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Punishment-Modulated Attentional Capture Is Context Specific

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Attention prioritizes stimuli previously associated with punishment. Despite the importance of this process for survival and adaptation, the potential generalization of punishment-related attentional biases has been largely ignored in the literature. This study aimed to determine whether stimulus-punishment associations learned in a specific context bias attention in another context (in which the stimulus was never paired with punishment). We examined this issue using an antisaccade task in which participants had to shift their gaze in the opposite direction of a colored square during stimulus-outcome learning. Two contexts and three colors were employed. One color was associated with punishment (i.e., electrical shock) in one context and never paired with punishment in the other context. For a second color, the punishment-context relationship was reversed. A third color never paired with shock in either context (neutral) was included in Experiment 1 but absent in Experiment 2. Participants then performed search for a shape-defined target in an extinction phase (in which no shock was delivered) in which attentional bias for the colors was assessed. Context was manipulated via the background image upon which the stimuli were presented. In each of the two experiments, a bias to selectively orient toward the color that had been associated with punishment in the current context was observed, suggesting that punishment-modulated attentional priority is context specific.

Keywords: attentional capture, associative learning, punishment, contextual learning

Stimuli associated with potential punishment are thought to be particularly relevant for adaptation (LeDoux, 2014). The efficiency with which these stimuli are detected is hypothesized to have a crucial impact on an organism's survival, notably by enabling a more rapid and appropriate behavioral response (Ledoux, 1996). Consistent with this conceptualization, attention is preferentially drawn to punishment-related cues (see, e.g., Anderson & Britton, 2020; Nissens et al., 2017). Prioritized perceptual processing of threat is widely considered stimulus driven and reliant on a fast, subcortical pathway (mediated by the limbic system, specifically the amygdala) that is unaffected by cognitive influences, such as current task goals or intentions (Öhman & Mineka, 2001).

Attentional biases toward punishment-related stimuli are typically observed in visual search tasks (see Watson et al., 2019, for a review). For instance, when presented as a distractor, a stimulus (e.g., a blue diamond) previously conditioned with aversive electrical shock impairs performance compared to a neutral stimulus (e.g., an orange diamond never associated with shock), independent of perceptual salience (Schmidt et al., 2015a). Distraction by punishment-associated cues was also reported after conditioning with white noise (e.g., Koster et al., 2004; S. D. Smith et al., 2006), monetary loss (e.g., Wentura et al., 2014), or negative social feedback (Anderson, 2017; Anderson & Kim, 2018). Furthermore, oculomotor capture by punishment-related stimuli was demonstrated in eye-tracking studies (Mulckhuyse & Dalmaijer, 2016; Schmidt et al., 2015b). Nissens et al. (2017) reported that punishment-modulated attentional capture occurred even though fixating punishment-related cues increased the probability of receiving punishment (see also Anderson & Britton, 2020). Thus, stimuli associated with punishment alter visual search performance, acting as a powerful attractor of attention, possibly in an automatic way (Watson et al., 2019).

Despite the importance of this process for survival and adaptation (e.g., detect threatening stimuli), the potential generalization of punishment-related attentional biases has been largely ignored in the literature. Context-dependent effects have been reported in various research domains, such as memory (S. M. Smith & Vela, 2001), visual object recognition (Gerlach & Toft, 2011), or associative learning (Abrahamse et al., 2016). Concerning punishment learning, contextual specificity of fear expression was evidenced in Pavlovian conditioning studies (see Maren et al., 2013, for a review); for example, when a conditioned stimulus (or conditional stimulus [CS]; e.g., a tone) is paired with an aversive unconditioned stimulus (e.g., an electrical shock) in one context but not in another, the CS induces a fear reaction only if it is presented in the context of reinforcement. However, fear expression can also generalize to different stimuli and contexts in some situations (e.g., Boyle et al., 2016; Grégoire & Greening, 2020), and such generalization is thought to play a role in posttraumatic stress disorder (e.g., Kaczkurkin et al., 2016). Predictions about the potential generalization of punishment-related attentional biases thus seem uncertain.

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A previous experiment reported that stimulus-reward associations that bias attention are context specific (Anderson, 2015). This mechanism would allow for the efficient guidance of attention across a large variety of visual environments, especially by allowing for guidance by reward-stimulus contingencies learned in a particular situation with minimal interference from past learning implicating similar stimuli in a different situation. To the degree that reward and punishment influence attention via a common underlying mechanism, potentially driven by the motivational salience of stimuli, a similar contextual dependence would be predicted in the case of aversive conditioning. Consistent with this, punishment- and reward-related stimuli have been shown to produce comparable effects on attentional processing in visual search tasks, including attentional capture (Watson et al., 2019), signal suppression (Grégoire et al., 2020), and carry-over effects (Liao et al., 2020). Recent experimental works in the domain of action control also reported comparable performance for reward and punishment, probably because both have an energizing effect on behavior (e.g., Dignath et al., 2020). On the other hand, neuroimaging studies have shown that reward and aversive outcomes are represented in dissociable neural systems (Yacubian et al., 2006) and have opposite effects on behavior. Reward indeed tends to promote approach, whereas aversive outcomes (such as punishment) tend to promote inhibition or avoidance (Chen & Bargh, 1999). Coupled with the aforementioned considerations concerning fear generalization, such findings might suggest that punishment-related attentional biases are more apt to generalize across contexts.

The present study aimed to determine whether stimulus-punishment associations learned in a specific context bias attention in another context (in which the stimulus was never paired with punishment). We examined this issue using an antisaccade task in which participants had to shift their gaze in the opposite direction of a colored square during training (Kim & Anderson, 2019); this paradigm was recently shown to be effective in demonstrating attentional bias toward punishment-related cues in a subsequent test phase in which color was task irrelevant (Kim & Anderson, 2020). Two contexts and three colors were employed. One color was associated with punishment (i.e., electrical shock) in one context and never paired with punishment in the other context during training. For a second color, the punishment-context relationship was reversed. The third color was never associated with punishment in either context (neutral). Context was manipulated via the background image upon which the stimuli were presented (as in, e.g., Anderson, 2015; Britton & Anderson, 2020; Cosman & Vecera, 2013). After having experienced contextually dependent aversive outcomes in a training phase, participants performed a test phase (in which no shock was delivered) involving search for a shape-defined target. The antisaccade task during training allows participants to learn color-outcome relationships in a situation in which it is never to their advantage to orient to stimuli that predict an aversive outcome such that any increased tendency to orient to aversively conditioned stimuli in the test phase can be taken as evidence for an involuntary and nonstrategic effect of learning on attention (Kim & Anderson, 2019, 2020). In the present study, we applied a context manipulation to this paradigm to examine whether any involuntary attentional bias resulting from aversive conditioning as measured in the test phase would be modulated by the context in which different colors predicted aversive outcomes during training.

