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Research

Fear relevancy, strategy use, and probabilistic learning of cue-outcome associations

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The goal of this study was to determine how the fear relevancy of outcomes during probabilistic classification learning affects behavior and strategy use. Novel variants of the "weather prediction" task were created, in which cue cards predicted either looming fearful or neutral outcomes in a between-groups design. Strategy use was examined by goodness-of-fit estimates of response patterns across trial blocks to mathematical models of simple, complex, and nonidentifiable strategies. Participants in the emotional condition who were fearful of the outcomes had greater skin conductance responses compared with controls and performed worse, used suboptimal strategies, and had less insight into the predictive cue features during initial learning. In contrast, nonfearful participants in the emotional condition used more optimal strategies than the other groups by the end of the two training days. Results have implications for understanding how individual differences in fear relevancy alter the impact of emotion on feedback-based learning.

Learning from emotional experiences is an important survival skill across species. Environmental contingencies predicting negative or positive outcomes provide key information useful for assessing the motivational value of selected actions and to assist decision-making processes in guiding future behavior. One form of contingency learning involves the gradual acquisition of cue-outcome associations guided by feedback (procedural or habit learning) (Mishkin et al. 1984). While much research has examined the cognitive and neural mechanisms underlying this form of learning, the influence of emotion has not been systematically addressed as it has for other domains of memory (LaBar and Cabeza 2006). Here we examine how individual differences in fear relevancy modulate behavioral performance and strategy use on a probabilistic classification learning (PCL) task that involves trial-and-error learning of associations between cues and outcomes that vary in emotional salience.

In the standard version of a PCL task (the "weather prediction" task) (Knowlton et al. 1994), participants predict the weather in a foreign city (rain or sunshine) based on the presence of a combination of four cue cards. Across training, participants learn to probability match the appearance of the cue cards by choosing the outcome with the same probability that they are reinforced. Given that individuals tend to have little insight into their performance, there has been interest in characterizing the underlying response patterns, or strategies used to solve the task. To accomplish this objective, each participant's data is mathematically modeled across trial blocks to determine the goodness-of-fit to an "ideal" responder following particular response patterns. Least-mean-square estimates indicate that participants use at least three classes of strategies varying in optimality: (1) no identifiable strategy, (2) simple strategies involving the use of one cue to make predictions, and (3) complex strategies involving the use of multiple cues and knowledge of the underlying probabilistic structure (Gluck et al. 2002; Lagnado et al. 2006; Meeter et al. 2006).

Probabilistic learning of this sort is likely to be important for assessing the motivational and emotional relevance of stimulus contingencies in real-life scenarios, which are often nondeterministic. However, it is not known how behavioral performance or strategy use on PCL tasks is impacted by varying the salience of the outcomes.

Although the weather-prediction task involves hypothetical outcomes with an inherent affective valence (rain/sunshine), neuroimaging studies suggest that the standard version of this task does not activate canonical emotional processing networks (e.g., Poldrack et al. 2001; Foerde et al. 2006). To provide an experimental model of probabilistic emotional contingency learning, we created two versions of a PCL task, in which neutral cue cards predicted either fearful or neutral outcomes (Fig. 1). Instead of predicting weather, participants predicted what they would encounter while walking in the woods. The outcomes were pictures of biologically prepared phobic stimuli (snakes/spiders) and environmental control stimuli (flowers/mushrooms) commonly used in studies of fear conditioning (e.g., Öhman and Soares 1994). Training was extended across two consecutive days to investigate learning both initially and after a 24-h period of consolidation, since emotional effects on memory sometimes emerge following a delay (Kleinsmith and Kaplan 1963; Sharot and Phelps 2004). Participants were subdivided into "fearful" and "control" subgroups according to self-report inventories of snake and spider phobia to assess the contribution of individual differences in fear relevancy to task performance.

We predicted that fearful participants in the emotional condition would exhibit: (1) impaired explicit knowledge of the task parameters, (2) greater use of suboptimal learning strategies, and (3) higher skin conductance responses (SCRs), an index of sympathetic arousal to the cue cards compared with controls. In contrast, nonfearful participants run in the emotional condition should show benefits on learning rates and/or strategy use, particularly after a period of consolidation, as predicted by studies of emotional influences on procedural learning in nonhuman animals (Packard et al. 1994). If supported, these findings would be

