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BRIEF REPORT

How Does the Attention System Learn From Aversive Outcomes?

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Learning about aversive outcomes plays a role in the guidance of attention. Classical conditioning generates a bias to predictors of aversive outcomes, whereas instrumental learning potentiates a negatively reinforced avoidance behavior, which can be difficult to dissociate in the case of attention to aversively conditioned stimuli. The present study examined the relative contribution from these two learning processes to the control of attention. Participants were first provided an opportunity to avoid an electric shock by generating a saccade in the direction opposite one of two stimuli. In contradiction to the practiced avoidance behavior, such training resulted in a bias to orient toward the shock-associated stimulus, indicative of a more dominant role of classical conditioning in the control of attention. The findings are in parallel with the influence of positive reinforcement on attention, suggesting that the attention system may be guided by motivational relevance rather than a particular emotional valence.

Keywords: selective attention, eye movements, punishment learning, aversive conditioning, negative reinforcement

Supplemental materials: http://dx.doi.org/10.1037/emo0000757.supp

Learning about environmental cues that signal an aversive outcome is crucial for survival. It allows an organism to predict and respond to not only present but also future aversive events. Upon detecting a potential source of an aversive outcome, attention is rapidly oriented to the source, and the organism executes an avoidance response (e.g., LeDoux, 1996; Vuilleumier, 2005). Two types of learning are involved in this process: classical conditioning and instrumental learning. Classical conditioning results in a stimulus–stimulus (S-S) association; an organism learns that a stimulus predicts an aversive outcome. In instrumental learning, an avoidance response (R) is reinforced by the absence of an aversive outcome (O), resulting in an R-O association (Hall, 2002).

Learning about aversive outcomes plays a role in the guidance of attention. Stimuli associated with aversive outcomes capture attention in a bottom-up, automatic fashion (Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Schmidt, Belopolsky, & Theeuwes, 2015a). The influence of such stimuli is not limited to covert attention but also saccadic shifts (Mulckhuyse, Crombez, & Van der Stigchel, 2013; Mulckhuyse & Dalmaijer, 2016; Schmidt, Belopolsky, & Theeuwes, 2015b, 2017). In these studies, an S-S association between a stimulus and an aversive outcome elicits a threat-detection response; this is consistent with the view that the processing of threat signals is prioritized because of its biological relevance (LeDoux, 1996).

In prior studies, the use of a task that combines elements of classical conditioning and instrumental learning makes the relative contribution from the two types of learning to the control of attention difficult to dissociate (Nissens, Failing, & Theeuwes, 2017; Schmidt et al., 2015b, 2017; Wang, Yu, & Zhou, 2013; Watson, Pearson, Wiers, & Le Pelley, 2019; Wentura, Müller, & Rothermund, 2014). Although the tasks used in these studies aimed at establishing an association between an aversive outcome and a specific stimulus feature, the manner in which the aversive outcome was delivered does not rule out a potential role for the instrumental learning of an orienting response (via negative reinforcement). When the task requires that a signal of a potentially aversive outcome be rapidly selected in order to avert or minimize the severity of the outcome (e.g., Wang et al., 2013; Wentura et al., 2014), there is explicit incentive to direct attention to signals of threat that are negatively reinforced. When aversive outcomes are unavoidable and passively administered (e.g., Schmidt et al., 2015a), explicitly orienting to signals of threat allows the observer to anticipate the aversive stimulus and thereby mitigate its aversiveness. In others tasks, the aversive outcome is signaled by a particular stimulus but can be avoided with fast and accurate

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responses, such that orienting to the threat signal provides useful information about when the observer should exert the most effort in the task (e.g., Nissens et al., 2017; Schmidt et al., 2015b, 2017). It is also frequently the case that, given the frequency of aversive outcomes, orienting to the threat signal more often than not results in the withholding of the aversive outcome, which, in combination with the relationship between aversive outcomes and task performance, could promote negative reinforcement (e.g., Nissens et al., 2017; Schmidt et al., 2015b, 2017).