Experiment 1

Method

Participants

Based on the power analysis of Kim and Anderson (2020), and to match the sample size of that study, we aimed to recruit at least 30 participants. As effect sizes for the influence of learned stimulus-outcome associations on attentional bias are often in the small-to-medium range (Anderson & Halpern, 2017; Kim & Anderson, 2019, 2020), we did not have a minimal effect size that we would consider theoretically meaningful beyond what we powered our study to be able to detect. Thirty-six participants, between the ages of 18 and 35 inclusive, were recruited from the Texas A&M University community. All participants were English speaking and reported normal or corrected-to-normal visual acuity and normal color vision. Data from two participants were not analyzed due to an inability to track their eye movements. Two additional participants were removed because of poor tracking quality (i.e., a percentage of correct fixation below 2.5 standard deviations from the group mean in the training phase), leading to a final sample of 32 participants (19 women), with a mean age of 18.66 years (*SD* = 0.81). All procedures were approved by the Texas A&M University Institutional Review Board and were conducted in accordance with the principles expressed in the Declaration of Helsinki. Written informed consent was obtained for each participant.

Apparatus

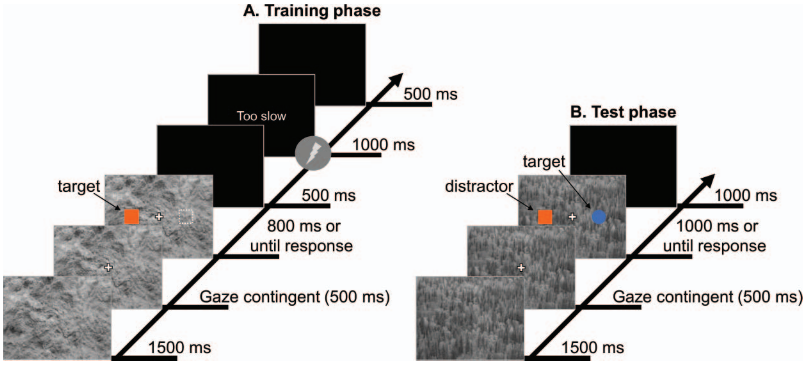
A Dell OptiPlex 7040 (Dell, Round Rock, TX) equipped with Matlab software (Mathworks, Natick, MA) and Psychophysics Toolbox extensions (Brainard, 1997) was used to present the stimuli on a Dell P2717H monitor. The participants viewed the monitor from a distance of approximately 70 cm in a dimly lit room. Paired electrodes (EL500, BioPac Systems, Inc., Goleta, CA) were attached to the left forearm of each participant, and 2-ms mild electric shocks were delivered through an isolated linear stimulator under the constant current setting (STMISOLA, BioPac Systems), which was controlled by custom Matlab scripts. Eye tracking was conducted using the EyeLink 1000 Plus system (SR Research Ltd., Ottawa, Ontario, Canada), and head position was maintained using an adjustable chin and forehead rest (SR Research Ltd., Ottawa, Ontario, Canada).

Training Phase

Stimuli. Each trial consisted of the presentation of a context scene upon which a fixation cross and a stimulus display were subsequently presented, followed by a blank screen and a feedback display when appropriate (Figure 1A). The context scene consisted of a black-and-white picture of a forest or a rocky terrain (similarly as, e.g., Anderson, 2015; Britton & Anderson, 2020; Cosman & Vecera, 2013), which remained on screen throughout the fixation cross and stimulus display. The fixation cross (white with a black outline, 0.8° × 0.8° visual angle) was presented at the center of the screen, and the stimulus display included the fixation cross and a 4.7° × 3.4° color square (i.e., the target of the antisaccade)

Figure 1

Sequence of Trial Events in (A) the Training Phase and (B) the Test Phase of Experiments 1 and 2



Note. Each trial began with the presentation of a background for 1,500 ms. A fixation cross then appeared at the center of the screen. After the participant fixated the cross for 500 ms, the search display was presented. In the training phase, the stimulus display remained on the screen for 800 ms or until an eye movement exceeding 8.2° in amplitude to the left or right was registered (the dotted line represents the location where the participant had to shift their gaze). In the test phase, the search display remained on the screen for 1,000 ms or until the participant fixated the target (i.e., the circle) for 100 ms. A 1,000-ms blank screen followed the search display before the next trial. During the training phase, a 1,000-ms feedback display was added in the sequence of trial events, 500 ms after the search display, for misses and incorrect responses (with an appropriate feedback, i.e., "too slow" or "incorrect," respectively). The shock was administered 500 ms after the stimulus display (so at the same time that the 1,000-ms feedback display for misses and incorrect responses) in 40% of the CS+ in-context trials (when a shock was delivered for a correct response on a preconfigured trial, a 1,000-ms blank screen was added in the sequence of trial events, 500 ms after the stimulus display). During the test phase, a 1,000-ms feedback display ("miss") was added immediately after the search display if participants failed to generate a saccade toward the target within the timeout limit. See the online article for the color version of this figure.

presented 12.2° center to center to the left or right of fixation. Red, green, and blue colors—matched for luminance—were used for the square. The background of the blank screen was black. The feedback display was presented only when participants failed to make an appropriate response. It showed the word "incorrect" if participants made a saccade toward the square and "too slow" if a correct response was not otherwise registered. Written information was presented at the center of the screen in white 40-point Arial font on a black background.

