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BRIEF REPORT

On the Automaticity of Attentional Orienting to Threatening Stimuli

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Attention is biased toward stimuli that have been associated with aversive outcomes in the past. This bias has previously been interpreted as reflecting automatic orienting toward threat signals. However, in many prior studies, either the threatening stimulus provided valuable predictive information, signaling the possibility of an otherwise unavoidable punishment and thereby allowing participants to brace themselves, or the aversive event could be avoided with fast and accurate task performance. Under these conditions, monitoring for threat could be viewed as an adaptive strategy. In the present study, fixating a color stimulus immediately resulted in a shock on some trials, providing a direct incentive not to look at the stimulus. Nevertheless, this contingency resulted in participants fixating the shock-associated stimulus more frequently than a neutral distractor matched for physical salience. Our findings demonstrate that threatening stimuli are automatically attended even when attending such stimuli is actually responsible for triggering the aversive event, providing compelling evidence for automaticity.

Keywords: selective attention, attentional capture, threat, aversive conditioning, associative learning

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It is critically important to our survival that potential threats be rapidly detected and acted upon. Given the limited representational capacity of the human perceptual system (Desimone & Duncan, 1995), threat detection is often an attention-demanding process. To more effectively cope with this demand, it has been hypothesized that humans have evolved a bias to automatically direct attention to signals for potential threat (e.g., Mulckhuyse, 2018; Öhman & Mineka, 2001; Vuilleumier, 2005).

Consistent with this hypothesis, a variety of experiments have demonstrated attentional biases toward aversively conditioned stimuli. For example, stimuli previously associated with aversive electric shock (e.g., Schmidt, Belopolsky, & Theeuwes, 2015a; Wang, Yu, & Zhou, 2013), white noise (e.g., Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004; Smith, Most, Newsome, & Zald, 2006), monetary loss (e.g., Wentura, Müller, & Rothermund, 2014), or negative social feedback (Anderson, 2017; Anderson & Kim, 2018) during a conditioning phase impair performance on visual tasks, consistent with distraction by aversively conditioned stimuli. Furthermore, goal-directed eye movements are biased toward aversively conditioned stimuli, which are more frequently fixated when presented as task-irrelevant distractors compared with otherwise equivalent distractors without such association (Mulckhuyse, Crombez, & Van der Stigchel, 2013; Mulckhuyse & Dalmaijer, 2016; Schmidt, Belopolsky, & Theeuwes, 2015b).

Although each of these cases provides strong evidence for biased attention to aversively conditioned stimuli, the degree of automaticity involved in this bias is less clear. In many of these prior studies, the aversively conditioned cues provide useful information about whether otherwise unavoidable punishment can be anticipated, with attention to the aversively conditioned stimulus allowing the observer to prepare. Cues that are informative of outcomes are generally thought to be prioritized by attention (Gottlieb, Oudeyer, Lopes, & Baranes, 2013). Although there is no benefit to continuing to monitor for the aversively conditioned stimulus in a subsequent task in which distraction is assessed, there is also little motivation for participants to stop explicitly monitoring for potential threat, as threat monitoring has no direct cost associated with it in this context. A strong case for automaticity requires that attention to the stimulus of interest be explicitly counterproductive (Anderson, 2018). Furthermore, to the degree that participants actively monitor for, and preferentially attend to, shock-predictive stimuli during conditioning, it could be this difference in selection history (Awh, Belopolsky, & Theeuwes, 2012) rather than the punishment association per se that is responsible for the attentional biases toward the conditioned stimulus (CS+) evident in extinction (e.g., Schmidt et al., 2015a; Wang et al., 2013).

Recently, Nissens, Failing, and Theeuwes (2017) attempted to overcome these limitations by presenting participants with two color distractors, one of which signaled potential shock at the end

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of the trial (CS+). Importantly, shock was only delivered following CS+ trials on which participants were slow to fixate the target. Reorienting to the target after fixating the distractor takes time; therefore, fixating the distractor was counterproductive, increasing the probability of receiving a shock. In spite of this contingency, participants more frequently fixated the CS+ distractor compared with the neutral (CS−) distractor.

In the design of Nissens et al. (2017), however, the CS+ still provided useful information about the possibility of shock, which was inevitable on some trials, given the individually adjusted response thresholds that were used. Furthermore, as shock could be avoided on some trials with fast and accurate performance, the CS+ indicated to participants when they should exert the most effort in the task; this indication might have encouraged explicit threat monitoring, particularly given that the majority of CS+ trials did not result in shock. In this regard, the withholding of punishment on these trials may have negatively reinforced the rapid orienting of attention to the distractor followed by motivated reorienting to the target.

