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Emotional enhancement of memory for neutral information: The complex interplay between arousal, attention, and anticipation

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ABSTRACT

It can be challenging to explain why certain mundane details circumstantial to an emotional event are nonetheless remembered long after the experience. Here, we examined how attention selectively shapes memory for neutral objects that happen to coincide with either an unexpected or anticipated emotional event. Pictures of neutral objects were presented for 2 s and terminated with either a high-intensity shock, a low-intensity shock, or no shock. Recognition memory was tested 24 -hs later in a surprise test. Results showed no effect of shock intensity on memory for attended objects when shocks were unpredictable (Experiment 1). Similarly, there was no effect of shock intensity for attended objects when shock delivery was signaled before the object appeared (Experiment 2). There was a reduction in memory for unattended objects paired with an anticipated high-intensity shock (Experiment 3). Finally, subjects recognized slightly more attended objects paired with a high-intensity shock if shock intensity was signaled one second after the object was encoded (Experiment 4). We conclude that simply pairing objects with high-intensity shocks is insufficient to drive episodic memory enhancements for neutral information. But anticipation of an impending source of arousal can induce bidirectional effects: attending to an impending emotional event interferes with encoding of neutral information, but encoding an object just prior to anticipation of an emotional event can sometimes benefit memory. Overall, these results highlight a complex interplay between arousal, attention, and anticipation on emotion-induced memory for neutral information.

1. Introduction

Emotionally arousing events outcompete neutral events in the allocation of perceptual resources and are often better remembered over time. For example, the routine experience of the drive to work will soon be forgotten, but a frightening automobile accident may be remembered for a lifetime. Emotional memories are typically composed of a number of neutral sensory and contextual details encoded during or around the time of the emotional event. Certain types of details are understandably associated with the event; e.g., the sight of oncoming headlights the moments before a head-on collision is a common intrusive memory after a life-threatening automobile accident. A case can be made that an adaptive memory system prioritizes this type of meaningful information in order to anticipate and respond appropriately in similar situations in the future (Ritchey, Murty, & Dunsmoor, 2016). For instance, knowledge that approaching headlights are attached to approaching cars easily and strongly links this detail to the memory of an automobile accident; hence, the sight of headlights acquires the capacity to trigger an emotional memory and corresponding emotional reaction (Dunsmoor & Murphy, 2015). But a host of circumstantial and idiosyncratic details loosely or not at all predictive of the event are often strongly remembered as well; e.g., the song playing on the radio at the time of the collision might feature prominently in the traumatic memory. Despite considerable research on how and why emotional experiences persist in long-term memory (LaBar & Cabeza, 2006; McGaugh, 2004), the factors that lead neutral circumstantial details to be incorporated as part of an emotional memory are far less clear. In other words, it is a challenge to predict what

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idiosyncratic information will be selectively remembered, and might later serve as reminders, after an emotional experience. The goal of this project was to investigate whether the temporal relationship between neutral objects and aversive shocks of varying intensity interacts with attentional allocation at the time of encoding to shape long-term memory.

One mechanism that helps promote memory for neutral details involves predictability between stimuli and a meaningful outcome. In human conditioning research, for example, neutral exemplars used as conditioned stimuli in the framework of appetitive or aversive Pavlovian conditioning tasks are preferentially recognized at later tests (Dunsmoor, Murty, Davachi, & Phelps, 2015; Patil, Murty, Dunsmoor, Phelps, & Davachi, 2017; Dunsmoor & Kroes, 2019). Memory is also improved by associating neutral items with reward (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006) or punishment (Clewett, Huang, Velasco, Lee, & Mather, 2018; Murty, LaBar, & Adcock, 2012) for remembering or forgetting that item at a later test. In these experiments, each neutral item holds value for predicting and receiving a meaningful outcome. Consequently, selective attention to these items at encoding, and/or selective consolidation following encoding, might help influence selective memory enhancements. But while reinforcement and associative learning can be used to modulate episodic memory, it is not a sufficient explanation for why circumstantial details that have no meaningful association with an emotional outcome are sometimes incorporated into an emotional memory as well. For example, the song playing on the radio during a motor vehicle accident might feature prominently in the memory of the event, despite the fact that the song was irrelevant to the accident and holds no value as a warning signal for another accident in the future.

A potential mechanism for linking circumstantial details to emotional events might involve mere temporal coincidence between attentional allocation to a stimulus and an increase in arousal. But here the literature has conflicting accounts whereby emotionally arousing events can induce a long-term memory benefit (Anderson, Wais, & Gabrieli, 2006) or memory impairment (Dolcos & McCarthy, 2006; Strange, Hurlemann, & Dolan, 2003; Strange, Kroes, Fan, & Dolan, 2010) for neutral information that precedes emotional stimuli (see Mather & Knight, 2008). Mather and colleagues have explained these conflicting results in their *arousal-biased-competition* (ABC) model (Mather & Sutherland, 2011), which proposes that arousal benefits encoding of prioritized information, but diminishes processing of low priority information. However, priority is not always clearly specified, and it is vague whether simply *attending* to an item around the time of arousal is sufficient to prioritize an item and drive arousal-mediated memory effects. It is possible that a neutral detail might be strongly encoded if it just happens to be the focus of attention (i.e., prioritized) at the time of an emotional event, even if there is no other discernable relationship between the information and the event. Another possibility is that neutral information receives a memory benefit if the information is encoded during a state of *anticipatory* arousal for an impending emotional event. For example, if the sight of oncoming headlights triggers fear, then a concomitant increase in arousal might strengthen memory for incidental details in the moments before the crash, like the song that happened to be playing on the radio. This would indicate that selective memory enhancements for neutral items involves an additional factor of whether the emotional event was predictable.