Procedure. Prior to the experiment, the participant was connected to the isolated linear stimulator, and a shock calibration procedure was conducted to achieve a level that was "unpleasant, but not painful" (Grégoire & Greening, 2019, 2020; Murty et al., 2012; Schmidt et al., 2015a, 2017). Starting at 8 mA, the current was increased stepwise by 1 mA, each time checking with the participant whether the stimulation evoked a pain response. When the participant first indicated that the stimulus was painful, the current was regulated down 1 mA, confirmed by the participant as "unpleasant, but painless," and used for the experiment. A practice phase (without shock) comprising 12 trials with no time limit followed by 24 trials with a time limit was then performed before the training phase. All possible combinations between the positions of the square and the background scenes were presented an equal number of times within each situation (i.e., with and without time limit). Note that we used achromatic (white) stimuli in all practice phases of this experiment to avoid any learning effects.

The training phase was split into six blocks, with each block consisting of 60 trials (360 trials in total). In each block, all possible combinations between the positions of the square and the colors were presented an equal number of times within each context (i.e., five times). One color was associated with the punishment of shock in one context (CS+ in context) and never paired with shock in the other context (CS+ out of context). For a second color, the punishment-context relationship was reversed. The third color was never paired with shock in either context (CS−). The assignment between the colors, the conditions, and the background scenes was fully counterbalanced across participants. The context scene was the forest on half of the trials and the rocky terrain on the other half. The trials were presented in a random order.

Each trial began with the presentation of a background scene for 1,500 ms. A fixation cross then appeared at the center of the screen and remained until eye position was registered within 1.1° of the center of the cross for a continuous period of 500 ms. Next, the stimulus display was presented for 800 ms or until an eye movement exceeding 8.2° in amplitude to the left or right was registered. A 1,000-ms blank screen followed the search display before the subsequent trial. When participants failed to make an appropriate response, a 1,000-ms feedback display was added in the sequence of trial events, 500 ms after the stimulus display. Specifically, the word "incorrect" was presented if an eye movement exceeding 8.2° in amplitude in the direction of the color square was registered, and the words "too slow" were presented if no eye movement exceeding 8.2° in amplitude in either direction was detected. The shock was delivered 500 ms after the search display. Thus, the shock was administered at the same time that the 1,000-ms feedback display appeared when participants failed to make an appropriate response. Participants could also receive a shock for a correct response (when their response time [RT] was slower than the latency time for shock; see details below). In this case, no text feedback was presented, but a 1,000-ms blank screen was added in the sequence of trial events, 500 ms after the stimulus display.

Participants received a shock on the CS+ in-context trials if they did not make a saccade to the opposite side of the square before the 800-ms timeout, responded too slowly (i.e., above the latency limit for shock), or saccaded toward the square, with a limit of four shocks per background scene per block. A latency limit for shock was defined for each background scene. It was based on the sixtieth percentile of all the correct RTs of the CS+ in-context trials, for each background scene, from the previous block (or the 24 trials with a time limit from the practice phase for the first block). To ensure that the number of shocks delivered in each block was comparable (as in, e.g., Grégoire et al., 2020), eight trials were preconfigured to produce a shock on the CS+ in-context trials, four per background scene, regardless of speed or accuracy. The first three CS+ in-context trials of each background scene were not preconfigured to deliver a shock (so the four preconfigured trials of each background scene were randomly distributed among the remaining seven CS+ in-context trials). If the participant received a shock on a nonpreconfigured trial before the first preconfigured trial (for a specific background scene), then the first preconfigured trial became a regular (CS+ in-context) trial. The same logic was applied for all the following preconfigured trials. This procedure allowed shocks to be to some degree performance-contingent, thus providing more direct motivation to rapidly orient away from the targets, while at the same time ensuring that the number of shocks per condition was equal and unbiased. Thus, all the participants received eight shocks per block (48 shocks in total). In total, 52.47% of shocks were contingent on performance, and 47.53% of shocks were delivered on preconfigured trials.

Participants were instructed to move their eyes to the opposite side of the color square on each trial as quickly as possible. They were also informed that some trials would sometimes result in a shock and that they were more likely to be shocked if their response was slow or incorrect. Participants were not explicitly informed of the shock contingencies, which had to be learned from experience in the task.

Test Phase

Stimuli. Each trial consisted of the presentation of a context scene upon which a fixation cross and a search array were subsequently presented, followed by a blank screen and a feedback display when appropriate (Figure 1B). The context scene was presented prior to the search array in order to ensure that adequate processing of the scene was possible before localization of the target. As in the training phase, the context scene remained on screen throughout the fixation cross and search display, which now consisted of a square and a circle, presented equidistant from fixation on the left and right. The size and spacing of these shapes matched those used in the training phase. Red, green, and blue were used for the shapes, with no color ever appearing twice in the same display. The two background scenes, three colors, and blank screen were similar to those used in the training phase. The feedback display was presented only when participants failed to look at the target (i.e., the circle) before the timeout. In this case, the word "miss" appeared at the center of the screen in white 40-point Arial font on a black background.

Procedure. The test phase was split into three blocks, with each block consisting of 96 trials (288 trials in total). Each color served as the target and distractor equally often in each block, with the color by position pairings fully crossed and counterbalanced separately within each context. The context scene was the forest on half of the trials and the rocky terrain on the other half. The trials were presented in a random order. Participants first completed 12 randomly ordered practice trials, six with each scene, using achromatic (white) shapes (the position of the target was presented equally often on each side of the screen for each context).

Each trial began with the presentation of a background scene for 1,500 ms. A fixation cross then appeared at the center of the screen and remained until eye position was registered within 1.1° of the center of the cross for a continuous period of 500 ms. Next, the search display was presented for 1,000 ms or until the participant fixated the target for 100 ms. A 1,000-ms blank screen followed the search display before the subsequent trial. A 1,000-ms feedback display (the word "miss") was added immediately after the search display if participants failed to generate a saccade toward the target within the timeout limit (this display was omitted following a correct response). A correct response was registered if eye position was measured at more than 8.2° from fixation in the direction of the target (for 100 ms) within the 1,000-ms timeout limit. If the participant generated a saccade landing more than 8.2° from fixation in the direction of the distractor, the trial was scored as containing an errant eye movement. No shock was delivered during the test phase.

Participants were instructed to fixate the circle on each trial as quickly as possible, regardless of the color of the shapes. They were also informed that no shock will be delivered in this phase. However, shock electrodes were kept attached until the end of the experiment to not eliminate the physical possibility to receive electrical stimulations. This manipulation aimed to prevent that the absence of predictability of shock affects reactions to punishment-related stimuli (Sevenster et al., 2012).