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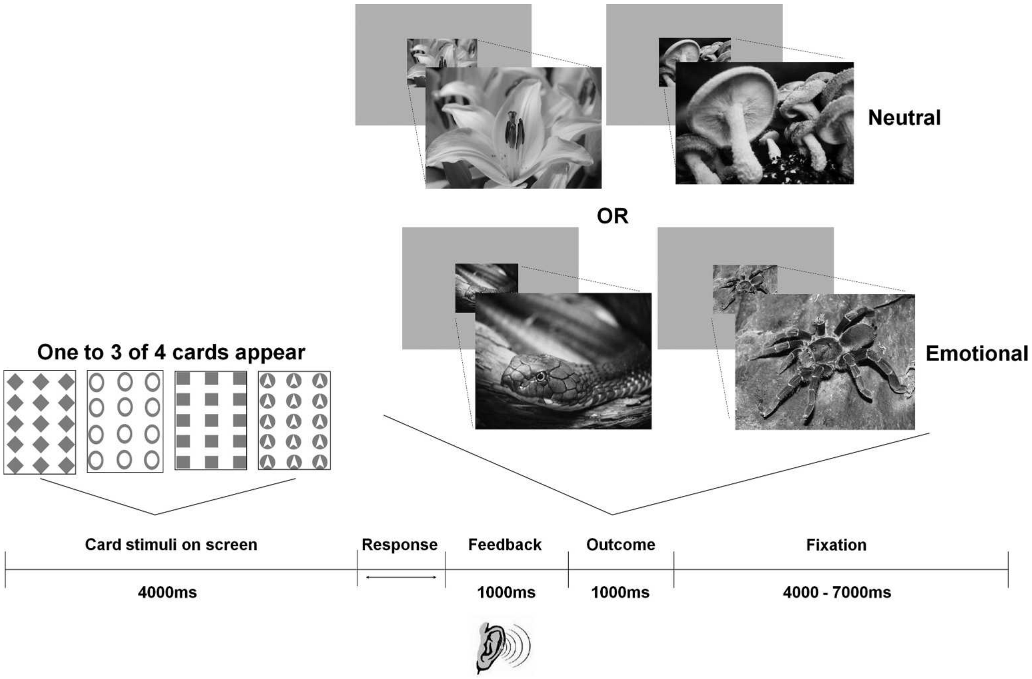

Figure 1. Trial structure of the modified weather prediction task. Participants were run either in the emotional version (snake/spider outcomes) or the neutral version (flower/mushroom outcomes). Outcomes were presented in a dynamic, looming manner.

important in revealing how learning cue-outcome associations are modulated by personal salience, with potential implications for understanding the diverse effects of emotion on memory systems in affective health and disease.

Results

Ratings

To validate the International Affective Picture System (IAPS) norms in our sample, all participants rated the six exemplars of each of the snake, spider, flower, and mushroom outcomes on 5-point valence and arousal manikin scales after completion of the study on Day 2 (1 = negative to 5 = positive; 1 = least arousing to 5 = most arousing). Overall, flowers and mushrooms were rated more positively than snakes and spiders, M (SD): 3.9 (0.5) flowers; 2.8 (0.4) mushrooms; 2.3 (0.7) snakes; 1.9 (0.8) spiders. Snakes and spiders were also rated more arousing than flowers and mushrooms: 3.1 (0.78) snakes; 3.2 (0.91) spiders; 2.3 (0.79) flowers; 1.8 (0.65) mushrooms. Correlations between the snake questionnaire scores and the snake photo ratings showed that the more fearful participants were of snakes, the higher were their arousal, $r\ (53) = 0.51$, $P < 0.0001$, and valence, $r\ (53) = 0.28$, $P < 0.04$, ratings of the snake photos. The same was true for the spider questionnaire scores and arousal $r\ (53) = 0.53$, $P < 0.0001$, and valence ratings $r\ (53) = 0.54$, $P < 0.0001$ for spider photos.

Learning rate

A mixed ANOVA revealed a main effect of Day, $F_{(1,74)} = 65.82$, $P < 0.0001$, $\eta_p^2 = 0.47$; a main effect of Run, $F_{(1,74)} = 16.75$, $P < 0.0001$, $\eta_p^2 = 0.19$; and a Day × Run interaction $F_{(1,74)} = 5.72$, $P < 0.02$, $\eta_p^2 = 0.07$, indicating that participants showed increased learning across Days and Runs, especially on Day 1 (see Fig. 2). Importantly, there was also a significant Day × Run × Group interaction, $F_{(3,74)} = 3.1$, $P = 0.04$, $\eta_p^2 = 0.11$, and a trend for a main Group effect, $F_{(3,74)} = 2.15$, $P = 0.10$, $\eta_p^2 = 0.08$. Follow-up ANOVAs showed that the Day × Run interaction was only significant for the fearful subjects in the emotional condition $F_{(1,14)} = 9.54$, $P < 0.008$, $\eta_p^2 = 0.41$, who exhibited an initial deficit in learning accuracy relative to the other groups. This finding was confirmed by a correlational analysis computed between accuracy and an aggregate snake/spider phobia score, which was inversely correlated on the first run of Day 1, $r(53) = -0.33$, $P < 0.05$. With the exception of the overall two-way interaction between Day and Run, results were identical with nonlearners included in the analyses (see Materials and Methods for definition of "nonlearners"). These results provide evidence that increased fearfulness toward snakes and spiders hindered the initial acquisition of card/outcome probabilities (Fig. 2).