It has remained challenging to determine how arousal modulates memory for neutral information that precedes, but is entirely circumstantial to, an emotional event. Ehlers, Michael, Chen, Payne, and Shan (2006) showed that incidental neutral objects preceding a negative image in a trauma story were perceptually primed, but were no better recognized than objects encoded during a neutral story. Schwarze, Bingel, and Sommer (2012) had subjects attend to random neutral pictures that were either paired or unpaired with electric shock, but found inconsistent results of the shock on 24-h recognition memory. Sakaki, Fryer, and Mather (2014) showed that subjects had better discrimination memory for items preceding an emotional picture, but memory was tested immediately and subjects were instructed to try and remember those items, lessening the incidental nature of the stimulus. Thus, the question of whether and how arousal modulates memory for circumstantial information coincident with the arousing event remains unclear.

In the present set of studies, we examined whether attention and the ability to anticipate an emotional event interacts to affect memory for preceding circumstantial information irrelevant to predicting a source of arousal. The information was pictures of neutral everyday objects, and the source of arousal was an unpleasant electrical shock to the wrist. Across four experiments, we manipulated attention towards the objects, and the relationship between attention and anticipation of the shock. We also manipulated the intensity of the electric shock to measure whether memory performance scales with the intensity of the outcome. For instance, prior research reported that memory for neutral items was only enhanced if the item preceded an emotional picture that was rated high in subjective emotional intensity (Anderson et al., 2006).

In Experiment 1, we tested whether simply attending to an object in the moments preceding an electrical shock to the wrist of varying intensity (high or low voltage, or no shock) modulates long-term memory when the succeeding shock intensity (or absence of shock) is entirely unpredictable (i.e., in the absence of anticipation). For the remaining three experiments, we induced anticipatory arousal by incorporating a secondary cue—unrelated to the target memoranda—that deterministically predicted the outcome, and we manipulated the focus of attention and timing between the object picture and the anticipatory cue. In Experiment 2, the anticipatory cue preceded the object and subjects attended to the *object*; in Experiment 3, the anticipatory cue preceded the object and subjects attended to the *cue*; and in Experiment 4, the anticipatory cue followed the object while subjects attended to the *object* (see Fig. 1, Top). In all studies, a surprise test of recognition memory was administered 24-hs after incidental encoding to help mitigate the explicit role of selective rehearsal during the interim period between encoding and test, and to allow for potential arousal-mediated enhancements of memory consolidation.

1.1. Experiment 1

The goal of experiment 1 was to determine whether people have better long-term memory for pictures of neutral objects that happened to precede delivery of co-terminating unpredictable high-intensity electrical shocks. Attention was focused on the object, and not on the relationship between the object and outcome. The pictures were fully randomized and had no predictive value in signaling the outcome, and thus subjects had no ability to successfully predict delivery or absence of shocks. This allowed us to test the specific role of coincident increases in arousal for circumstantial information irrelevant to the source of arousal that happened to be the focus of attention.

1.2. Method

1.2.1. Participants

Participants in all of the experiments provided written informed consent approved by the University Committee on Activities Involving Human Subjects at New York University. Participants were recruited from the New York City area, and self-reportedly free of neurological or psychiatric disorders and not currently taking any psychoactive medication. Twenty-two healthy adult subjects participated in Experiment 1. Two subjects were excluded from the final analysis: one subject quit shortly after the experiment began and another subject did not follow task instructions. The final sample size was 20 (mean age ± SD = 22.35 ± 4.71; 10 females).

To evaluate sample size, we conducted a power analysis on two experiments from our recently published work (Dunsmoor et al., 2018)