General Procedure

Head position was maintained throughout the experiment using an adjustable chin and forehead rest. Participants were provided a short break between each block of the experiment in which they were allowed to reposition their head to maintain comfort. Eye position was calibrated prior to each block of trials using 5-point calibration and was manually drift corrected by the experimenter as necessary (the next trial could not begin until eye position was registered within 1.1° of the center of the fixation cross for 500 ms; see, e.g., Kim & Anderson, 2019; Nissens et al., 2017). During the presentation of the search array, the X and Y positions of the eyes were continuously monitored in real time such that fixations were coded on line (Anderson & Kim, 2019a, 2019b; Le Pelley et al., 2015). In the training phase, to increase the likelihood to be shocked for incorrect responses (and so decrease the likelihood to be shocked for correct responses), an eye movement toward the square resulted in the termination of the trial. In the test phase, to maximize our sensitivity to measure selection bias, errant eye movements were recorded but did not result in the termination of the trial such that participants could still fixate the target within the timeout limit and not receive "miss" feedback even if gaze was initially directed toward the distractor.

Contingency-Awareness Questionnaire

After the test phase, participants provided self-report evaluations of their contingency awareness about the relationship between each specific stimulus display of the training phase and shock (as in, e.g., Grégoire & Anderson, 2019; Grégoire & Greening, 2020; Liao et al., 2020). All possible combinations between the positions of the square and the colors were presented two times within each context, in a random order (24 trials in total). Participants were asked to indicate how likely each trial was to result in shock by clicking on a continuous scale ranging from 0 to 100 (0 meant shock was impossible and 100 meant shock was guaranteed).

Data Analysis

The coding of RT and errant saccades was performed online during each trial of the experiment as described above. RTs below 70 ms (anticipatory saccades) and exceeding 3 standard deviations of the mean of a given condition (for each participant) were trimmed in each phase (Anderson & Kim, 2019b; Anderson & Yantis, 2012; Grégoire et al., 2020). In the training phase, correct RT was registered from the onset of the stimulus display until the participant made an eye movement exceeding 8.2° in amplitude to the opposite side of the square. In the test phase, correct RT was registered from the onset of the search display until the participant looked at the target for 100 ms. We subtracted 100 ms from all RTs of the test phase to yield the time at which eye position first entered into the region of the target. Error rate in the training phase corresponds to the proportion of trials on which a correct response was not registered (i.e., miss or incorrect response). In the test phase, error rate corresponds to the proportion of trials on which the participant looked at the distractor.

The training phase data were subjected to 3 × 6 analyses of variance (ANOVAs) with condition (CS+ in context, CS+ out of context, CS−) and block (1, 2, 3, 4, 5, 6) as within-subject variables, separately for RT and error rate. For the test phase, we used the same approach as Kim and Anderson (2019). Analyses were performed separately for saccades with respect to target color and distractor color (to preserve independence of conditions), directly comparing the CS+ in and out of context, separately for RT and error rate. For each condition (bar) depicted in Figure 3, the conditional mean collapses across the color of the nonreferenced stimulus (e.g., CS+ in-context target trials collapse across trials on which the distractor was the CS+ out-of-context color and the CS− color). Data were subjected to 2 × 2 ANOVAs with type of stimulus (target, distractor) and condition (CS+ in context, CS+ out of context) as within-subject variables. For each ANOVA, sphericity was tested with Mauchly's test of sphericity, and when the sphericity assumption was violated and sphericity was therefore not assumed, degrees of freedom were adjusted using the Greenhouse–Geisser epsilon correction. We ran ANOVAs on untransformed data because ANOVA is generally robust to violations of normality (Blanca et al., 2017; Schmider et al., 2010).

Additional *t* tests were performed (when appropriate) to compare two-by-two data from the experimental conditions (CS+ in context, CS+ out of context, and CS−). Note that we calculated Cohen's *d* using the formula $d_z = t/\text{sqrt}(n)$ for paired-sample *t* tests (Lakens, 2013; Rosenthal, 1991). For all *t* tests performed on error rates, we additionally report p_{rand}, which reflects the probability of the observed effect when comparing to an empirically derived sampling distribution in which the assignment of error rate to condition is randomly determined (i.e., random sign flipping) for each participant over 100,000 iterations; such a randomization test does not make assumptions about the normality of the distribution of the data, which can be problematic for the analysis of error rate, and therefore makes our analysis plan further robust to any violations of normality (Grégoire et al., 2020). The data of the two experiments reported in this article can be found at https://osf.io/xda6j/.

Results

Training Phase

An antisaccade (i.e., a correct response) was registered within the timeout limit on 94.62% of all trials. A 3 × 6 ANOVA conducted on mean RTs with condition (CS+ in context, CS+ out of context, CS−) and block (1, 2, 3, 4, 5, 6) as within-subject variables revealed no significant main effect of condition, $F(2, 62) = 0.19$, $p = .832$, no significant main effect of block, $F(3.49, 108.22) = 0.16$, $p = .946$, and a significant interaction between condition and block, $F(10, 310) = 2.11$, $p = .023$, $\eta_p^2 = 0.064$. This interaction resulted from the partial interaction between condition (CS+ out of context, CS−) and block (1, 2, 3, 4, 5, 6), $F(5, 155) = 3.24$, $p = .008$, $\eta_p^2 = 0.095$. The mean RTs of the training phase are presented in Table 1.

