk, a rate of 1 s per picture might be enough to allow some selective rumination on previously presented items (Baddeley, 1986), particularly if subjects anticipated a memory test. In addition, 24% of subjects in the filler condition reported ruminating on the slides between the first test and the second test, despite the filler task; thus, there may have been some brief pauses at various points in the procedure prior to the memory test.

Another study that provides data pertinent to selective rumination was reported by Guy and Cahill (1999). These investigators had subjects view two sets of 12 2-min film clips, one dealing with a highly emotional subject matter (e.g., animal mutilation or violent crime) and the other dealing with more neutral content. One week later, they were given a surprise memory test requiring them to describe as many of the film clips as possible. Subjects described nearly twice as many of the emotional clips as neutral ones. One group of subjects was instructed not to talk about the films to anyone, another group was instructed to talk to at least three people, and a third served as a control group. The advantage for emotional clips was roughly the same in all three groups. While the results are very intriguing, as a refutation of the idea that selective rumination is necessary for emotional enhancement of memory, they are not wholly convincing, as the authors clearly recognized. Subjects were instructed and asked only about overt discussions of the materials; they may (as Guy and Cahill acknowledged) have covertly recollected the material during the retention interval. Presumably, the investigators did not instruct the subjects not to think about them because they suspected this might backfire (as in the "do not think about a white elephant effect"; Uleman & Bargh, 1989); however, the instruction "Do not discuss X" may not have prevented people from thinking about X.

Heuer and Reisberg (1990) compared the effects of instructions to memorize slides with the effects of an emotional context produced by an accompanying narration. Whereas instructions to memorize enhanced memory, they enhanced memory for central plot

[1] The term *rumination* is used here in preference to the more commonly used term, *rehearsal*, because studies have shown that increased rehearsal time per se does not generally enhance subsequent recall (Craik & Watkins, 1973; Wixted, 1991). On the other hand, retrieving a memory that is not already in working memory has a substantial effect (e.g., Allen, Mahler, & Estes, 1969; Carrier & Pashler, 1992; Izawa, 1970), as does elaboration (Craik & Watkins, 1973).

[2] A reviewer of an earlier version of this article pointed out that these studies did not provide evidence that subjects had actually felt a strong emotional reaction when learning of the events involved in these flashbulb memories, making the relevance of these observations to effects of emotion open to challenge.

elements over details, whereas emotional content enhanced memory for even peripheral details of objects central to the plot (see also Burke et al., 1992, for further analysis on this point). Thus, as Heuer and Reisberg pointed out, it may be that desire to remember promoted rehearsal of the plot, with effects that did not entirely mimic the effects of emotionality per se.

In sum, there are a number of reasons to suspect that emotionally charged materials are better remembered even if they have not been the object of more extensive postencoding rumination. However, evidence on this point is inconclusive.

Present Approach

In the present study, we compressed encoding and retention into a much faster time scale than in previous research. Pictures (some neutral, some emotional) were presented at a very rapid rate (250 ms/picture). In Experiment 1, recall (brief verbal description of the pictures) was either immediate or delayed by 20 s, during which time subjects performed a demanding task. In Experiment 2, we went further and designated the pictures as to-be-ignored distractors, which the subjects sought to ignore in favor of a primary speeded task. Here, subjects were abruptly, and without warning, asked to recall the pictures as best they could, and the experiment involved only one trial to avoid development of strategies that might promote selective rumination.

Experiment 1

The first experiment, as noted above, used intentional recall with either immediate recall or recall after a 20-s task-filled interval. The task that was used was counting backward, which has long been used to suppress rehearsal (Glanzer & Cunitz, 1966; see Pashler, 1998, for a discussion of why counting backward is especially effective in interfering with other centrally demanding activities). If the enhanced memorability of emotional stimuli depends solely on selective rumination, we anticipate that emotional content should not have any opportunity to enhance memory in this design. Of equal interest, the present work (unlike the study by Kern et al., 2002) used sequences in which an individual emotional picture was embedded among neutral pictures. The results also have a bearing on possible mechanisms of emotional enhancement, as is described in the General Discussion section.