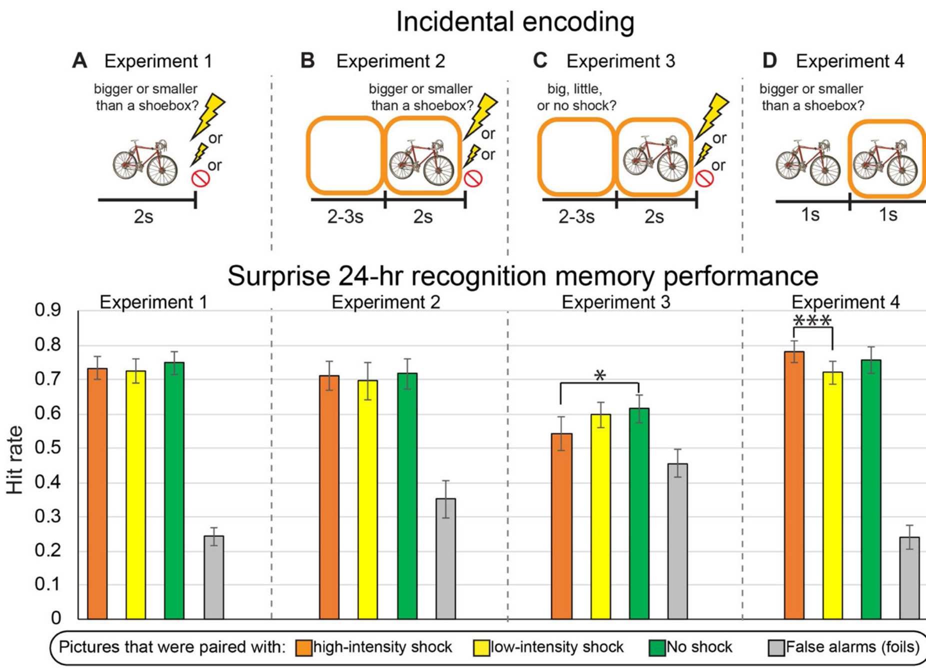

Fig. 1. Experimental procedure and 24-h recognition memory results from all four experiments. Each experiment involved encoding a neutral object preceding one of three outcomes: a high-intensity or low intensity shock to the wrist, or no shock. When the outcome was entirely unpredictable, there was no effect on recognition memory (A). Likewise, when the outcome was signaled prior to the neutral object and subjects attended to the object, there was no effect on memory (B). When the outcome was signaled prior to the neutral object, and subjects attended to the outcome and not the object, memory was weakest for objects preceding an anticipated high-intensity shock (C). When the object was encoded first, and the outcome was signaled 1 s later, memory was enhanced for objects preceding an anticipated high-intensity as compared to low-intensity shock. Error bars reflect standard error of the mean. * $P < 0.05$, ***, $P < .0001$. See Table 1 for descriptive statistics for all experiments.

that are related to the current protocol investigating the effects of electric shock on 24-h recognition memory. As in our other work (Dunsmoor, Martin, & LaBar, 2012, 2015; Patil et al., 2017), memory was better for items from a shocked category versus an unshocked category. A power analysis (SPSS Sample Power 2, IBM Corp) on 24-h memory for the shocked minus unshocked categories showed that, with a sample size of 20 and alpha of 0.05 (2-tailed), power was estimated at 89% and 99% for the two experiments, indicating a high chance to detect an existing effect. By taking the mean and standard deviations from both studies, a power analysis indicated that for the given effect size based on the prior studies (Cohen's $d = .80$) a sample size of 15 would yield a significant effect at 82% power at an alpha of 0.05 (2-tailed). Thus, the effect of shocks on recognition memory enhancement in our prior category conditioning studies is robust. We therefore sought to include at least 15 subjects in the experiments below.

A priori exclusion criteria for every experiment included inconsistencies in subjective electrical shock intensity ratings from the start to the completion of the study. Subjective intensity of the electrical stimulation can change over time due to fluctuations in skin potential, i.e., electrode-skin impedance. Changes in skin potential can occur for a variety of reasons; e.g., changes in sweating, hydration levels, electrodes drying over time or decoupling from the skin. Any of these factors will affect electrode-skin impedance and thus the level of current delivered by the stimulation. These fluctuations could contribute to changes in subjective intensity over time. Since the design was predicated on the success of the shock intensity manipulation, subjects rerated the intensity from the left and right wrist (see below) separately after the encoding session was complete, and subjects were removed from the primary analysis for reporting substantial changes in intensity for the high-intensity and low-intensity shock. The cutoff for a meaningful change was defined as the high-intensity shock falling below 5, or the low-intensity shock rising above 5, on the 0–9 subjective intensity scale described below.

Importantly, because data analysis was conducted at the completion of the study, we did not know the number of subjects who would be excluded. We did not replace excluded subjects with new subjects; hence, there are slightly different sample sizes across the different experiments. But based on the power analysis of related prior work, we would expect to see an effect with sample sizes as low as 15 if indeed pairing shocks has an effect on recognition memory outside the context of a fear conditioning protocol.

1.2.2. Design and materials

This was a two-day study separated by 24-hrs involving an incidental encoding task on Day 1 and a recognition memory test on Day 2. During encoding, subjects viewed 90 pictures of neutral everyday objects presented centrally on a white background. Pictures were obtained from the KONKLAB image set (Brady, Konkle, Alvarez, & Oliva, 2008). Each trial was 2 s duration, followed by jittered 6–9 s waiting period with a fixation cross on a white background. One third of the pictures (30 trials) co-terminated with a high intensity electrical shock, one third co-terminated with a low intensity electrical shock, and one third were presented without any shocks. By "co-terminated", we mean that the shock and the picture partially overlapped and ended simultaneously; thus, the picture was still on the screen during delivery of the brief electrical shock. As described below, high and low electric shocks were individually adjusted prior to the experiment and presented to the right or left wrist (counterbalanced). The pictures paired with the different outcomes were fully randomized across subjects. The next day, subjects returned for a surprise recognition memory test comprised of the 90 pictures shown the previous day and 90 new items (lures). Data and stimulus materials are available upon request.

1.2.3. Procedure

Following informed consent, the electrical shock was calibrated to reach a subjective level of high and low-intensity. Electrodes were attached to the left and right wrist, and the order for which wrist received the high or low-intensity shocks was counterbalanced between subjects. Starting with the low-intensity calibration, the shock voltage was initially set at a level near a perceptible threshold and increased in stages. After each pulse, subjects rated intensity using a modified Pain Intensity scale anchored from 0 (= "no sensation") to 9 (= "very high intensity") (see also Dunsmoor, Kroes, Braren, & Phelps, 2017). Calibration ceased when subjects indicated the shock intensity felt "very low" to "low." To set the high-intensity shock, the calibration procedure ceased when the subject indicated the shock felt "high-intensity" or stronger. We then retested the low-intensity shock to ensure that the subjective intensity remained low. Shocks were 200 ms and delivered using two Grass Medical Instruments SD9 square pulse stimulators (Grass Technologies), each connected to a different set of leads to the right and left wrist. Stimulus presentation was controlled using E-Prime 2.0 (Psychology Software Tools, Inc.).