The same ANOVA conducted on error rates revealed a significant main effect of condition, $F(2, 62) = 5.39$, $p = .007$, $\eta_p^2 = 0.148$, no significant main effect of block, $F(3.40, 105.52) = 1.26$, $p = .291$, and no significant interaction between condition and block, $F(6.32, 205.56) = 0.45$, $p = .861$. Subsequent *t* tests

Table 1

RTs (ms) in the Training Phase of Experiment 1 and Experiment 2 as a Function of Condition and Block

	CS+ in context	CS+ out of context	CS−
Experiment 1			
Block 1	284.71 (42.27)	293.41 (44.52)	281.11 (40.80)
Block 2	285.29 (38.77)	284.74 (41.80)	292.15 (46.60)
Block 3	285.83 (41.12)	289.38 (46.21)	285.42 (46.21)
Block 4	289.35 (55.94)	287.60 (48.60)	293.26 (53.38)
Block 5	288.98 (44.81)	287.00 (45.38)	287.78 (44.32)
Block 6	288.50 (46.99)	286.04 (46.62)	285.06 (41.06)
Experiment 2			
Block 1	296.94 (43.62)	302.95 (48.35)	—
Block 2	304.58 (45.70)	304.18 (46.73)	—
Block 3	309.08 (49.53)	313.58 (55.78)	—

Note. CS = conditioned stimulus. Standard deviations are in parentheses.

indicated that error rates were significantly higher for the CS+ in context ($M = 6.31$, $SD = 6.33$) than for the CS+ out of context ($M = 4.80$, $SD = 5.73$) and the CS− ($M = 4.98$, $SD = 4.49$), $t(31) = 3.60$, $p = .001$ ($p_{rand} < 0.001$), $d_z = 0.64$, and $t(31) = 2.30$, $p = .028$ ($p_{rand} = 0.025$), $d_z = 0.41$, respectively. No significant difference was observed between the CS+ out of context and the CS−, $t(31) = 0.37$, $p = .716$ ($p_{rand} = 0.711$), $d_z = 0.07$ (Figure 2A).

Test Phase

A fixation on the target was registered within the timeout limit on 98.14% of all trials. A 2 × 2 ANOVA conducted on mean RTs with type of stimulus (target, distractor) and condition (CS+ in context, CS+ out of context) as within-subject variables revealed no significant main effect of type of stimulus, $F(1, 31) = 0.01$, $p = .913$, no significant main effect of condition, $F(1, 31) = 0.50$, $p = .484$, and no significant interaction between type of stimulus and condition, $F(1, 31) = 0.99$, $p = .327$ (see Table 2).

The same ANOVA conducted on error rates revealed no significant main effect of type of stimulus, $F(1, 31) < 0.01$, $p > .99$, no significant main effect of condition, $F(1, 31) = 1.16$, $p = .291$, and a significant interaction between type of stimulus and condition, $F(1, 31) = 7.36$, $p = .011$, $\eta_p^2 = 0.192$. Subsequent *t* tests indicated that when the target was rendered in the CS+ in-context color ($M = 8.40$, $SD = 6.90$), participants were overall more accurate than when the target was rendered in the CS+ out-of-context color ($M = 9.51$, $SD = 6.50$), but the effect did not reach significance, $t(31) = 1.85$, $p = .074$ ($p_{rand} = 0.072$), $d_z = 0.33$. When the distractor was rendered in the CS+ in-context color ($M = 9.93$, $SD = 6.92$), participants made significantly more errors than when the distractor was rendered in the CS+ out-of-context color ($M = 7.98$, $SD = 6.81$), $t(31) = 2.55$, $p = .016$ ($p_{rand} = 0.018$), $d_z = 0.45$ (Figure 3A). An additional analysis revealed that when the CS+ in-context and CS+ out-of-context colors directly competed for attention (i.e., appeared on the same trial), participants made significantly more errors when they needed to orient away from the CS+ in-context distractor ($M = 10.68$, $SD = 7.53$, when the target corresponded to the CS+ out-of-context color and the distractor corresponded to the CS+ in-context color, and $M = 8.01$, $SD = 8.30$, when the relationship between the color and the type of stimulus was reversed), $t(31) = 3.06$, $p = .005$ ($p_{rand} = 0.003$), $d_z = 0.54$.

Contingency-Awareness Questionnaire

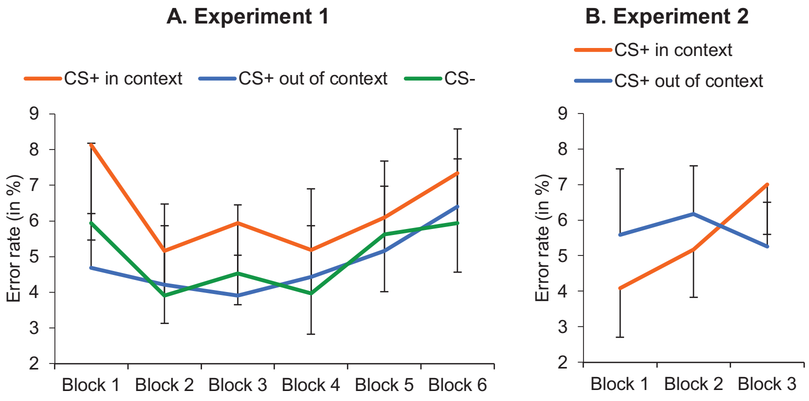
Participants self-reported that the likelihood of receiving a shock on the CS+ in-context trials ($M = 45.44\%$, $SD = 14.76$) did not differ significantly from the likelihood of receiving a shock on the CS+ out-of-context trials ($M = 45.13\%$, $SD = 14.83$), $t(31) = 0.29$, $p = .778$, $d_z = 0.05$. Likewise, participants self-reported that the likelihood of receiving a shock on the CS+ in-context and CS+ out-of-context trials did not differ significantly from the likelihood of receiving a shock on the CS− trials ($M = 38.59\%$, $SD = 15.79$), $t(31) = 1.86$, $p = .072$, $d_z = 0.33$, and $t(31) = 1.84$, $p = .076$, $d_z = 0.32$, respectively.