The studies just discussed suggest that in addition to classical conditioning, instrumental learning (negative reinforcement) may also play a role in the guidance of attention. To our knowledge, no study investigating the impact of aversive outcomes on attention has explicitly manipulated and examined the potential role of negative reinforcement in the development of attentional bias. Therefore, the present study aimed to directly assess the relative contribution of these two learning processes in the control of attention. Studies examining the influence of reward learning on the development of attentional bias (see Anderson, Laurent, & Yantis, 2011) offer some relevant insights into this issue. They demonstrate that classical conditioning plays a dominant role in value-driven attentional capture (Bucker & Theeuwes, 2017, 2018; Le Pelley, Pearson, Griffiths, & Beesley, 2015; Mine & Saiki, 2015; Sali, Anderson, & Yantis, 2014), and classical conditioning overshadows instrumental learning when the two sources of learning compete directly against each other (Kim & Anderson, 2019). This, together with the idea that reward and aversive outcomes encompass comparable biological relevance and therefore receive similar attentional priority (Brosch, Sander, Pourtois, & Scherer, 2008; Vuilleumier, 2005), suggests a potentially similar pattern with learning from aversive outcomes.

To test this idea, we adapted the methodology of Kim and Anderson (2019) to learning from aversive outcomes. Participants generated antisaccades (saccades in the direction opposite a stimulus) in response to color-defined targets, one of which signaled the possibility of receiving a mild electric shock (conditioned stimulus, CS+). The execution of an antisaccade was necessary to avoid a shock on CS+ trials. A shock was only delivered if participants were slow to orient away from the CS+ or mistakenly saccaded toward the CS+, dissociating a threat-detection orienting response driven by classical conditioning from the orienting response needed to avert the shock. Therefore, classical conditioning should bias eye movements toward the CS+, whereas negative reinforcement should bias eye movements away from the CS+.

Method

Participants

Thirty participants (ages 18–20, mean [*M*] = 18.3, standard deviation [*SD*] = 0.52; 25 female and 5 male) were recruited from the Texas A&M University community. Participants were compensated with course credit. All reported normal or corrected-to-normal visual acuity and normal color vision. All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki. The sample size was informed by a power analysis. The effect size for attentional bias was set at $d_z = 0.54$ based on Kim and Anderson (2019), which used a similar task with reward feedback. A sample size of 30, which was set to match that of Kim and Anderson (2019), indicated power $1\text{-}\beta > 0.8$ with $\alpha = .05$ (computed using G*Power 3.1).

Apparatus

A Dell OptiPlex equipped with MATLAB software 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. Eye position was monitored using an EyeLink 1000 Plus desktop-mounted eye tracker. Head position was maintained using an adjustable chin and forehead rest. Electric shocks were generated by an isolated linear stimulator (BIOPAC) operating in current mode.

Materials

Training phase. The training phase consisted of a fixation display, a stimulus display, and a feedback display (see Figure 1). The stimulus display included a 4.7° × 3.4° color square presented 12.2° center-to-center to the left or right of fixation, which served as the target of an antisaccade. Red, blue, and green—matched for luminance—were used for the square, with each color serving as the CS+ color, CS– color, and neutral color. Only the CS+ and CS– colors appeared in the training phase. The color-outcome mapping was counterbalanced across participants.

The feedback display was presented only when participants failed to make an appropriate response. It showed “Incorrect” if they made a saccade toward the square and “Too slow” if a correct response was not otherwise registered. A mild shock was delivered simultaneously with the feedback display on CS+ trials.

Test phase. The test phase consisted of a fixation display, a search display, and a feedback display. The search display included a distractor (square) and a target (circle) simultaneously presented, one on each side, 12.2° from fixation center-to-center. Red, blue, and green—matched for luminance—were used for the shapes. The same shape as the targets from training was used for the distractors during the test phase to maximize the overall similarity between the distractors and the trained stimuli when probing trained orienting responses. The feedback display “Miss” was presented if participants did not make a correct response.

Procedure

Shock calibration. Electric shocks were delivered via two electrodes attached to participants’ left forearm. The shock intensity was individually calibrated by gradually increasing it to a level where it was perceived as “uncomfortable but not painful” prior to the completion of the training phase (as in, e.g., Nissens et al., 2017; Schmidt et al., 2015a, 2015b, 2017).

Training phase. The training phase began with 40 practice trials using an achromatic (white) square without shock. Participants had to score 80% accuracy by the end; otherwise, they completed an additional 20 practice trials.