Method

Subjects. Fifty-five University of California, San Diego undergraduates (36 women) received class credit for their participation.

Design, stimulus materials, and list construction. Subjects saw a total of 60 pictures, of which 50 were neutral and 10 were emotional (negative). For each subject, these 60 pictures were divided into 12 sequences of 5 pictures, each constituting a trial. In 10 of the sets of 5 pictures, 1 picture was emotionally charged and 4 were neutral. In the remaining 2 sets, all the pictures were neutral. The experiment used a 6 (position of emotionally charged picture in sequence = 1, 2, 3, 4, 5, or none) × 2 (immediate vs. delayed recall condition) design, with each subject receiving one trial in each condition. The order of conditions was counterbalanced across subjects. All pictures were drawn from the International Affective Picture Set (IAPS; see Lang, Bradley, & Cuthbert, 1999). On the basis of IAPS norms, the 10 emotional pictures were rated highly negative (valence range = 1.46–3.46) and high in arousal (range = 6.0–7.26); examples were bloody hand, dead dog, man with gun, and dirty toilet. For the neutral pictures, the valence averaged 5.77, and the arousal averaged 3.3. On a 15-in. VGA monitor, the pictures measured 10.5 cm in height by 14.5 cm in width (9.9 × 13.6° visual angle based on a viewing distance of 60 cm).

Procedure. Subjects were instructed that their task was to watch, and then report on, a very rapidly presented series of five pictures. They were told that they should describe each picture in a few words and try to describe as many pictures as they could. Subjects performed two practice trials (using neutral pictures) to familiarize themselves with the task. Each sequence was preceded by a fixation point in the center of the screen for 250 ms. This was followed by a sequence of 5 pictures, exposed for 250 ms per picture. After the final picture had been displayed, the subject saw (with no delay) either a response box indicating that he or she should type in the gist of the pictures immediately (immediate recall condition) or a 3-digit number (delayed recall condition). When a number was presented, the subject immediately commenced counting backward aloud by sevens for 20 s. The need to begin this task as soon as the numbers were presented, and continue it without interruption, was emphasized. At the end of this interval, the response box was presented, and recall of the pictures commenced. Subjects were instructed to type a brief description of each picture into the response box without delay, at which time they clicked the "OK" button to continue to the next trial. The program saved their typed responses in a text file.

Results

Most subjects used a noun phrase to describe each picture (e.g., *mushroom, large truck, man holding gun*). These were scored as correct or incorrect by a coder who was blind to condition and instructed to use lenient scoring ("Did the subject get the gist of the picture?"). Figure 1 shows the proportion of pictures named as a function of condition (emotional vs. neutral) and recall condition (immediate vs. delayed).

As seen in the figure, emotional pictures are named significantly more often than are neutral pictures in both recall conditions. An analysis of variance (ANOVA) with two factors (Emotionality × Delay of Recall) revealed a significant effect of emotional versus neutral, $F(1, 54) = 7.5$, $p < .01$. There was also an advantage for immediate over delayed recall, $F(1, 54) = 60.9$, $p < .001$, and a nonsignificant trend toward an interaction between these two variables, $F(1, 54) = 3.13$, $p < .10$. There was no sign of an effect of gender on memory for either emotional or neutral pictures ($p > .30$), although there is some recent evidence that neural underpinnings of emotional memory enhancement may show gender differences; Cahill et al., 2001).