Discussion

Results revealed higher error rates in the antisaccade task when the color was associated with shock in the current context (CS+ in context) than when the color was either associated with shock in the other context (CS+ out of context) or neutral (CS−). We observed no significant difference for error rates between the CS+ out-of-context and CS− conditions. Thus, attention was biased only if the color was reinforced with shock in the current context. Importantly, in a subsequent test phase (in which no shock was delivered) involving search for a shape-defined target, a bias to orient toward shock-associated colors was particular to the context in which the color had been previously paired with shock (in the training phase), suggesting a contextually specific attentional bias driven by associative learning. The fact that this bias emerged

Figure 2

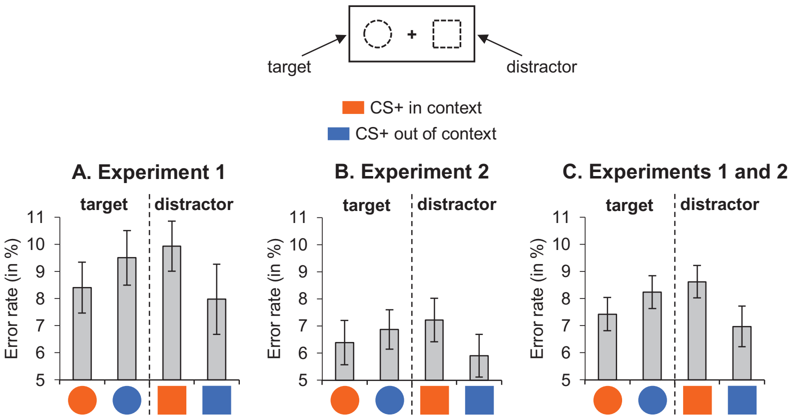
Error Rates (Incorrect Saccades and Misses) in the Training Phase of (A) Experiment 1 and (B) Experiment 2 as a Function of Condition and Block



Note. CS = conditioned stimulus. Error bars (downward for CS+ in context, upward for CS+ out of context and CS−) depict within-subjects 95% confidence intervals calculated using the Cousineau method (Cousineau, 2005) with a Morey correction (Morey, 2008). See the online article for the color version of this figure.

Figure 3

Error Rates (Percent Fixations on the Distractor) in the Test Phase of (A) Experiment 1, (B) Experiment 2, and (C) Experiments 1 and 2 Combined (N = 62) as a Function of Type of Stimulus (Target, Distractor) and Condition (CS+ in Context, CS+ out of Context)



Note. CS = conditioned stimulus. Error bars depict within-subjects 95% confidence intervals calculated using the Cousineau method (Cousineau, 2005) with a Morey correction (Morey, 2008). See the online article for the color version of this figure.

following training in which it was never to the advantage of participants to orient toward a CS+ suggests that the bias is involuntary and nonstrategic. Although no difference between the experimental conditions was observed on RTs in the two phases, there was no evidence for a speed-accuracy trade-off either, and our results are overall consistent with contextual learning of stimulus-punishment associations. After the test phase, participants self-reported that the likelihood of receiving a shock in the antisaccade task did not differ between the CS+ in-context and CS+ out-of-context trials, suggesting that the learning was implicit.

Experiment 2

The results of Experiment 1 show that the same stimulus does or does not capture attention, depending on whether it has been associated with shock specifically in the context within which it appears. We conducted a second experiment to provide additional confidence in our conclusions. The main difference with Experiment 1 was the removal of the neutral condition from the training phase. We supposed that this change would facilitate the learning of the shock contingencies and would strengthen the observed effects.

Method

Participants

Thirty-six new participants, between the ages of 18 and 35 inclusive, were recruited from the Texas A&M University community. All participants were English speaking and reported normal or corrected-to-normal visual acuity and normal color vision. Data from three participants were not analyzed due to an inability to track their eye movements. Three additional participants were removed because of poor tracking quality (i.e., a percentage of correct fixation below 2.5 standard deviations from the group mean in the training phase), leading to a final sample of 30 participants (18 women), with a mean age of 18.97 years (*SD* = 0.66). All procedures were approved by the Texas A&M University Institutional Review Board and were conducted in accordance with the principles expressed in the Declaration of Helsinki. Written informed consent was obtained for each participant.

Table 2

RTs (ms) in the Test Phase of Experiment 1, Experiment 2, and Experiments 1 and 2 Combined (N = 62) as a Function of Type of Stimulus (Target, Distractor) and Condition (CS+ in Context, CS+ out of Context)

	Target		Distractor	
	CS+ in context	CS+ out of context	CS+ in context	CS+ out of context
Experiment 1	294.15 (58.00)	295.13 (57.36)	295.67 (53.17)	293.16 (54.02)
Experiment 2	283.66 (31.64)	283.22 (32.23)	282.53 (31.78)	283.02 (31.13)
Experiments 1 and 2	289.07 (47.05)	289.37 (46.92)	289.31 (44.28)	288.25 (44.38)

Note. CS = conditioned stimulus. Standard deviations are in parentheses.

Stimuli and Procedure

Experiment 2 was similar to Experiment 1 except for three points of the training phase: (a) the CS− condition was removed, (b) the number of blocks was reduced (with a greater number of trials per block), and (c) the number of preconfigured trials (to produce a shock on the CS+ in-context trials) per block was increased accordingly. The training phase of Experiment 2 was split into three blocks, with each block consisting of 80 trials (240 trials in total). Sixteen trials were preconfigured to produce a shock on the CS+ in-context trials, eight per background scene, regardless of speed or accuracy. The first five CS+ in-context trials of each background scene were not preconfigured to deliver a shock (so the eight preconfigured trials of each background scene were randomly distributed among the remaining 15 CS+ in-context trials). As in Experiment 1, if the participant received a shock on a nonpreconfigured trial before the first preconfigured trial (for a specific background scene), then the first preconfigured trial became a regular (CS+ in-context) trial. The same logic was applied for all the following preconfigured trials. Thus, all the participants received 16 shocks per block (48 shocks in total). In total, 52.78% of shocks were contingent on performance, and 47.22% of shocks were delivered on preconfigured trials.

Contingency-Awareness Questionnaire

The contingency-awareness questionnaire was similar to the one of Experiment 1 except that all possible combinations between the positions of the square and the colors were presented one time (instead of two) within each context, in a random order (eight trials in total).

Data Analysis

Data were analyzed in the same manner as in Experiment 1, with the exception that ANOVAs of the training phase included one fewer condition (i.e., CS−). We have also included analyses for the test phase that collapse across Experiments 1 and 2 ($N = 62$); we thus aimed to determine whether data were consistent between the two experiments.

Results

Training Phase

An antisaccade (i.e., a correct response) was registered within the timeout limit on 94.43% of all trials. A 2 × 3 ANOVA conducted on mean RTs with condition (CS+ in context, CS+ out of context) and block (1, 2, 3) as within-subject variables revealed a significant main effect of condition, $F(1, 29) = 4.63$, $p = .040$, $\eta_p^2 = 0.138$, with faster RTs for the CS+ in context than for the CS+ out of context, a significant main effect of block, $F(1.65, 47.83) = 3.91$, $p = .034$, $\eta_p^2 = 0.119$, with a significant positive linear trend, $F(1, 29) = 5.29$, $p = .029$, $\eta_p^2 = 0.154$, indicating that participants became slower across blocks, and no significant interaction between condition and block, $F(2, 58) = 1.08$, $p = .346$ (see Table 1).