At the start of each block, eye position was calibrated using 5-point calibration. On each trial, participants had to maintain their gaze within 1.1° of the center of the fixation cross for a continuous period of 500 ms to proceed. Eye position was manually drift

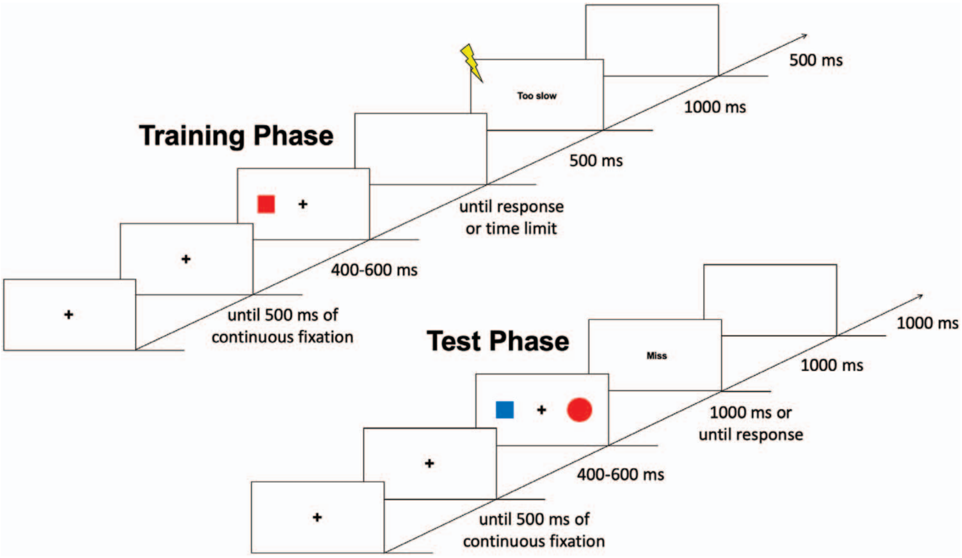

Figure 1. Sequence of trial events. During the training phase, each trial concluded with a 1,500-ms blank interval following a correct response. During the test phase, the feedback display was omitted if a correct response was registered. See the online article for the color version of this figure.

corrected by the experimenter as necessary. Next, 400–600 ms later, either a CS+ stimulus display or a CS– stimulus display was presented for a preadjusted duration. Specifically, the duration of each stimulus display varied as a function of cumulative accuracy for the CS+ and CS– colors separately. If the cumulative accuracy for trials with the current target (CS+ or CS–) was below 70%, the duration was increased by 5% from the prior trial with that target. If it was above 70%, the duration was reduced by 5%. The average response time (RT) from practice trials ($M = 307$ ms, $SD = 52$ ms) was used as an initial duration. The final durations at the end of the training phase were 580 ms for the CS+ color ($SD = 635$ ms) and 621 ms ($SD = 541$ ms) for the CS– color (excluding one participant whose durations exceeded 2.5 *SD* of the group mean).

Participants were instructed to make a saccade opposite to the square as quickly as possible, equidistant from fixation as the color square. Participants were informed that they would sometimes receive a shock if they did not look away fast enough, although they were not informed of the relationship between color and shock, which needed to be learned from experience in the task. The colors uniquely predicted the delivery of a shock, although the color of the squares was explicitly task irrelevant because the task was to make an antisaccade in response to any color square. A trial was scored as correct if an eye movement exceeding 8.2° in amplitude in the direction opposite the target was detected, and a trial was scored as an error if an eye movement exceeding 8.2° in amplitude in the direction of the target was detected.

If participants made a correct response within the preadjusted duration, the trial ended with a 1,500-ms blank interval. An eye movement toward the square resulted in the immediate termination of the trial. If participants failed to make a correct response within the preadjusted duration, following a 500-ms blank interval, the feedback display was presented for 1,000 ms. On CS+ trials, a mild shock was delivered for 2 ms with the feedback display. The CS+ and CS– targets were presented equally often, with each color target presented equally often on each side of the screen. Trials were presented in random order. Participants completed four runs of 60 trials.

Test phase. The test phase was identical to that of Kim and Anderson (2019). Participants first completed 12 practice trials using achromatic (white) shapes. Participants were informed that no shock would be delivered in the test phase.

Initial calibration and gaze-contingent fixation followed the procedures used in the training phase. The search display followed the fixation display for 1,000 ms or until a correct response was registered. Participants were instructed to make a saccade in the direction of the target as quickly as possible, and eye movements were coded in the same manner as in the training phase. Errant eye movements were recorded but did not result in the termination of the trial. A correct response concluded the trial with a 1,000-ms blank interval; otherwise, the feedback display and a blank interval were presented for 1,000 ms each. Within a run, target side, distractor side, target color, and distractor color were fully crossed and counterbalanced, with the limitation that no color ever appeared twice in the same display. Trials were presented in random order. Participants completed three runs of 96 trials.