Table 1 shows the results, broken down by the serial position in which the picture was presented. An ANOVA including position of the picture disclosed a significant effect of position, $F(4, 51) = 7.5$, $p < .01$. There was also a significant interaction of position and emotionality, $F(4, 51) = 11.5$, $p < .001$. This appears mostly to reflect the fact that the emotional enhancement is greater when the emotional picture is presented in middle positions (especially Position 4), as compared with the ends. More generally, the serial position function for emotional items appears somewhat shallower than that for neutral items, although neither shows the highly

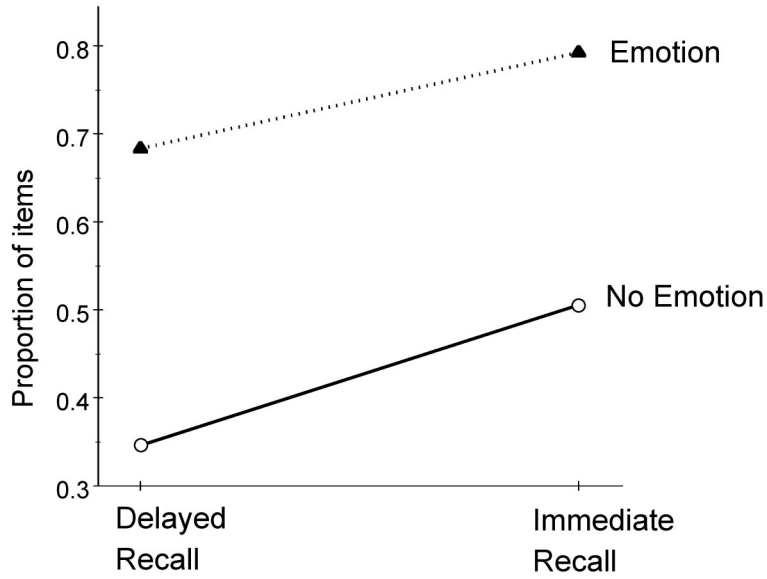

Figure 1. Proportion of pictures recalled in Experiment 1 as a function of stimulus emotionality and recall timing (immediate or delayed with task-filled interval).

bowed serial position functions commonly encountered in free recall of much longer lists of spoken words.[3]

Discussion

Stimulus emotionality clearly enhanced recall based on long-term memory (LTM) in this study. Does it also enhance storage and retrieval from short-term memory (STM)? The enhancement at immediate recall does not necessarily indicate that it does, because immediate recall relies on both STM and LTM (Bjork & Bjork, 1996). Following the method of Baddeley (1970), we can estimate the effect of emotionality on STM alone. This method assumes that storage in STM and LTM is independent and that there is no loss of information from LTM between the immediate and delayed recall conditions.

$$N_{STM}=(I - D)/(N_{TOT} - D) * N_{TOT},$$

where N_{STM} is the number of items in STM, I is the number immediately recalled, D is the number recalled at the delay, and N_{TOT} is the total number of items presented. This method yields estimates of 1.23 items in STM in the nonemotional condition and 1.71 items in STM in the emotional condition, or a 39% increase. This 39% increase seems much smaller than the 94% increase observed for the LTM component (based on the delayed recall). However, the results strongly suggest that emotionality enhances recall based on STM as well as LTM.

It should be noted that both of the two assumptions mentioned above are arguable (in the present situation, but equally in the situation considered by Baddeley, 1970). However, the qualitative conclusion just noted (some enhancement in STM storage due to emotionality) is likely tolerant to partial violations of these assumptions. The only definitive test of whether emotionality of items presented in rapid displays enhances storage in STM as well as LTM would require that one test patients suffering from profound anterograde amnesia, thereby eliminating the contribution of LTM to the task. This would be an interesting direction for future research.

Table 1
Proportion of Items Recalled in Experiment 1 As a Function of Task (Count Versus no Count), Position, and Word Type

	Word type	
Position	Emotional	Neutral
	No-count trials	
1	.8	.64
2	.73	.49
3	.78	.42
4	.89	.41
5	.82	.57
	Count trials	
1	.62	.34
2	.6	.3
3	.6	.28
4	.87	.29
5	.76	.52

[3] Other researchers who have examined recall for rapid serial visual presentations of pictures have also failed to find "classic" serial positions functions (M. Potter, personal communication, May 20, 2005).