The same ANOVA conducted on error rates revealed no significant main effect of condition, $F(1, 29) = 0.42$, $p = .522$, no significant main effect of block, $F(2, 58) = 1.44$, $p = .245$, and an interaction between condition and block that did not reach the threshold for significance, $F(2, 58) = 2.84$, $p = .067$, $\eta_p^2 = 0.089$, but exhibited a significant positive linear trend, $F(1, 29) = 5.21$, $p = .030$, $\eta_p^2 = 0.152$, indicating that the difference between the CS+ in context and the CS+ out of context increased across blocks (Figure 2B).

Test Phase

A fixation on the target was registered within the timeout limit on 99.54% of all trials. A 2 × 2 ANOVA conducted on mean RTs with type of stimulus (target, distractor) and condition (CS+ in context, CS+ out of context) as within-subject variables revealed no significant main effect of type of stimulus, $F(1, 29) = 0.20$, $p = .660$, no significant main effect of condition, $F(1, 29) < 0.01$, $p = .974$, and no significant interaction between type of stimulus and condition, $F(1, 29) = 0.07$, $p = .793$ (see Table 2).

The same ANOVA conducted on error rates revealed no significant main effect of type of stimulus, $F(1, 29) = 0.02$, $p = .877$, no significant main effect of condition, $F(1, 29) = 1.38$, $p = .249$, and a significant interaction between type of stimulus and condition, $F(1, 29) = 7.11$, $p = .012$, $\eta_p^2 = 0.197$. Subsequent *t* tests indicated that when the target was rendered in the CS+ in-context color ($M = 6.39$, $SD = 6.45$), error rates were numerically lower than when the target was rendered in the CS+ out-of-context color ($M = 6.88$, $SD = 5.72$), but this difference was not significant, $t(29) = 1.02$, $p = .318$ ($p_{rand} = 0.292$), $d_z = 0.19$. When the distractor was rendered in the CS+ in-context color ($M = 7.22$, $SD = 5.36$), participants made significantly more errors than when the distractor was rendered in the CS+ out-of-context color ($M = 5.90$, $SD = 4.88$), $t(29) = 2.63$, $p = .014$ ($p_{rand} = 0.009$), $d_z = 0.48$ (Figure 3B). An additional analysis revealed that when the CS+ in-context and CS+ out-of-context colors directly competed for attention (i.e., appeared on the same trial), participants made more errors when they needed to orient away from the CS+ in-context distractor ($M = 7.43$, $SD = 6.13$, when the target corresponded to the CS+ out-of-context color and the distractor corresponded to the CS+ in-context color, and $M = 5.90$, $SD = 5.69$, when the relationship between the color and the type of stimulus was reversed), $t(29) = 2.26$, $p = .032$ ($p_{rand} = 0.024$), $d_z = 0.41$.

Contingency-Awareness Questionnaire

Participants self-reported that the likelihood of receiving a shock on CS+ in-context trials ($M = 43.95\%$, $SD = 18.28$) did not differ significantly from the likelihood of receiving a shock on CS+ out-of-context trials ($M = 43.56\%$, $SD = 17.49$), $t(29) = 0.36$, $p = .719$, $d_z = 0.07$.

Experiments 1 and 2 Combined (Test Phase)

A 2 × 2 ANOVA conducted on mean RTs with type of stimulus (target, distractor) and condition (CS+ in context, CS+ out of context) as within-subject variables revealed no significant main effect of type of stimulus, $F(1, 61) = 0.12$, $p = .730$, no significant main effect of condition, $F(1, 61) = 0.31$, $p = .580$, and no significant interaction between type of stimulus and condition, $F(1, 61) = 0.30$, $p = .584$ (see Table 2).

The same ANOVA conducted on error rates revealed no significant main effect of type of stimulus, $F(1, 61) = 0.01$, $p = .926$, no significant main effect of condition, $F(1, 61) = 2.54$, $p = .116$, and a significant interaction between type of stimulus and condition, $F(1, 61) = 13.49$, $p = .001$, $\eta_p^2 = 0.181$.[1] Subsequent t tests indicated that when the target was rendered in the CS+ in-context color ($M = 7.43$, $SD = 6.71$), participants made significantly less errors than when the target was rendered in the CS+ out-of-context color ($M = 8.23$, $SD = 6.22$), $t(61) = 2.09$, $p = .040$ ($p_{rand} = 0.037$), $d_z = 0.27$. Likewise, when the distractor was rendered in the CS+ in-context color ($M = 8.62$, $SD = 6.32$), participants made significantly more errors than when the distractor was rendered in the CS+ out-of-context color ($M = 6.97$, $SD = 6.00$), $t(61) = 3.56$, $p = .001$ ($p_{rand} < 0.001$), $d_z = 0.45$ (Figure 3C). An additional analysis revealed that when the CS+ in-context and CS+ out-of-context colors directly competed for attention (i.e., appeared on the same trial), participants made more errors when they needed to orient away from the CS+ in-context distractor ($M = 9.11$, $SD = 7.03$, when the target corresponded to the CS+ out-of-context color and the distractor corresponded to the CS+ in-context color, and $M = 6.99$, $SD = 7.18$, when the relationship between the color and the type of stimulus was reversed), $t(61) = 3.80$, $p < .001$ ($p_{rand} < 0.001$), $d_z = 0.48$.

Discussion

Results of Experiment 2 largely mirror those of Experiment 1. In the antisaccade task, participants made more errors when the color was associated with shock in the current context than when the color was associated with shock in the other context, a difference that exhibited a linear trend over block. Importantly, in the subsequent extinction phase, a bias to orient toward shock-associated colors was particular to the context in which the color had been paired with punishment in the previous phase, consistent with a contextually specific attentional bias to punishment-related cues. The same pattern of results was observed when the data of the test phase were combined for Experiments 1 and 2, reflecting a robust overall influence of context-specific learning. As in Experiment 1, participants showed no evidence for awareness of the shock contingencies, suggesting that the learning was implicit.