Learning strategies

Although performance was equated across the groups by the end of training on Day 1, it is possible that other emotional differences emerge when task strategy is taken into consideration. Therefore, strategy use (simple, complex, nonidentifiable) was mathematically modeled according to the procedures described in Lagnado et al. (2006) (see Materials and Methods), and the proportion of participants using each strategy was characterized for each group and run. For statistical purposes, subjects using multimax and multimatch strategies were collapsed into a "complex strategy" category, and subjects using singleton and one-cue strategies were collapsed into a "simple strategy" category. A descriptive table of the percentage of subjects in each group using each individual strategy is provided in Table 1. Participants fearful of the emotional outcomes did not exhibit a strategy preference early in training, Day 1 Run 1: $\chi^2(2) = 0.4$, $P = 0.82$. Because strategy use optimality and performance accuracy were correlated during this initial training, $r\ (78) = 0.36$, $P < 0.001$, the increased usage of nonidentifiable strategies in these participants had adverse behavioral consequences. In contrast, all other groups used simple and complex strategies to a greater extent than nonidentifiable strategies throughout training, all $\chi^2(2) > 6$, P's < 0.03. A direct comparison of strategy use across groups revealed that control participants in the emotional condition were

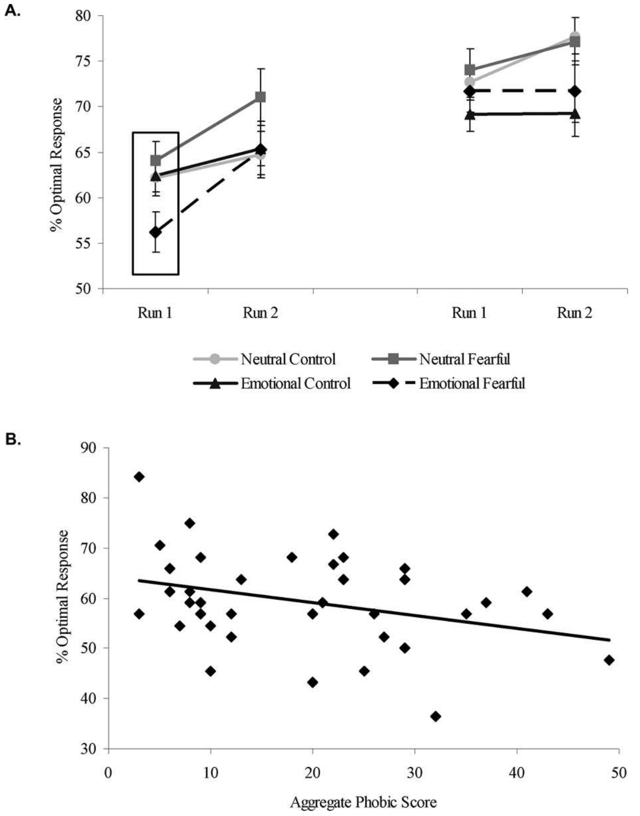

Figure 2. Learning rates over time as a function of experimental group. (*A*) Participants fearful of the snakes and spiders performed worse on the first run compared with the other groups. (*B*) Aggregate snake/spider phobia score correlates inversely with performance during initial training (Day 1 Run 1) for participants run on the emotional version of the task.

more likely to use complex strategies than the other groups by the end of training, Day 2, Run 2: $\chi^2(3) = 9.77$, $P < 0.02$. This relationship was confirmed by correlating strategy use and aggregate phobia scores for participants in the emotional condition, which showed an inverse relationship between optimal strategy use and phobia scores at the end of training, $r\ (37) = -0.37$, $P < 0.03$. Thus, the presence of emotion in the outcomes had differential effects on strategy use over time as a function of individual differences in fear relevancy (Fig. 3).

Reaction time

A mixed ANOVA revealed a main effect of Day, $F_{(1,74)} = 35.00$, $P < 0.0001$, $\eta_p^2 = 0.32$, a main effect of Run, $F_{(1,74)} = 8.63$, $P < 0.0004$, $\eta_p^2 = 0.10$, and a Day × Run interaction, $F_{(1,74)} = 6.06$, $P < 0.02$, $\eta_p^2 = 0.08$. Results demonstrate that as learning progressed, participants responded more quickly, particularly on Day 1. There was no effect of experimental group on reaction time.

Post-experimental questionnaire

Participants' free-response descriptions of how they made their predictions were coded as belonging to one or more of the following six strategies: (1) guessing, (2) card suit, (3) number of cards in a series/combination of cards, (4) card location, (5) matching the patterns/shapes/colors of cards with those associated with an outcome, or (6) gut/intuition. On Day 1, all groups used the suit of the cards to make their predictions more than the other strategies; all $\chi^2(5) > 20$, *P*'s < 0.001, except the fearful subjects in the emotional condition, who had no strategy preference. On Day 2, all groups showed an explicit preference toward using card suit over any other strategy; all $\chi^2(5) > 20$, *P*'s < 0.001 (Table 2).