Experiment 2

In the previous experiment, subjects had the conscious goal of retaining the pictures. Whereas the digit task was immediate, and assigned very high priority in the instructions, subjects would have an incentive to engage in strategies that would enhance memory for the pictures, possibly including selective processing of various kinds. To determine whether the enhanced memory for emotional stimuli found with very rapid displays in Experiment 1 would generalize to incidental memory, subjects in Experiment 2 were instructed that their primary task was to respond to rapidly appearing digit pairs. To minimize any incentives for strategic processing of the visual stimuli, subjects were told that any other stimuli besides these digits were distractors that they should try to ignore. In the middle of performing this digit task, a set of five pictures was presented in a rapid-fire sequence as in the previous study (sometimes including one emotional picture in Positions 3 or 4). Shortly thereafter, they were abruptly and unexpectedly asked to type in a brief description of the pictures they had just seen (the delay was chosen to be as brief as possible while precluding any role for visual iconic memory; see Bjork & Bjork, 1996, for a discussion).

Method

Subjects. One hundred fifteen University of California, San Diego undergraduates (73 women) received class credit for their participation.

Design, stimulus materials, and list construction. Subjects were randomly assigned to one of three conditions: Position 3 (emotional picture in Position 3), Position 4 (emotional picture in Position 4), or no emotional picture. The single emotional picture presented to each subject (in the Position 3 and Position 4 conditions) was drawn randomly from the same set of 10 emotional pictures used in Experiment 1. The neutral pictures were selected randomly (without replacement) from the neutral picture set from Experiment 1.

Procedure. Subjects were told that their primary task was to judge the parity of a pair of digits, pressing the "Z" key if the digits were both odd or both even or pressing the "/" key if one was odd and one was even. On each trial of the digit task, two nonidentical digits in the range 2–9 were randomly selected and presented simultaneously for 200 ms to the left and right of fixation. As soon as the subject responded, the next digit pair appeared with no delay.

At the outset of the experiment, subjects were told that the point of the experiment was to determine how well they could "Ignore visual stimuli that you are looking directly at" and that they should pay as little attention as possible to any visual stimuli apart from digits. They were also advised that if they heard any spoken instructions through the computer speakers, they should obey these instructions.

Subjects began by completing a practice block of 25 trials of the parity judgment task. Next, they performed another block of 25 trials. Interspersed between the trials in this block were four abrupt 250-ms presentations of large colored shapes, occurring after a digit response and prior to the presentation of the next digit pair. In Block 3, after subjects had performed 5 trials of the parity judgment task, a rapid sequence of five pictures was presented as in Experiment 1, at the rate of 250 ms/picture. After a 250-ms delay from the onset of the final picture in the sequence, another digit pair was presented. Subjects responded to this digit pair and then to one further digit pair presented after their response. As soon as they made this second digit response after the picture sequence, a voice sounded through the computer speakers without any warning, instructing subjects to type in a description of the pictures they had just seen.

Results

The typed descriptions of the picture were coded by raters blind to condition. Figure 2 shows subjects' mean accuracy as a function of the position of the picture in the sequence. At each position, a Kruskal-Wallis test was used to compare performance between the three different groups of subjects. Only at Positions 3 and 4 did the groups differ significantly, $\chi^2(2) = 11.1$, $p < .005$, and $\chi^2(2) = 9.0$, $p < .02$, respectively, with a trend toward a difference between groups in Position 1, $\chi^2(2) = 5.8$, $p < .10$; ANOVAs confirmed this pattern of results. Planned comparisons were performed, comparing the Position 3 and Position 4 groups in the two critical positions. In Position 3, the Position 3 group performed better than did the Position 4 group, $F(1, 76) = 11.2$, $p < .001$ (or, tested nonparametrically with Mann–Whitney, $p < .002$). In Position 4, the Position 4 group performed better than did the Position 3 group, $F(1, 76) = 5.3$, $p < .05$ (with a Mann–Whitney test, $p < .05$). Finally, the interaction between position (3 vs. 4) and group (Position 3 vs. Position 4) was tested with a Fisher's exact test; it was significant at $p < .01$. There was no sign of an effect of gender on memory for either emotional or neutral pictures ($p > .40$).