General Discussion

The purpose of the current study was to determine whether stimuli associated with punishment in a specific context bias attention when presented in another context (in which they are never paired with punishment). We investigated this issue using the antisaccade task in which participants had to shift their gaze in the opposite direction of a colored square. In two experiments, we observed that the color associated with shock in the current context (CS+ in context) induced more errors (i.e., fixations of the square and misses) than the color associated with shock in the other context (CS+ out of context). In Experiment 1, error rates were also greater for the CS+ in-context color than for the neutral color, which was never associated with shock in either context. Consequently, results from the antisaccade task are consistent with the context-specificity hypothesis of punishment-modulated attentional capture.

Of primary interest was the data from the subsequent test phase (in which no shock was delivered), which provides a sensitive measure of attentional bias following training in which it was never to the advantage of participants to look at the color stimuli. In the test phase, a bias to orient toward shock-associated colors was observed that was particular to the context in which the color had been previously paired with punishment, for each experiment separately. A consistent and robust effect was evidenced when the two experiments were combined (with no difference between experiments). Participants were less error prone when the target was rendered in the CS+ in-context color compared to when the target was rendered in the CS+ out-of-context color. A reciprocal effect was observed when analyses focused on the distractor: Participants were more error prone when the distractor was rendered in the CS+ in-context color compared to when the distractor was rendered in the CS+ out-of-context color. Furthermore, when the CS+ in-context and CS+ out-of-context colors directly competed for attention, participants made more errors when they needed to orient away from the CS+ in-context distractor. Overall, attention was more efficiently attracted to the CS+ in-context color than to the CS+ out-of-context color. Thus, context-specific attentional bias observed in the training phase persisted into extinction.

Our findings are consistent with results observed following the delivery of contextually dependent rewards (Anderson, 2015). Such similar biases for reward and aversive outcomes are consistent with the idea that attention is primarily guided by motivational salience (Watson et al., 2019) rather than separate mechanisms driven by distinct brain systems for reward and punishment (Chen & Bargh, 1999; Yacubian et al., 2006). Our results are also in line with context-dependent effects reported in studies on memory (S. M. Smith & Vela, 2001), visual object recognition (Gerlach & Toft, 2011), and different aspects of associative learning (Abrahamse et al., 2016; Maren et al., 2013) and extend this work by showing that the control of attention is similarly capable of incorporating contextual dependencies tied to the relationship between stimuli and aversive outcomes.

In the present study, punishment-related attentional bias was evident only in error rate and not in RT, which contrasts with prior research using this paradigm without a context manipulation in which punishment-related attentional bias was evident in both measures (Kim & Anderson, 2020; see also Kim & Anderson, 2019). It is unclear why we did not similarly observe RT effects in the test phase, although it is possible that given the complexity of the underlying learning, contextually modulated attentional biases are less robust, and recent evidence suggests that bias in the direction of initial eye movements is a more reliable indicator of learning-dependent attentional bias than saccadic RT (Anderson & Kim, 2019b; see also Anderson & Kim, 2019a). We also note that the biases observed in error rate were replicated over two experiments and there was no evidence for a speed-accuracy trade-off in the test phase of either experiment, which adds confidence to our conclusions.

Postexperiment measures indicate that participants were not explicitly aware of the color-context contingencies governing shock outcome in the training phase, for each experiment separately. Importantly, in the test phase, the contextual information was completely task irrelevant, and the shock was no longer delivered. Altogether, our findings suggest that contextual modu-

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[1] Note that when Experiment (1, 2) was added as a between-subject variable in the ANOVAs, for mean RTs and error rates, no interaction or main effect of experiment was observed (all $ps > 0.10$).

lation of punishment-based attentional priority is an automatic cognitive process that is implicitly learned. It is worth noting that the colors used for experimental stimuli (square and circle) were equiluminant (and the assignment of color to condition counterbalanced across participants), so effects observed could not be explained by perceptual salience.

Our results therefore suggest that punishment-modulated attentional capture is context specific, in accordance with outcomes reported for value-driven attentional capture (Anderson, 2015) and Pavlovian conditioning studies focusing on emotional expression of fear (Maren et al., 2013). This mechanism could allow the attention system to overcome problems related to overgeneralization. Given the diversity of visual environments that we experience in everyday life, it would likely be maladaptive that stimuli associated with punishment capture attention independently of the context in which they appear. In this way, our findings support an adaptive view of punishment-related attentional biases and are consistent with the idea that the processes underlying punishment- and reward-related attentional biases are similar (Grégoire et al., 2020; Liao et al., 2020; Watson et al., 2019).

Contextual specificity of punishment-related attentional capture could be perceived as maladaptive if a stimulus previously paired with a negative outcome in a specific context does not attract attention when it is presented in a new context in which it has never been presented before. However, the design used in the current study does not reflect the same situation. In the training phase of our experiments, each color is presented in the two contexts, so each color that is paired with shock in a specific context is also presented without any aversive outcome in the other context. Thus, participants can learn that a particular color is threatening in a specific context and not in the other one as the participants are repeatedly exposed to the same stimuli in both contexts. Our findings show that when context provides discriminative information concerning which stimuli are threatening, contextual information is automatically incorporated into the manner in which attentional priority is assigned, even when individuals are not explicitly aware of these contingencies. We suppose that punishment-modulated attentional capture would generalize to a novel context (background) if the color-shock relationship were only presented in one specific context during the training phase. Consistent with this idea, in the case of reward learning, stimulus-reward associations learned in only one context do in fact generalize to different stimuli that share a defining feature (color) in a novel context (Anderson et al., 2012), whereas value-driven attentional capture is context specific in a design similar to the one used in the present study (Anderson, 2015).

Conclusions

The present study reveals that attention to punishment-related stimuli is context dependent. In combination with previous results (Anderson, 2015), the present finding supports the idea that attentional control is primarily guided by motivational salience, with reward and punishment having a comparable influence on attention. Our results are also consistent with context-dependent effects reported for different cognitive and learning processes (Abrahamse et al., 2016; Gerlach & Toft, 2011; Maren et al., 2013; S. M. Smith & Vela, 2001), suggesting a broader principle of contextually dependent memory that appears to reflect the nature of the memory system that guides attention.

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