Data Analysis

RT was measured from the onset of the target until eye position first reached the saccade amplitude threshold. RTs exceeding 3 *SD* of the mean of a given condition were trimmed. Saccadic precision was measured as the distance between the end positions of the first saccades that correctly landed within the saccadic target area (i.e., the region where the square would have been if presented on the opposite side of the screen) and the center of the saccadic target area.

Results

Training Phase

Accuracy was 69.4% for both the CS+ and CS– targets, which did not significantly differ, $t(29) = 0.02$, $p = .984$, indicating that the adjustable RT threshold was successful in calibrating performance. Neither did RT significantly differ for CS+ (283 ms) and CS– (295 ms) targets, $t(29) = 1.07$, $p = .293$. There was no significant difference in saccadic precision between the CS+ (2.6°) and CS– targets (2.4°), $t(29) = 1.88$, $p = .07$. The lack of a reliable difference in latency between the CS+ and CS– colors may have stemmed from a floor effect imposed by the adjustable response threshold, which created a strong incentive to perform the task as quickly and accurately as possible.

Test Phase

A 2 × 3 analysis of variance (ANOVA) on mean RT with stimulus type (target, distractor) and stimulus pair (CS+ and CS–, CS+ and neutral, CS– and neutral) as factors indicated a significant interaction, $F(2, 58) = 7.51$, $p = .005$, $\eta_p^2 = 0.21$ (Greenhouse–Geisser corrected). Planned contrasts revealed that when the CS– and neutral colors competed for attention, participants were facilitated in looking away from the CS–, $t(29) = 2.07$, $p = .048$, $d = 0.38$, demonstrating a stimulus-response selection-history effect. Importantly, when the CS+ and CS– colors competed for attention, participants were faster to look toward the CS+ when it was the target, $t(29) = 2.68$, $p = .012$, $d = 0.49$. When the CS+ and neutral colors competed for selection, no bias was evident, $t(29) = 1.23$, $p = .228$ (Part A of Figure 2).

A similar pattern was observed in error rates, $F(2, 58) = 6.57$, $p = .012$, $\eta_p^2 = 0.19$ (Greenhouse–Geisser corrected). The selection-history effect for the CS– color was now only marginally significant, $t(29) = 1.85$, $p = .075$, and there was again no bias evident in performance when the CS+ and neutral colors competed for attention, $t(29) = 0.76$, $p = .452$. Importantly, when the CS+ and CS– colors competed for attention, participants made more errors when they needed to orient away from the CS+ distractor, $t(29) = 2.55$, $p = .016$, $d = 0.46$ (Part B of Figure 2).

Breaking the data down by block (1–3), there was no three-way interaction between block, stimulus type, and stimulus pair for either RT, $F(4, 116) = 0.63$, $p = .646$, or error rate $F(4, 116) = 2.37$, $p = .057$, and although there was a trend toward extinction in the error rate, the critical difference between the CS+ versus CS– remained significant in the last block for both measures, $ts > 2.38$, $ps < 0.025$, $ds > 0.43$. This suggests that the learned attentional bias was robust to extinction over the time frame tested, consistent with prior findings concerning the effects of reward history on attention (Anderson et al., 2011; Anderson, Laurent, & Yantis, 2014; Sali et al., 2014).

Discussion

Learning about aversive outcomes encompasses establishing two associations. A stimulus comes to predict aversive outcomes via classical conditioning, and avoidance behavior is negatively reinforced by the absence of aversive outcomes via instrumental learning. The present study examined the relative contribution from these two learning processes to the control of attention. The results demonstrate that classical conditioning potentiated attentional bias to the CS+ color. In particular, when the CS+ and CS– colors, possessing equal selection history as former targets of antisaccades, competed for attention, the CS+ color was prioritized. This contradicts the pattern expected from the negative reinforcement of an avoidance response, indicating that the influence of classical conditioning on attention outcompeted that of negative reinforcement.