The four cue cards had different strengths of predicting the outcomes—two cards were strong predictors, whereas the other two cards were weak predictors. Participants' explicit estimates of card-outcome probabilities showed a main effect of card strength, $F_{(1,72)} = 26.45$, $P < 0.0001$, $\eta_p^2 = 0.27$, a trend for a main effect of Day, $F_{(1,72)} = 3.47$, $P = 0.07$, $\eta_p^2 = 0.05$, and an interaction between card strength and Day, $F_{(1,72)} = 6.75$, $P < 0.02$, $\eta_p^2 = 0.09$. Follow-up tests showed that strong cards were more likely to be rated as good predictors on Day 2 than Day 1, $t_{(75)} = 2.59$, $P < 0.02$, with no difference in ratings for the weak cards. The presence of emotional outcomes did not modify awareness of card strength, demonstrating differential emotional effects on strategy use and insight into cue-outcome associations. While this result suggests dissociation between emotional effects on implicit and explicit forms of memory, it is acknowledged that mapping performance and subjective awareness measures onto these processes is not straightforward.

Skin conductance

A mixed ANOVA revealed a main effect of Day, $F_{(1,57)} = 4.33$, $P < 0.05$, $\eta_p^2 = 0.07$, a Day × Run interaction, $F_{(1,57)} = 17.57$, $P < 0.0001$, and a trend for a main effect of Group, $F_{(3,57)} = 2.22$, $P = 0.096$, $\eta_p^2 = 0.23$. As depicted in Figure 4, SCRs to the cue cards were lower on Day 2 relative to Day 1, reflecting a general

Table 1. Percentage strategy use in each run in each group

	Day 1		Day 2	
A	**Run 1**	**Run 2**	**Run 1**	**Run 2**
Multimax	0	0	0	5
Multimatch	55	55	50	82
Singleton	14	9	18	5
One cue	18	32	27	5
Nonidentifiable	14	5	5	5

	Day 1		Day 2	
B	**Run 1**	**Run 2**	**Run 1**	**Run 2**
Multimax	0	0	8	17
Multimatch	58	67	58	42
Singleton	17	8	13	4
One cue	17	17	21	42
Nonidentifiable	13	13	4	0

	Day 1		Day 2	
C	**Run 1**	**Run 2**	**Run 1**	**Run 2**
Multimax	0	0	0	0
Multimatch	40	47	60	53
Singleton	13	13	0	13
One cue	13	27	40	33
Nonidentifiable	33	13	0	0

	Day 1		Day 2	
D	**Run 1**	**Run 2**	**Run 1**	**Run 2**
Multimax	0	13	0	13
Multimatch	56	38	63	38
Singleton	0	13	0	0
One cue	44	38	38	50
Nonidentifiable	0	0	0	0

Breakdown of percentage of subjects in each group who used each strategy type in each run. (A) Emotional control, (B) neutral control, (C) emotional fearful, (D) neutral fearful.

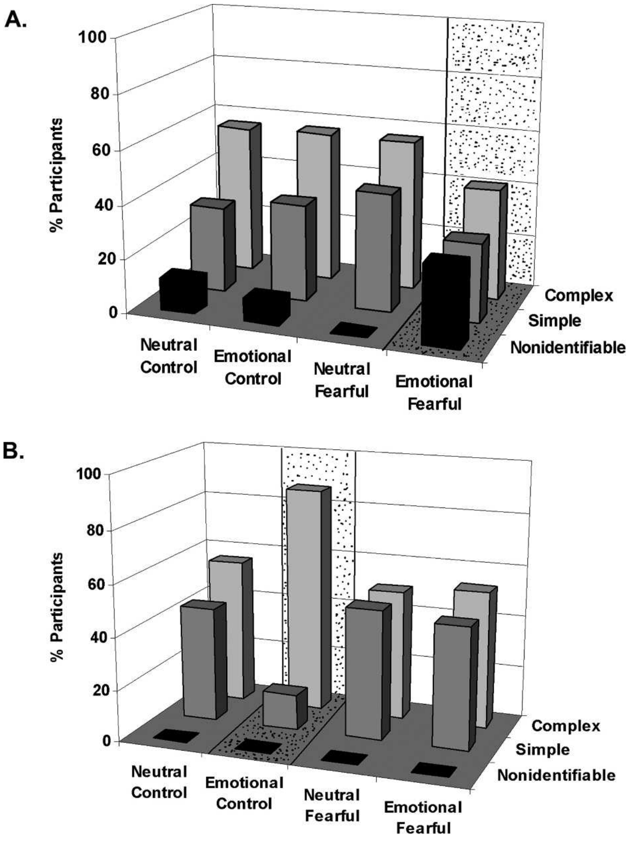

Figure 3. Strategy use over time as a function of experimental group. (*A*) Fearful participants run on the emotional version of the task showed no strategy preference during initial training (Day 1 Run 1), whereas the other groups used simple and complex strategies more than nonidentifiable ones. (*B*) At the end of training (Day 2 Run 2), more control participants run on the emotional version of the task used complex strategies than the other groups.

habituation over testing sessions. However, the interaction with Run indicates a tendency for SCRs to habituate more within trials on Day 1 than Day 2. To further analyze group differences, planned contrasts were run between the fearful and control groups in each condition. For the emotional condition, fearful participants had significantly higher SCRs overall compared with their controls, $F_{(1,28)} = 5.40$, $P < 0.03$, $\eta_p^2 = 0.16$, whereas for the neutral condition, there were no group differences in SCRs, $F_{(1,29)} = 1.96$, $P = 0.95$, $\eta_p^2 = 0.00$. These results show that increased SCRs to the cue cards were specific for subjects who were fearful of the outcome stimuli.