Discussion

The results clearly show superior memory for an emotional picture presented for 250 ms without warning, spliced in between neutral pictures, with the subject treating all the pictures as task irrelevant. There were no significant differences between groups in the other positions, although there was a trend for superior performance on the first item in the no emotional picture condition. This trend, if real, may reflect a tendency of some subjects to attempt to recall items in the order of presentation, a tendency that appears to be disrupted by the presentation of an emotional picture. In sum, the results generalize the findings of Experiment 1 to a rather extreme form of an incidental memory paradigm.

General Discussion

The main finding of this study was a marked enhancement in memory for highly negatively charged pictures as compared with neutral pictures. This enhancement occurred despite presentation at what is, by the standard of research on emotion and memory, an unusually rapid rate (4 pictures/sec) and the lack of intervening time provided for selective retrieval and elaboration. The advantage was apparent not only with immediate recall (reflecting both STM and LTM) but also after a filled interval (likely reflecting exclusively contents of LTM; see Bjork & Bjork, 1996, for an overview of cognitive research on LTM storage). The effect was also evident throughout the serial position function.

The first conclusion would seem to be that enhanced storage in LTM can occur even without any selective rumination or extra rehearsal and even in situations in which subjects are attempting to ignore the information altogether (Experiment 2). This reinforces the conclusions of other investigators who have argued that emotionality can potentiate storage in long-term store even without mediation by selective rumination or rehearsal (Guy & Cahill, 1999; Heuer & Reisberg, 1990; Kern et al., 2002). Naturally, this does not challenge the idea that selective rumination may some-

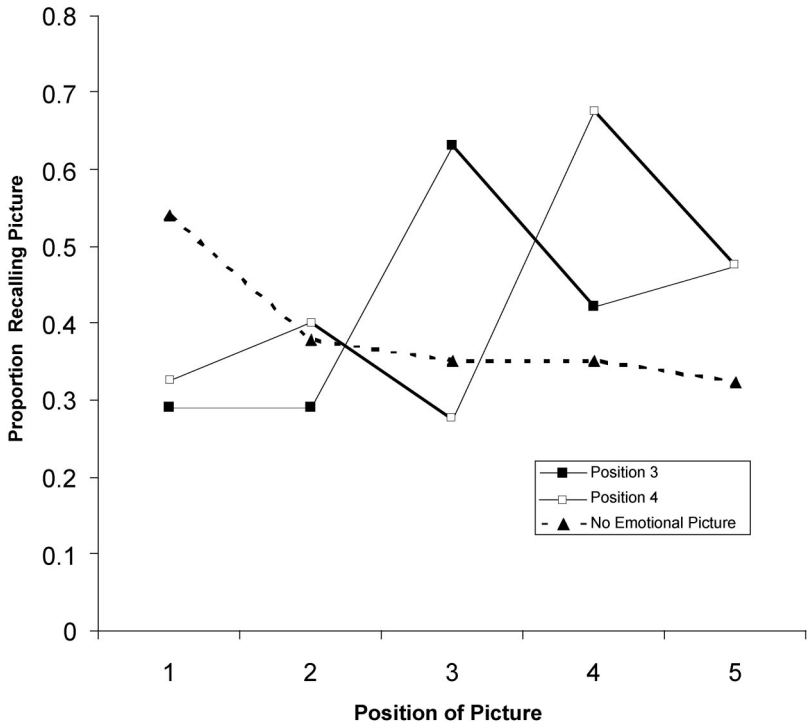

Figure 2. Proportion of subjects recalling the picture in each of the five positions in the sequence presented in Experiment 2, as a function of position of the emotional picture in the sequence (Position 3 vs. Position 4 vs. No Emotional Picture).

times contribute further to the memorability of emotional materials (Bohannon, 1988), possibly even mediated by some of the same neuronal mechanisms as have been postulated to play a role in direct enhancement of memory storage (Cahill, 2000).