1.2.3.1. Encoding. The task involved viewing pictures of real-world objects while making a semantic judgment for whether the picture was "bigger or smaller" than a shoebox by pressing 1 of 2 corresponding buttons on the keypad (Fig. 1A). To conceal the fact that we were going to test their memory the next day, subjects were told the purpose of the study was to measure the effects of shocks on reaction times and semantic judgments. They were told that their button presses did not determine the outcome, thus mitigating the chance to misattribute their semantic judgments with the outcome.

1.2.3.2. Retrieval. Subjects returned 24-hs later for a surprise recognition memory test. The test was self-paced and included 180 pairs of similar objects presented side-by-side on the screen (e.g., two different umbrellas). The purpose for including counterpart images was to assess pattern separation, which followed the recognition memory question. For half the object pairs (90), one of the objects was old (e.g., one of the umbrellas); for the other half (90), both objects were new (foils; e.g., two different bicycles, neither of which were shown the previous day). Recognition memory was assessed by asking whether either one of the two object pictures had been shown the previous day. Subjects were instructed that a correct response involved identifying one of the object pairs on the screen as old (e.g., one of the two different umbrellas was seen the day before), or identifying both image counterparts as new (e.g., a bicycle was not seen the day before). Subjects rated their confidence using "definitely old," "maybe old," "maybe new," or "definitely new." Pattern separation was then assessed by asking whether the old picture was on the left, on the right, or neither (i.e., it was a new item). Finally, subjects were asked whether the item had been paired with a high-intensity shock, a low-intensity shock, or no shock as a test of source memory. The pattern separation and source memory results are not reported here. The memory test was identical in all four experiments.

1.2.3.3. Recognition memory analysis. As false alarm rates at both confidence intervals were low and, correspondingly, corrected recognition (hits minus false alarms) was above chance, memory responses were collapsed across confidence for analysis. Repeated measures ANOVA included condition as a factor (i.e., items that had preceded a high-intensity, low-intensity, and no shock the previous day) considered significant at $P < .05$. Effect sizes for two-tailed t-tests were calculated using Cohen's d_{av} as proposed by Lakens (2013) for within-subjects designs: $[(M_{diff})] / [(SD_1 + SD_2) / 2]$. Table 1 presents descriptive statistics for all experiments.

1.3. Results

1.3.1. 24-h recognition memory

Memory for items paired with high-intensity, low-intensity, and no shock were substantially greater than the false alarm rate, which was (mean ± SEM) 24.27% ± 2.57%, all $Ps < .001$. Repeated measures ANOVA showed no effect on recognition memory for items paired with a high-intensity, low-intensity, or no shock, $F_{2,\ 38} = .519$, $P = .599$ (Fig. 1A).

Table 1
Mean hit rate (standard deviation) at 24-h retrieval for each of the 4 experiments as a function of whether pictures were paired with a high-intensity, low-intensity, or no shock outcome, as well as false alarm rates. Data illustrated in Fig. 1.

	Pictures paired with:			
	High-intensity shock	Low-intensity shock	No shock	False Alarms
Experiment 1	.73 (.15)	.72 (.16)	.75 (.15)	.24 (.12)
Experiment 2	.71 (.16)	.69 (.21)	.72 (.17)	.35 (.21)
Experiment 3	.54 (.21)	.59 (.16)	.61 (.16)	.46 (.18)
Experiment 4	.78 (.13)	.72 (.13)	.76 (.15)	.24 (.14)

1.4. Discussion

Experiment 1 showed that pairing random neutral pictures with an unpredictable high-intensity electrical shock to the wrist had no effect on 24-h recognition memory for those pictures. The ABC model (Mather & Sutherland, 2011) would seem to propose that objects that are the center of attention during an emotional event are prioritized in memory. Thus, attending to items that co-terminate with highly unpleasant electrical shocks to the wrist might be expected to produce better memory for those items, as compared to items paired with much less unpleasant shocks or no shocks. But although subjects were attending to the target item (it was central on the screen, without distractors, and subjects responded with a semantic judgement), long-term recognition memory was unaffected by phasic arousal induced by coincident high intensity electrical shocks to the wrist. These findings suggest that encoding of a neutral stimulus that temporally coincides with a phasic increase of emotional arousal is insufficient to drive a selective long-term episodic memory benefit for that stimulus.

It may be that the unpredictable nature of the emotional outcome limited effects on selective memory for preceding neutral items. That is, an important component to emotional enhancements of memory for neutral information might be the ability to anticipate the impending outcome while encoding circumstantial information. This would fit with our prior work using a Pavlovian fear-conditioning paradigm that showed that anticipation of an electrical shock enhances memory for items preceding an expected shock (Dunsmoor et al., 2012). In the next experiment, we reasoned that anticipatory arousal might support stronger memory encoding when items appear during heightened phasic arousal induced by the anticipation of a predictable aversive electrical shock to the wrist. In other words, is recognition memory better for items that happen to appear during a state of high versus low arousal? We manipulated anticipation by using a secondary cue that deterministically signaled the impending outcome.

1.4.1. Experiment 2

The purpose of Experiment 2 was to examine whether attending to a neutral item while anticipating an emotional event affects episodic memory for items preceding the anticipated delivery of a shock. Similar to Experiment 1, the target memoranda provided no information about whether to expect a high-intensity, low-intensity, or no shock. But unlike Experiment 1, a secondary cue appeared a few seconds prior to a picture of a neutral object. This secondary cue was a square border, and the color of the square's border deterministically signaled the outcome. A few seconds after the border appeared, a picture was presented in the middle of the border and subjects made a semantic judgment on the picture like in the prior experiment. In this way, neutral picture encoding occurred during one of three putative states of arousal (high, medium, and low) that fluctuated trial-by-trial according to the anticipated outcome (high-intensity, low-intensity, and no shock).