Discussion

The present study reveals novel influences of emotion on feedback-based learning, which are determined by the fear relevancy of outcomes paired with predictive cues. Across 2 d of training, participants learned to associate cue cards with either emotional (snake/spider) or neutral (flower/mushroom) outcomes in a probabilistic manner. Interestingly, the same emotional manipulation yielded both impaired and enhanced learning, depending on individual differences in attitudes toward the outcome stimuli. Individuals fearful of the emotional outcomes had higher SCRs to the cue cards compared with emotional controls and exhibited reduced insight, suboptimal strategy use, and retardation in initial learning relative to the other groups. Individuals who were not fearful of the emotional outcomes used more complex (optimal) strategies after a 24-h period of memory consolidation relative to the other groups, reflecting greater knowledge of the task structure. These results show that: (1) Task-relevant emotional arousal has diverse effects on feedback-based learning across individuals, (2) strategy use is important to consider because emotional effects do not always impact indices of performance or explicit knowledge, and (3) emotional effects are time variant, occurring either during initial training or following a period of memory consolidation. Altogether, these findings advance an understanding of how individual differences in emotion impact memory systems that govern the learning of probabilistic stimulus contingencies. Because salient life events are rarely deterministic, the results from this PCL task are likely to generalize to real-world situations in which complex information about regularities in the environment is extracted to guide behavior.

Accumulating evidence from a variety of disciplines has supported the idea that emotional arousal has beneficial influences on explicit forms of learning and memory (McGaugh 2004; LaBar and Cabeza 2006). However, the findings in the present study implicate impairing effects of emotional arousal on probabilistic contingency learning, with self-reported level of fearfulness toward the emotional outcome categories negatively correlating with performance on the first 50 trials. Mathematical modeling revealed that fearful participants confronted by emotional outcomes were the only group who had no strategy preference early in training, being equally likely to use complex, simple, or nonidentifiable strategies. On Day 1, these individuals were also less likely than the other groups to attend to the suit of the cards explicitly, and had greater SCRs to the cue cards throughout training compared with their respective controls. Since these behavioral and psychophysiological patterns were specific to fearful participants run on the emotional version of the task, they are not indicative of trait differences in general learning abilities.

The initial learning impairment in fearful individuals could be due to a variety of converging factors. For instance, fearful individuals could be particularly susceptible to the distracting influence

Table 2. **Post-experimental questionnaire data after training on Day 1 and Day 2**

		Emotional control	Neutral control	Fearful emotional	Fearful neutral
A					
Day 1	Guessing	27	16	33	25
	Card suit	77	76	60	88
	# Cards	18	24	20	56
	Location	27	24	47	25
	Matching	18	36	13	25
	Gut	5	4	13	0
Day 2	Guessing	27	20	20	13
	Card suit	77	72	80	88
	# Cards	36	36	33	50
	Location	36	20	20	19
	Matching	9	20	13	25
	Gut	5	4	0	0
B					
Day 1	Strong	65	66	65	70
	Weak	53	59	64	58
Day 2	Strong	73	74	72	78
	Weak	55	60	60	56

Raw data for post-experimental questionnaires. (A) Free-response descriptions of how subjects made predictions. On Day 1 all groups used the suit of the cards to make their predictions more than the other strategies, except the fearful emotional subjects. On Day 2 all groups showed a preference for using card suit over any other strategy. (B) Explicit estimates of cue-card strength, collapsed across highly predictive (strong) cards and not predictive (weak) cards. There were no group differences, but strong cards were rated as more predictive on Day 2 vs. Day 1.