Implications

The first implication of the results is that emotional enhancement can occur without selective retrieval and elaboration during presentations or during the retention interval. As pointed out in the introduction, most previous research has used relatively slow presentations with subjects free to do what they will during the substantial study and retention intervals. The present finding of a markedly better recall for emotionally charged items despite rapid and controlled presentations and retention intervals implies that there is actual enhancement of storage due to emotional content, as several previous researchers have suggested (Guy & Cahill, 1999; Heuer & Reisberg, 1990; Kern et al., 2002). Because the items were presented sequentially, this finding is not reducible to the tendency of emotionally charged materials to attract attention when presented among competing stimuli present at the same time, a phenomenon that is in any case somewhat more fragile than is commonly believed (cf. Harris & Pashler, 2004; Harris, Pashler, & Coburn, 2004).

Neurochemical Theories of Emotional Enhancement

A second implication of these results pertains to the possible underlying mechanisms. Recent neurally inspired theorizing has suggested some specific candidate mechanisms for emotional enhancement of memory storage. The most widely discussed of these is the epinephrine–norepinephrine pathway described by Cahill, McGaugh, and their colleagues (for reviews, see Cahill & McGaugh, 1998; McGaugh, 1992). Epinephrine injections, administered to animals shortly after training, markedly potentiates learning, as first noted by Gold and van Buskirk (1975). This has been confirmed in dozens of published studies, including not only aversively motivated tasks but also appetitively motivated discrimination learning tasks (Sternberg, Isaacs, Gold, & McGaugh, 1985), and in studies involving humans (Cahill & Alkire, 2003). Furthermore, some recent work that combined beta-adrenergic blockade (so-called "beta-blocker drugs") with manipulations of stimulus emotionality have found that the drugs can reduce emotional enhancement of memory (Cahill & McGaugh, 1998). Van Stegeren, Everaerd, Cahill, McGaugh, and Gooren (1998) found that the widely used beta-blocker propanolol, which crosses the blood–brain barrier, inhibited emotion-induced memory much more effectively than did nadolol, which crosses it far less. It would appear, then, that central adrenergic activity is critical.

These adrenergic mechanisms involve processes that are thought to be relatively slow acting (requiring at least several seconds to arise and several seconds to decay) and would seem likely to potentiate any memory storage taking place at the time, not just storage of the experiences that triggered the emotional reaction. Epinephrine is metabolized relatively rapidly, that is, about 20% remains 5 min after the administration of the substance (Roberts, Greenberg, Knaub, Kendrick, & Baskin, 1979). How-

ever, this is very slow compared with the presentations used in the present study, in which we found enhancement essentially confined to the emotionally charged item itself. If epinephrine responses underlie memory enhancement for emotionally charged pictures, the effect should persist well after the emotion-inducing picture. Furthermore, epinephrine potentiates memories that were established several minutes earlier (Sternberg et al., 1985), so it might be expected to affect earlier pictures as well. In short, it is not clear how the effects of this mechanism could be restricted specifically to such rapidly occurring emotional stimuli (to use Livingston's terminology, one might say that such a mechanism offers a "Now-Print-Everything!" mechanism, not a "Now-Print-This!" mechanism).