It is important to note that stimulus-response (S-R) learning influenced the orienting of attention in our experimental task, which could have been negatively reinforced in the case of the CS+. In trials where the CS– and neutral colors were presented

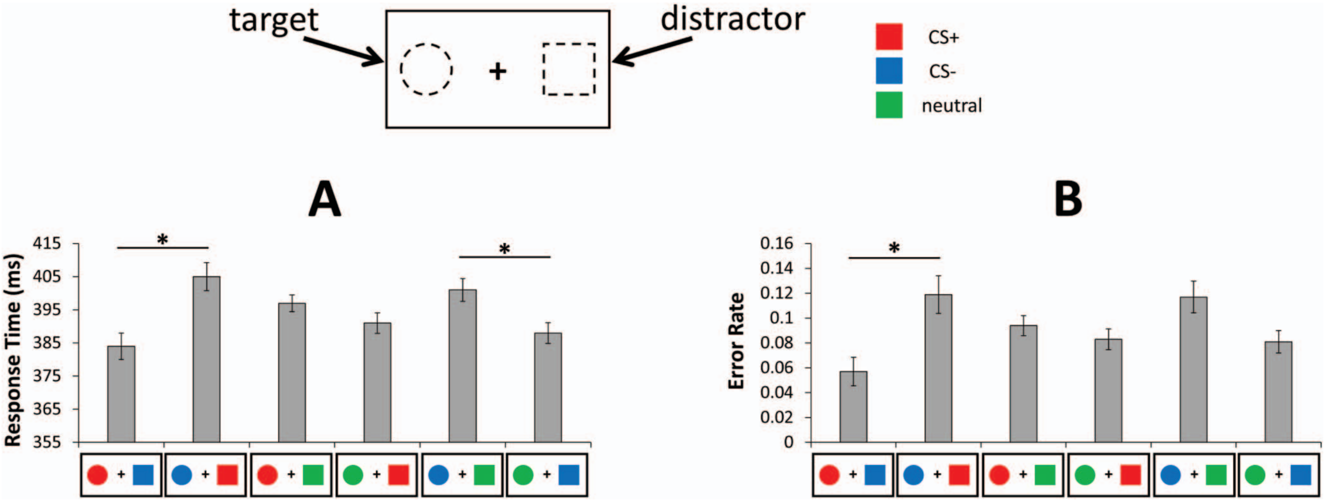

Figure 2. Behavioral data. Response time (A) and error rate (B) broken down into all possible color pairings in the test phase. The left two bars on each graph isolate the effect of aversive conditioning with selection history equated. Error bars reflect within-subjects confidence intervals. See also the online supplemental materials. $^* p < .05$. See the online article for the color version of this figure.

simultaneously, the CS– color elicited a bias to generate saccades in the opposite direction. Thus, participants did develop a bias to perform a stimulus-triggered orienting response from selection history and performance feedback in the case of the CS–, which could have been potentiated by negative reinforcement in the case of the CS+. Given that the CS+ and CS– colors received the same number of exposures during training, this result implies that such avoidant saccadic shifts should have been learned for the CS+ color too. Indeed, in addition to an S-S association that elicits an orienting response to the CS+, the CS+ color acquired an S-R association that was linked to the avoidance of an aversive outcome during training. The influence of this S-R relationship is evident in trials where the CS+ and neutral colors were presented simultaneously; the contradictory responses generated by the two associations roughly cancel out, making the summed effect on attention negligible.

The pattern of results we obtained in the present study is consistent with that of Kim and Anderson (2019), in which participants were positively reinforced to look away from one of two color-defined targets. When rewarded and unrewarded colors matched for selection history were presented simultaneously, attention preferentially shifted to the rewarded color, suggesting classical conditioning dominantly influenced the orienting of attention. When the unrewarded and neutral colors competed for attention, the unrewarded color generated a bias to elicit a saccade in the opposite direction (antisaccade), indicative of the role of instrumental learning. The similarities between the two studies suggest that rather than a particular emotional valence, motivational relevance may be prioritized by the attentional system. The motivational relevance model emphasizes the role of motivational intensity on cognitive functions, regardless of affective state (Brosch et al., 2008; Gable & Harmon-Jones, 2010; Lang, Bradley, & Cuthbert, 1997). Both reward and aversive outcomes are crucial for survival and thus high in motivational intensity. Consequently, they elicit automatic attentional orienting, which facilitates threat detection and preparation of an appropriate action (Elliot & Covington, 2001; Lang et al., 1997; LeDoux, 1996; Vuilleumier, 2005).

In conclusion, our study presents evidence that in the case of learning from aversive outcomes, classical conditioning plays a more dominant role in the control of attention, outcompeting the effect of instrumental learning. The consistency of our results with those of Kim and Anderson (2019) suggests that the attentional system may be guided by motivational relevance, a hypothesis that makes specific predictions, such as a common neural substrate (see, e.g., Anderson, 2019), that should be investigated in future research.

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