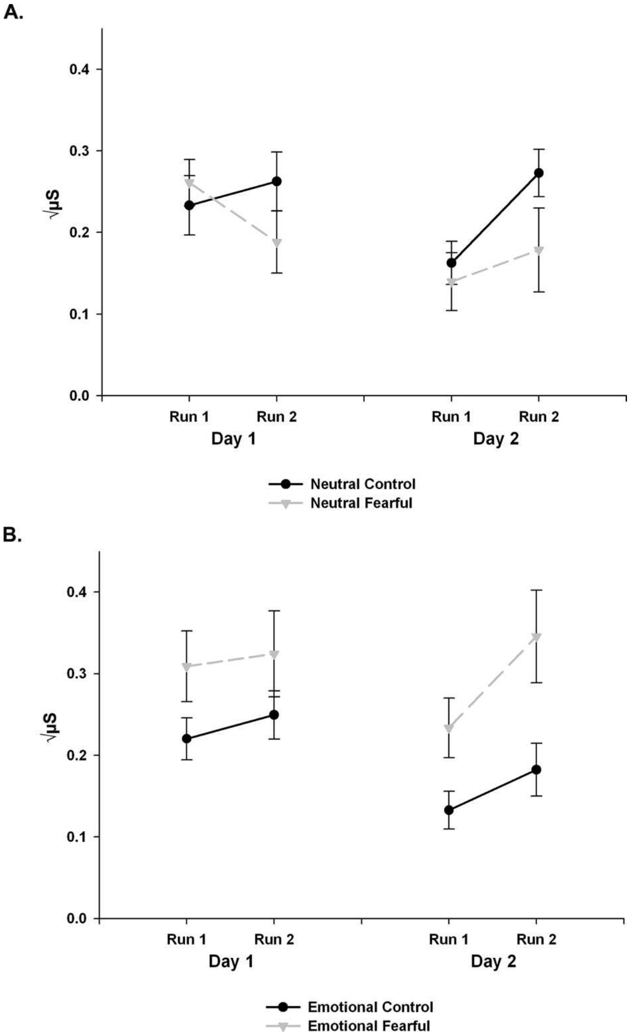

Figure 4. Skin conductance response (SCR) to cue card presentation over time as a function of experimental group. (*A*) Participants fearful of the snakes and spiders in the neutral condition showed equivalent level of SCRs as compared with controls in the neutral condition. (*B*) Participants fearful of the snakes and spiders in the emotional condition showed significantly higher SCRs across learning as compared with controls in the emotional condition. µs = Microsiemens.

of highly fear-relevant photographs that diverts processing resources away from the primary task, leading to cognitive overload (see Anderson 2005). In support of this idea, Steidl et al. (2006) showed that task-irrelevant emotional distraction impaired initial learning on the standard weather-prediction task. Emotional distraction is commonly reported on a variety of attention-demanding paradigms (e.g., Dolcos and McCarthy 2006; Wang et al. 2006), and anxiety is associated with attentional biases toward fear-relevant stimuli (Mineka and Nugent 1995). However, in a nonemotional divided attention experiment, Foerde et al. (2007) showed adverse effects on PCL performance during a dual-task condition, but not during intermittent probe trials where executive resources were untaxed. These authors concluded that divided attention affects performance of the task but not learning per se. Although we cannot distinguish performance and learning differences in the current study, the examination of strategy use implies that fearful subjects in the emotional condition did not have good knowledge of the underlying probability structure of the task.

In addition to the possible distracting influence of emotional arousal on learning, high emotional arousal may impair the binding of objects and their contexts in working memory (Mather et al. 2006), which would impair learning the probabilistic associations between cues and emotional outcomes. A failure of source binding would be more specific than that of general distraction, but behavioral performance would be affected similarly. Finally, studies of decision-making have suggested that under conditions of high arousal, people are often insensitive to probability estimates, as the mere possibility of an emotional outcome is weighted more heavily (Rottenstreich and Hsee 2001; Sunstein 2003; Slovic and Peters 2006). Thus, people may be more likely to use heuristics or to make inexact probability estimates when confronted with immediate fear-relevant outcomes. It is noteworthy that, unlike the other experimental groups, the fear-relevant group run in the emotional condition showed no bias toward using optimal strategies early in training. Future studies are warranted to clarify whether these or other mechanisms underlie the observed learning impairments.

In contrast, nonfearful individuals run in the emotional condition showed greater proportional use of complex strategies relative to the other groups at the end of training on Day 2. For the purpose of the present study, complex strategy use was defined to include both multimatch strategies, in which participants distribute their predictions similarly to the learned probabilities, and multimax strategies, in which participants choose the most probable outcome given the cue card pattern. The bias toward using more optimal strategies could indicate greater knowledge of the complex probability structure inherent to the task. Interestingly, this effect was dissociated from both performance measures and explicit estimates of card predictability, which did not differ across groups by the end of training. A period of memory consolidation and/or extended training appears to be necessary to observe this emotional benefit. These results implicate a specific influence of emotion on knowledge of probabilistic associations and highlight the importance of considering strategy use when interpreting emotional effects on PCL tasks.

Two alternative models can be advanced to help develop a mechanistic understanding of fear-relevancy effects on this task, which depend on the time course of fear. According to a "delay" model, fear is present early and then habituates such that initial fear levels are associated with both retardation in learning and subsequent complex strategy-use development. In contrast, according to a "continuous" model, fear is present continually, and independently affects the expression of both initial learning and later strategy use. In the continual presence of fear, retrieval of what was learned/consolidated from the previous day could be blocked and could prevent more complex associations from being formed with extended training. These alternate accounts could be tested in future experiments by including additional training trials on Day 3. If the "delay" model is correct and the effect of fear dissipates as training continues, fearful subjects run on Day 3 should be able to consolidate what was learned on Day 2 and develop more complex strategy use. However, if the "continuous" model is correct and fear remains high throughout training, extended training on Day 3 would have no effect on developing complex strategy use in fearful individuals.