Naturally, however, this epinephrine mechanism may still play an important role in stress- or emotion-induced memory enhancement in people, even if it is not responsible for the temporally very precise enhancement observed in the present studies (and, presumably, in the many other studies using similar materials). For example, the epinephrine mechanism might operate only when people are subject to events more traumatic than viewing emotionally disturbing pictures. There are also other stress-hormone-based processes besides epinephrine that might potentiate emotion-enhanced memory storage (Cahill & McGaugh, 1998), but there is no reason to believe that these would turn on and off over a time scale of fractions of a second.

Are Emotionality Effects Mediated by Felt Emotion?

The rapidity of the effect reported here raises a further question that goes beyond the issue of possible neurochemical mechanisms: Is enhanced memory for emotional materials, such as that observed here, really mediated by changes in emotional state? The general assumption in discussions of this topic has been that the stimuli produce an emotional reaction, which then triggers additional cognitive processing. There is little doubt that the negative IAPS pictures used in the present study do indeed trigger negative emotions (Lang, Greenwald, Bradley, & Hamm, 1993). However, one may doubt whether these arise and subside fast enough to enhance memory for the emotional picture without much affecting subsequent pictures. Psychophysiological responses, certainly, rise and fall far more slowly than does our rate of stimulus presentations (Craig & Wood, 1971). Unfortunately, there is no well accepted method for determining the temporal extent of an emotional experience over brief time periods.

What alternative account might exist? One possibility is that emotional stimuli elicit more processing because they differ from other stimuli in ways that are relevant to the cognitive processes they undergo. Christianson (1992) examines the possibility that emotional stimuli may be more unusual or distinctive than other stimuli. He points out that, in several studies from his laboratory (e.g., Christianson et al., 1991), placing stimuli in surprising but emotionally neutral contexts (e.g., a woman carrying a bicycle on her shoulder) did not enhance memory for central details in the same way as an emotionally charged context. Hence, he concludes that the effects of emotion are not accounted for by distinctiveness alone.

A second possibility is that the emotionally important content of a picture triggers more extensive elaborative processing separately from, and in parallel with, its elicitation of emotional states. Consistent with this nonmediational account is the finding by Reber, Perrig, Flammer, and Walther (1994), who found that the advantage for emotional words was reduced when subjects were given a semantic orienting task, presumably causing all stimuli (neutral as well as emotional) to enjoy the same degree of semantic elaboration. Another possibility (suggested to the authors by D. Reisberg, personal communication, January 13, 2004) is that emotionally charged stimuli may evoke familiar schemata, producing superior memory in much the same way as that produced by self-referential information (Symons & Johnson, 1997). On that account, the effects would in some ways be analogous to effects of expertise on memory (Ericsson & Kintsch, 1995).

Limitations

Several limitations of this study should be acknowledged, some of which may suggest worthwhile lines of follow-up research. First, we have not attempted to disentangle (negative) emotional valence from interest or interestingness. We suspect that this "confound" is inherent and unavoidable, in the sense that people are invariably interested in anything that provokes strong emotional reactions in them. Thus, emotional charge may be a sufficient, although not a necessary, condition for eliciting interest. If so, one cannot look forward to more refined experiments that will ask about memory for emotionally charged but uninteresting materials. However, at least one study looked at interest as a predictor of memory for paragraphs that seem emotionally neutral and found, perhaps counterintuitively, that interest per se did little to enhance memory (Sadoski, Goetz, & Fritz, 1993).

A second limitation of the present study is that we looked exclusively at recall. Our findings leave open the question of whether the memory enhancement found here is predominantly a change in the retrievability of the memories or an increase in the amount of information stored. Some variables (such as word frequency and proactive interference) have major effects on recall without corresponding effects on recognition. Unfortunately, the feasibility of examining emotionality of pictures with recognition tests seems questionable because of the problem of selecting appropriate foils. Nonetheless, the question is important, and other methods might be found to address it.

These limitations aside, the present results seem to provide one especially clear indication that emotional content in pictures directly and quickly enhances memory storage or accessibility, rather than operating solely by triggering additional retrievals, rehearsals, or elaborative processing after the materials are no longer present.

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