1.5. Method

1.5.1. Participants

Twenty-two healthy adult subjects participated in Experiment 2. Two subjects did not return for Day 2 and one subject quit early. Four subjects reported a substantial change in subjective shock intensity ratings from calibration to after encoding and were removed from analysis. The final sample size was 15 (mean age = 22.73 ± SD = 4.07; 9 females).

1.5.2. Design and materials

Memoranda were the same as those used in Experiment 1.

1.5.3. Procedure

The procedures were similar to Experiment 1 with the following exception. First, a color border appeared for 2–3 s (jittered) that was green, orange, or yellow: the color deterministically (100% probability) predicted a high-intensity shock, low-intensity shock, or no shock (the color associated with each outcome was counterbalanced). Next, target memoranda appeared in the center of the color border for 2 s during which time subjects made a semantic judgment ("bigger or smaller than a shoebox?"). Subjects were informed that the color border predicted the outcome with 100% certainty. The shock co-terminated with the color border and memoranda. A short practice session preceded the encoding phase that included one practice trial of each condition. This way subjects entered the experiment having had a chance to learn the association between the color of the border and the outcome. This association was intended to be straightforward. Subjects returned 24 -h later for a surprise memory test.

1.5.3.1. Skin conductance responses. We collected skin conductance measurements throughout encoding to evaluate the effect of the cues (color borders) on anticipatory autonomic arousal. Disposable pre-gelled electrodes were placed on the hypothenar eminence of the left palm and connected to the BIOPAC MP100 System (Goleta, CA). Measurements were collected using AcqKnowledge software at 200 Hz and phasic SCRs were analyzed using a custom Matlab script (Green, Kragel, Fecteau, & LaBar, 2013) to extract the trough-to-peak response during the cue interval prior to the outcome. An SCR was scored for each trial if the trough-to-peak deflection occurred between 0.5 s after the onset of the trial to 3.8 s after the start of the trial. In this way, we could dissociate responses elicited by the cue from SCRs to the shock. Trials without a measurable SCR were scored as zero. Raw SCRs were square-root transformed to normalize the distribution.

1.6. Results

1.6.1. Skin conductance responses

Repeated measures ANOVA showed an effect of the color border (signaling an impending high-intensity, low-intensity, or no shock) on SCRs, $F_{2,\ 28} = 15.856$, $P < .001$, partial eta squared = .531 (Fig. 2A). ANOVA showed a linear trend, $F_{1,\ 14} = 17.899$, $P = .001$, partial eta squared = .561, such that high-intensity cue elicited the largest mean SCRs, and the no-shock cue elicited the lowest mean SCRs.

1.6.2. Reaction times

On each trial, subjects made a semantic judgment whether the item was bigger or smaller than a shoebox. Unlike Experiment 1, subjects made this rating during anticipation for the known outcome, and hence the reaction time data was informative as to the success of the anticipation cue on modulating processing of the items at the time of encoding. Repeated measures ANOVA showed an effect of condition on reaction times, $F_{2,\ 28} = 6.961$, $P = .004$, partial eta squared = .332 (Fig. 2B). ANOVA showed a linear trend, $F_{1,\ 14} = 10.060$, $P = .007$, partial eta squared = .418, such that subjects were fastest to respond to items presented during anticipation for high intensity and slowest to respond to items during anticipation of no shock. Collectively, the SCR and reaction time data provide evidence that the color border affected anticipatory arousal and had variable effects on the speed of processing the items presented during anticipation of the expected outcomes.

1.6.3. 24-f memory

The false alarm rate was low: 35.18% ± 5.35%, and memory for each condition was above the false alarm rate, $Ps < .001$. Repeated measures ANOVA showed no effect of condition, $F_{2,\ 28} = .427$, $P = .657$, partial eta squared = .030 (Fig. 1B).

1.7. Discussion

Twenty-four hour recognition memory was unaffected for neutral items that were encoded during a state of anticipatory arousal preceding the delivery of a high-intensity, low-intensity, or no shock. This null result was somewhat surprising because the cue for the high-intensity shock reliably generated an increase in phasic arousal and affected reaction times at the time of encoding. Prior research suggests that arousal at the time of encoding is associated with emotional-enhancement of memory for neutral items (Cahill, Prins, Weber, & McGaugh, 1994; Tambini, Rimmele, Phelps, & Davachi, 2017). One post hoc explanation of this null result is that allocating attention toward the picture (as in Experiment 1) simply minimized the potential effect of anticipatory arousal. It is noteworthy, for instance, that the overall hit rate between Experiments 1 and 2 are remarkably similar, perhaps suggesting that the ability to anticipate an emotional event is not sufficient to influence encoding when the item preceding that event is the focus of attention. That is, attended items encoded during a period of low arousal were remembered just as well as attended items encoded during a period of high arousal. In the next experiment, attention was oriented away from the item and instead toward the predictive cue. This should lower recognition memory overall, since the memoranda is no longer the focus of attention. But the critical question is whether diverting attention toward the impending emotional event selectively influences memory for the unattended item preceding delivery of a high-intensity shock.