The SCR data seem to support the latter model, since there was only a main effect of a group that extended throughout training. Moreover, we attempted to mitigate habituation effects in the design by using multiple exemplars of snakes/spiders and presenting the stimuli in a dynamic fashion. However, SCR is only one index of the physiological arousal component of fear, and subjective ratings of the outcomes were only obtained after the completion of training on Day 1 and Day 2. Thus, future work using online indices of subjective fearfulness and additional training on Day 3 are required to distinguish these alternative accounts.

The results from this experiment are important for demonstrating that the effects of task-relevant emotion on procedural learning do not function in a singular way and can be either beneficial or harmful according to individual differences in fear relevancy. There was no evidence for an intermediate pattern of response—emotion either benefited strategy use over time, or immediately impeded performance and strategy use in association with high SCR. It is important to note that these results were obtained in subclinical populations of subjects, and thus, learning was not conducted at the extreme end of arousal. The findings from fearful participants are somewhat surprising in light of theoretical perspectives regarding the role of emotion in memory and attentional functions. For instance, the Memory Modulation Hypothesis would predict that emotional arousal benefits consolidation of a striatal-based task such as PCL (Cahill and McGaugh 1998). While nonhuman animal research has demonstrated that emotion enhances striatal-based learning and memory (see Packard et al. 1994; Packard and Teather 1998), the present study indicates that higher emotional arousal associated with fearful attitudes toward the outcomes impaired performance and insight into the task structure. Our findings could also be considered unexpected given previous work on attentional biases toward threatening stimuli in anxious subjects (Öhman et al. 2001). However, attentional biases do not necessarily translate into memory biases (Mineka and Nugent 1995), and anxious subjects have difficulty disengaging from threatening stimuli, leading to a decreased ability to detect other stimuli in the environment (Cisler et al. 2007). Thus, subjects fearful of the emotional outcomes could have shown decreased ability to learn the cue contingencies, since their cognitive resources were focused on the threatening photographs. The current study thus extends research on the influence of emotion on striatal-based learning that had previously been limited to nonhuman animals and highlights complexities in delineating the relationship among emotion, attention, and learning in this domain.

In sum, the present study demonstrates separable influences of emotion on feedback-based learning according to individual differences in fear relevancy. Most experimental studies of emotional memory have emphasized singular, beneficial effects of emotion on encoding and consolidation processes. Here we report evidence for both strategy benefits following extended training in nonfearful participants exposed to emotional outcomes, and impairments in learning rates, strategy use, and self-insight during initial training in fearful participants exposed to the same outcomes. These findings have implications for understanding how individual differences in emotional salience can lead to diverse and sometimes opposing effects on learning and memory systems. Future work can take advantage of the brain-behavioral correlations inherent in neuroimaging research to reveal the dynamics of interacting neural systems that mediate these effects and to characterize their dysregulation in anxiety disorders.

Materials and Methods

Participants

Participants ($N = 116$) were Duke University students or members of the community who either received course credit or were recruited through posted advertisements and reimbursed at a rate of $10(US)/h. All participants were screened by a self-report questionnaire for history of neurological and psychiatric illness, substance abuse, current psychotropic medication use, and for depression by the Beck Depression Inventory (Beck et al. 1961). Although no participant reported a specific phobia of snakes or spiders, individuals who scored within two SD's of the phobic norms on questionnaires assessing attitudes toward snakes and spiders were categorized as "fearful" for the purposes of this study (Klorman et al. 1974). Following Aron and colleagues (2004), individuals who did not score above chance after the first 50 trials were not included in the data analyses ("nonlearners"). The final sample ($N = 78$) included 22 controls in the emotional condition (nine female, $M_{\text{age}} = 21.4$ yr), 25 controls in the neutral condition (15 female, $M_{\text{age}} = 21.3$ yr), 15 fearful participants in the emotional condition (13 female, $M_{\text{age}} = 20.1$ yr), and 16 fearful participants in the neutral condition (13 female, $M_{\text{age}} = 19.8$ yr). The proportion of nonlearners was characterized for each group, and a χ^2 test showed only a marginal trend for these distributions to be significantly different, $\chi^2(3) = 6.42$, $P = 0.09$. To ensure that the fearful and control groups did not differ on other emotional characteristics, questionnaires were administered assessing emotional experience (Positive and Negative Affect Schedule) (Watson et al. 1988), affect intensity (Affect Intensity Measure) (Larsen 1984), and current stress levels (Daily Stress Inventory) (Brantley and Jones 1993), which showed no differences between groups (all F's < 1.5). The groups also did not differ in the reported amount of sleep between the two training days. The Institutional Review Board at Duke University approved the experimental protocol and human subjects procedures.