1.7.1. Experiment 3

The goal of Experiment 3 was to test whether orientation toward threat anticipation influences memory for incidental information that just happens to appear prior to the expected outcome. We left nearly all

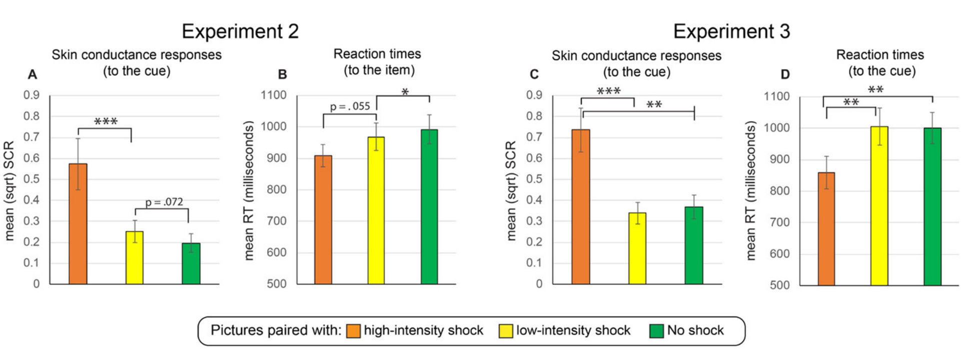

Fig. 2. Behavioral results from the time of incidental encoding in Experiments 2 and 3. In both experiments, a color border appeared before the neutral stimulus, and signaled with 100% certainty what outcome would be delivered at the end of the trial. In Experiment 2, subjects attended to the neutral stimulus, after the color border appeared, by semantically rating the object as bigger or smaller than a shoebox. In Experiment 3, subjects attended to the color border prior to the presentation of the object by rating expectancy for high-intensity, low-intensity or no shock. Skin conductance Responses (A, C) and Reaction Times (B, D) in both experiments showed heightened SCRs and faster RTs when encoding was accompanied by the color border indicating a high-intensity shock. Results confirm that the encoding manipulation successfully affected physiological arousal and RTs. Error bars reflect standard error of the mean. * $P < 0.05$, **, $P < .01$, ***, $P < .0001$.

of the task parameters the same as the previous experiment, but modified the instructions from the prior experiment by asking subjects to focus on the cue-outcome association, rather than on the pictures of the neutral objects. Thus, the target memoranda were truly incidental and the picture commanded no explicit attention. The change in task instructions (rating shock expectancy for the cue instead of making a semantic judgment for the picture) was the only modification from Experiment 2. One possibility is that memory should be *reduced* for items preceding a strong shock because attention is focused on the impending outcome. The other possibility is that heightened arousal engages memory systems involved in encoding and remembering details that happen to appear while in a state of anticipatory anxiety.

1.8. Method

1.8.1. Participants

Twenty-six healthy adult subjects participated in Experiment 3. Data from the first 3 subjects was lost due to a coding error. Two subjects did not show up for the memory test, and three subjects had inconsistent shock ratings after encoding. The final sample size was 18 (mean age = 23.72 ± SD = 3.61; 9 females).

1.8.2. Design and materials

Memoranda were the same as those used in the previous experiments.

1.8.3. Procedure

The procedure was identical to Experiment 2, with the important exception that the subjects' task was to predict the outcome (3-alternative-forced choice: "big shock, little shock, or no shock") based on the color border that preceded the target memoranda. Subjects were told that pictures of different objects would appear throughout the task, but no explicit information was provided about the presence of the pictures. Skin conductance was collected, recorded, and analyzed as in Experiment 2, and memory was tested 24-h later in a surprise recognition memory test.

1.9. Results

1.9.1. Skin conductance responses

SCR data from 3 subjects was lost due to a technical error with the AcqKnowledge software (BIOPAC). Repeated measures ANOVA showed an effect of the color border indicating high-intensity, low-intensity, or no shock on SCRs, $F_{2,\ 28} = 18.018$, $P < .001$, partial eta squared = .563 (Fig. 2C). ANOVA showed a linear trend, $F_{1,\ 14} = 16.607$, $P = .001$, partial eta squared = .543, such that high-intensity cue elicited the greatest mean SCRs relative to the low-intensity and no-shock cue.

1.9.2. Reaction times

On each trial, subjects responded to the presentation of the color border to judge whether they expected a high-intensity, low-intensity, or no shock. Response data from one subject was lost due to a technical glitch. Repeated measures ANOVA showed an effect of the border color on reaction times, $F_{2,\ 32} = 9.482$, $P = .001$, partial eta squared = .372 (Fig. 2D). ANOVA showed a linear trend, $F_{1,\ 16} = 13.226$, $P = .002$, partial eta squared = .453, such that subjects were fastest to respond to the border indicating a high-intensity shock relative to the other two borders (Fig. 2). Similar to Experiment 2, the SCR and reaction time data confirmed differences in anticipatory arousal, and reaction times to the borders signaling the expected outcome.

1.9.3. 24-h memory

The first noteworthy finding is that memory was markedly lower overall compared to the previous two groups (Fig. 1C). This finding was not unexpected, as subjects were not instructed to attend to the target memoranda and hence encoding would be inferior to the prior studies. The proportion of recognized items that had been paired with a low-intensity or no shock was greater than the false alarm rate, $Ps < .005$. But memory for items paired with a high-intensity shock was not better than the false alarm rate, $P = .067$. Repeated measures ANOVA of recognition memory for Experiment 3 (items paired with big-shock, little-shock, or no-shock) did not show a main effect of condition, $P = .089$ (Fig. 1D), but there was a linear effect $F_{1,\ 17} = 4.749$, $P = .044$, partial eta squared = .218. Post-hoc paired samples *t*-test showed that memory was greater for the items preceding the expected absence of shock than items preceding delivery of an expected high-intensity shock $t_{17} = 2.179$, $P = .044$, $d_{av} = 0.381$.