Stimuli

The card-cue stimuli used were acquired from the Russ Poldrack laboratory at UCLA (Aron et al. 2004). The outcome stimuli were taken from the IAPS picture set (Lang et al. 1997). According to the IAPS norms, the snake and spider pictures were rated lower in valence and higher in arousal than the flower and mushroom pictures. Low-level visual properties, including luminance, contrast, color content, and picture size were equated across the outcome exemplars. Unlike in the original weather prediction task, which only presents a single "rain" and "sunshine" exemplar, six exemplars of each outcome type were presented to minimize emotional habituation to the outcome photographs.

Study design

The task design was modeled after that used by Aron et al. (2004). Between one and three (out of four) cue cards appeared on the screen, comprising 14 possible cue patterns. These patterns were associated with two outcomes in a probabilistic manner. For example, one pattern had cue cards 2, 3, and 4 present. The probability that outcome A occurred with this pattern was 75%, while the probability that outcome B occurred was 25%. Since outcome A occurred over 50% of the time, this outcome was considered "correct." Due to strong practice effects found on procedural learning tasks (e.g., Walker et al. 2003), a between-subjects design was used in which participants received either all emotional or all neutral outcomes. Participants completed 100 trials on the first day of training (two runs of 50 trials each), and another 100 trials 24 h later.

On each trial, one of the 14 card patterns appeared and remained on the screen for 4 sec, at which time the subject was prompted to respond with a left button press for outcome A and a right button press for outcome B. Participants then heard a high-frequency tone (duration = 500 msec) when they predicted the correct outcome and four 100-msec bursts of white noise at 80 db when they did not predict the correct outcome (Knowlton et al. 1996; Aron et al. 2004; Shohamy et al. 2004). To increase the emotional impact of the manipulation, all outcomes were presented dynamically with an apparent motion-induced looming effect, first appearing small in the center of the screen for 300 msec and then appearing at full screen for 700 msec. There was a 4–7-sec fixation screen intertrial interval (Fig. 1). The first 25 trials on Day 1 were pseudo-randomized, such that an equal number of patterns appeared that were "easy" (highly predictive) or "hard" (less predictive). This procedure was conducted to reduce the number of nonlearners, as indicated by pilot testing. The following 75 trials on Day 1 and all 100 trials on Day 2 were fully randomized.

Strategy questionnaire

Following Gluck et al. (2002), explicit knowledge was assessed via a questionnaire concerning strategy use and cue-outcome probabilities after both Day 1 and Day 2 (see Appendix). The questions assessed how participants thought they performed and what strategy they thought they were using. Participants also rated the predictiveness of each card for the two outcomes by reporting the percentage of time an outcome appeared if one of the four cards was on the screen.

Learning strategy analysis

Learning strategies were evaluated using mathematical models to fit each participant's data to the ideal data if a subject were reliably following a particular strategy using procedures detailed by Lagnado et al. (2006). Separate analyses were conducted for each run in each group to assess changes in strategy use across the experiment. The performance of individual participants was compared with that of an ideal participant performing one of three different strategies: (1) "simple strategies" encompassing both singleton and one-cue strategies, (2) "complex strategies" including both multimatch and multimax strategies, or (3) "no identifiable strategy" (for details, see Lagnado et al. 2006). A least-means-squared estimate was computed to evaluate the likelihood that each participant's pattern of responses followed a certain strategy across each 50-trial run.

Skin conductance responses (SCR)

SCR was recorded from the middle phalanges of the second and third digits of each participant's nondominant hand. The responses were monitored at 200 Hz and stored offline using AcqKnowledge Software for subsequent analysis (BIOPAC Systems). The physiologic data were time locked to cue-card onset, scored for the amplitude of the first interval response, and square-root transformed to attain normality according to conventional methods, as previously described (LaBar et al. 2004). Missing data occurred for five participants, and 12 participants were classified as "non-responders," meaning that they did not show any measurable SCRs, and were removed from the analyses (LaBar et al. 2004). The SCR data were scored from the remaining 61 participants (16 controls in the emotional condition, 20 controls in the neutral condition, 14 fearful participants in the emotional condition, and 11 fearful participants in the neutral condition). We calculated an overall ANOVA as well as planned contrasts for the control groups versus fearful participants in each condition.

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Appendix

Post-experimental questionnaire for the emotional condition

(1) Describe the strategy you used to predict whether the outcome would be a spider or a snake.
(2) If just the square card was showing, what percentage of the time would the outcome be "snake"? (Respond with a number from 0 to 100.)
(3) If just the circle card was showing, what percentage of the time would the outcome be "snake"? (Respond with a number from 0 to 100.)
(4) If just the diamond card was showing, what percentage of the time would the outcome be "snake"? (Respond with a number from 0 to 100.)
(5) If just the circle with the arrow in the center card was showing, what percentage of the time would the outcome be "snake"? (Respond with a number from 0 to 100.)

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