1.10. Discussion

Shifting the task goals towards the impending outcome somewhat reduced subsequent memory for items preceding an anticipated high-intensity shock than the absence of shock. This suggests that encoding of an incidental and unattended item suffers when attention is instead occupied by the anticipation of an aversive event. Yet, it does not address the factors that promote *better* memory for items associated with threat, e.g., remembering the song that was on the radio during a motor vehicle accident from our earlier example. In our final experiment, we reasoned that (a) attentional weight and (b) the ability to anticipate the outcome are probably both critical factors for determining whether neutral information is later remembered, but that the timing of the two factors may be critical.

1.10.1. Experiment 4

The purpose of Experiment 4 was to examine whether directing attention toward the object *prior* to the generation of expectancy for the impending outcome would affect long-term recognition memory. In other words, is recognition memory improved if an item is encoded prior to the generation of anticipatory arousal. In keeping with our example of a head-on collision, this would be akin to paying attention to the song playing on the radio (perhaps singing along) prior to seeing approaching headlights the moment just before the crash. Similar to Experiments 2 and 3, a color border appeared signaling the outcome. However, in Experiment 4 the neutral picture preceded the color border by 1 s. The color border then appeared surrounding the picture for 1 s and co-terminated with the anticipated outcome. To ensure that the time to encode the picture was equal between experiments, we shortened the presentation time of the predictive cue to 1 s. This ensured that the picture is the focus of attention just prior to the generation of anticipatory arousal, but still preceding the arrival of the anticipated outcome.

1.11. Method

1.11.1. Participants

Twenty-one healthy adult subjects participated in Experiment 4. One subject did not return for Day 2. Four subjects reported a substantial change in subjective shock intensity ratings from calibration to after encoding. The final sample size was 16 (mean age = 20 ± SD = 1.77; 12 females).

1.11.2. Design and materials

The target memoranda were the same as those used in the other experiments.

1.11.3. Procedure

Target memoranda were presented for 2 s during which time subjects made a semantic judgment ("bigger or smaller than a shoebox?"). After 1 s, a square color border appeared around the object that predicted the outcome (high, low, no-shock) (Fig. 1B). Subjects returned 24-h later for a surprise memory test. Because the anticipatory period preceding the shock was short, we did not collect SCRs in this experiment—that is, the temporal proximity of the onset of the color border and shock would have made it impossible to distinguish anticipatory SCRs from SCRs evoked by the shocks. Also, because button presses could occur to the pictures before the outcome was signaled, the reaction time data is uninformative to the primary hypothesis and therefore not included here.

1.12. Results

1.12.1. 24-h recognition memory

Memory for all conditions was greater than the false alarm rate (24.09% ± 3.51%), $Ps < .001$. Repeated measures ANOVA on recognition memory revealed an effect of condition, $F_{2,\ 30} = 4.484$, $P = .02$, partial eta squared = .230 (Fig. 1D). Recognition memory evinced a U-shaped curve as revealed by a significant quadratic trend $F_{1,\ 15} = 15.528$, $P < .001$, partial eta squared = .509. More precisely, recognition memory was greater for items paired with a high-intensity versus a low-intensity shock ($t_{15} = 4.212$, $P = .001$, $d_{av} = .466$); however memory was not greater for items paired with a high-intensity versus no shock ($P = .333$). Memory for items unpaired with shock was not different from items paired with a low-intensity shock ($P = .09$).

1.13. Discussion

Subjects recognized more neutral items paired with high-intensity shocks than low-intensity shocks 24 -hs after encoding. This suggests that a highly arousing event can improve memory for neutral information that is the focus of attention at the time anticipation for that event is initiated–even if that information is entirely unrelated to the source of arousal. Interestingly, this effect was not graded (linear) as a function of shock intensity. This U-shaped curve might suggest that relief also somewhat enhanced memory for items encoded during the anticipated absence of shock. Notably, in our prior Pavlovian conditioning studies where we tested episodic memory for the conditioned stimuli, we find that recognition memory is typically heightened for CS category exemplars associated with shock versus exemplars from a different category associated with the absence of shock (e.g., Dunsmoor et al., 2015). Altogether, the present results suggest that the episodic memory enhancement for shock paired versus unpaired items is muted when the target memoranda don't offer any value for predicting a future shock.

2. General discussion

From an adaptive memory framework, remembering details associated with a salient event guides behavior when seeking out (in the case of positive memories) or avoiding (in the case of negative memories) similar outcomes in the future. But a host of idiosyncratic neutral details often get incorporated into an emotional memory as well, and it is far more challenging to explain how and why this type information sticks. The purpose of this set of experiments was to examine the conditions that might affect long-term episodic memory for neutral details that happen to coincide with an unrelated emotional event.

Results from the first experiment showed that items randomly paired with an unpredictable high-intensity electrical shock did not affect 24 -h recognition memory for those items. On the one hand results from the first experiment were surprising, given that our prior work on conditioning-induced enhancements of episodic memory (e.g., Dunsmoor et al., 2015) shows that memory benefits extend to different neutral objects from the same conceptual category paired with a shock (e.g., different animals). However, in our prior work, subjects have the opportunity to learn an association between the category (e.g., animals) and the outcome. This type of associative learning helps participants link each exemplar from that category to the outcome, thus evoking a sense of anticipation of threat and safety for each individual memoranda. From a Levels-of-Processing (Craik & Lockhart, 1972) perspective, anticipation of an impending source of arousal might constitute a form of deep encoding that allows stimuli with an association to the salient outcome to receive prioritized encoding. In the present study, it was not possible to form a rule to predict the outcome (high-intensity, low-intensity, or no shock) based on the neutral stimulus (random picture of an everyday object), because stimulus-outcome pairing was random. The attentional focus (rating the object as either bigger or smaller than a shoebox) was likewise unrelated to the outcome, further distancing the stimulus from the outcome. It is worth noting that a prior study has shown that pictures randomly paired with an electrical shock are better remembered after 24 h than unpaired pictures (Schwarze et al., 2012); although a caveat to those findings is that the behavioral effect did not replicate in a separate neuroimaging cohort, suggesting that pairing random images with shock does not produce robust long-term memory effects.

The null result from the first experiment motivated three follow-up experiments to uncover conditions that do influence emotional memory enhancements for neutral information paired with phasic increases in arousal. In Experiment 2, attending to an item while in a state of anticipatory arousal did not influence memory. In Experiment 3, attending to the impending outcome instead of the item, weakened memory for items paired with an expected high-intensity shock. In Experiment 4, attending to an item prior to a state of anticipatory arousal somewhat enhanced memory of items paired with an expected high-intensity shock. Collectively, these results highlight an inherent complexity to identifying when emotion selectively influences memory for random neutral details, if the details themselves serve no value as warning signals.

The ABC model (Mather & Sutherland, 2011), referred to in the introduction, describes how neutral information that is high priority will benefit when encoding occurs around the time of an arousing event. The present results found that an arousing electrical shock was not sufficient to induce a long term memory benefit for neutral items. It is possible that the ABC model is better able to describe memory effects under explicit encoding situations, as studies designed to test the ABC model have often defined “priority” in terms of an intentional encoding strategy (e.g., Sakaki et al., 2014), and not merely as attending to the item, per se.

The first two experiments, in which pairing neutral pictures with high-intensity electric shocks did not affect memory, might appear to contradict basic concepts of arousal-mediated memory effects. That is, increases in stress or arousal at or around the time of encoding is known to impact hippocampal-dependent memory in mammals (McGaugh, 2004). Notably, animal research in this domain has often manipulated global increases in arousal induced prior, during, or after training. How phasic trial-by-trial changes in arousal influences memory processes for neutral items that are unrelated to the source of arousal is less clear from the extant research on emotional memory enhancements. In some cases, emotional arousal can enhance memory for preceding neutral information (Anderson et al., 2006), but in other paradigms arousal leads to retrograde forgetting (Strange et al., 2003). Some episodic memory studies follow a one-shot Pavlovian conditioning design, akin to the design here, by pairing non-repeating and random neutral items with an electrical shock (Bauch, Rausch, & Bunzeck, 2014; Schwarze et al., 2012). However, it is worth noting that in much of this prior work, the shocks had minimal effect on selective episodic memory. This suggests that a relationship between the item and the outcome is an important component to get a reliable memory effect for neutral items preceding salient outcomes. In category fear-conditioning, for instance, subjects learn that the neutral item (or category of items) has associative value in predicting the presence or absence of the salient outcome (e.g., Dunsmoor et al., 2015). This meaningful association likely helps drive selective episodic memory for category exemplars encoded during fear-conditioning, as seen in our prior work. Likewise, motivated memory encoding paradigms (e.g., Adcock et al., 2006; Clewett et al., 2018; Murty et al., 2012) help ensure selective memory by imbuing some neutral trials with significance via association with a future reward or punishment. But results from the present study, and prior studies (Bauch et al., 2014; Ehlers et al., 2006; Schwarze et al., 2012), show that circumstantial details with no meaningful connection to a salient outcome (and therefore hold no value in predicting a future meaningful outcome) seem far less likely to receive a selective enhancement in long-term memory. After the first two experiments, an account of the factors needed to prioritize memory for neutral information remained elusive. The remaining two experiments shed some light on this question.

The results from Experiment 3, in which memory for high-intensity shocks was diminished, might best be interpreted in the framework of emotional modulation of attention, and processing of central versus peripheral details during emotional encoding (Christianson & Loftus, 1991; Kensinger, 2009). That is, the attention to the impending high-intensity shock likely consumed cognitive resources for encoding incidental neutral items. However, this finding did not address conditions that promote *better* memory for neutral items, which was a primary question motivating this collection of studies. Results from Experiment 4 showed somewhat enhanced recognition memory for items that are the focus of attention prior to the generation of anticipatory arousal for an expected high-intensity shock. This finding was most similar to an emotional enhancement of memory effect, but memory was only enhanced for items paired with a high-intensity versus low-intensity shock.

Altogether, the present results show that arousal alone is insufficient to drive memory for items that do not provide any warning signal value for an impending emotional event. Factors governing selective enhancements in memory for neutral information appear to be influenced by where attention is focused prior to an anticipated emotional event. But the interplay between arousal, attention, and anticipation is complex and necessitate further specificity in the emotional memory literature. At the very least, the findings suggest that a lack of any meaningful association between the stimulus and the outcome mitigates the chance that the stimulus will be prioritized in memory. Thus, a major takeaway from these findings is that emotional arousal does not necessarily enhance memory for coincident neutral items, even if those items are the focus of attention at the time of a highly unpleasant electrical shock to the wrist. Forming an associative link between the stimulus and the outcome may be important to derive strong memory benefits. Future investigations will be needed to further deconstruct the role of different stages of memory processing (encoding, consolidation, retrieval) on emotional enhancements of neutral memory. For instance, in real world emotional situations, there is also likely to be rumination of the experience afterwards, which may strengthen memory for certain idiosyncratic details that, in retrospect, might seem relevant to the event after all.

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