In the present study, we provide a strong and direct test of the automaticity of attention to threatening stimuli. Participants performed a similar task to the one used by Nissens et al. (2017), although in our design shocks were delivered with 50% probability immediately upon fixating the CS+. Therefore, fixating the CS+ was directly and immediately punished, providing a strong incentive to curb the orienting behavior responsible for shock. The presence of an attentional bias toward the CS+ cue under these circumstances would provide compelling evidence for automaticity.

Method

Participants

Twenty-eight participants (18–24 years of age, $M = 19.0$; 15 female) were recruited from the Texas A&M University community. Data were collected from two additional participants, who were replaced due to difficulty eye tracking. Participants were compensated with course credit. All reported normal or corrected-to-normal visual acuity and normal color vision, and all provided written informed consent. All procedures were approved by the Texas A&M University Institutional Review Board and conformed to the principles outlined in the Declaration of Helsinki. The sample size was informed by a power analysis. The effect size for the difference in performance between CS+ and CS− distractors was estimated at $d_z = 1.4$, the effect size reported by Nissens et al. (2017). This analysis indicated power $\beta > 0.9$ with $\alpha = .05$ (G*Power; Faul, Erdfelder, Buchner, & Lang, 2009; http://www.gpower.hhu.de/).

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 (SR Research, Mississauga, Canada). Head position was maintained using an adjustable chin rest (SR Research, Mississauga, Canada). Paired electrodes (EL500; BioPac Systems, Goleta, CA) were attached to the left forearm of each participant, and electric shocks were delivered through an isolated linear stimulator under the constant current setting (STMISOLA; BioPac Systems, Goleta, CA), which was controlled by custom Matlab scripts.

Stimuli

Each trial consisted of a fixation display, a search array (1,500 ms or until a fixation on the target was registered), and a blank intertrial interval between 1,400 and 1,600 ms (Figure 1A). The fixation display remained on screen until eye position was registered within 2.4° of the center of the fixation cross for a continuous period of 500 ms. In the event that participants did not fixate the target within the timeout limit, the word "Miss" was centrally presented for 1,000 ms immediately following the search array. The search array consisted of six shapes, each approximately 5.7° × 5.7° in visual angle, placed at equal intervals along an imaginary circle with a radius of 8.2°. On each trial, the target was either a single diamond in an array of circles or a single circle in an array of diamonds (shape singleton). On distractor-present trials, one of the nontargets was rendered in either red or blue

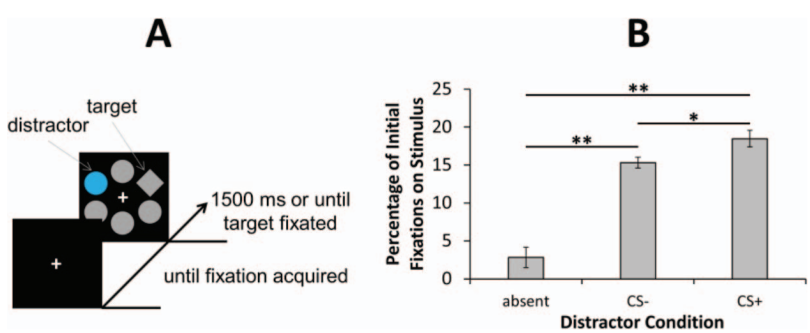

Figure 1. (A) Example trial. The task was to fixate the unique shape target. Fixations on one of the two color stimuli used as distractors immediately resulted in shock on 50% of associated trials (CS+), while the other color distractor was never paired with shock (CS−). (B) The percentage of initial fixations on a distractor for each distractor condition. Error bars reflect the within-subjects standard error of the mean. * $p < 0.05$. ** $p < 0.001$. See the online article for the color version of this figure.

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while the rest were gray. On distractor-absent trials, all six shapes were gray. All shape stimuli were equiluminant.

Design

The target appeared in each of the six possible locations equally often. The color singleton distractor was red on one third of trials, blue on one third of trials, and absent on one third of trials. For each color distractor, target and distractor position were fully crossed and counterbalanced. On half of all trials on which one color distractor was presented, the participant would receive an electric shock (2-ms pulse at the individually calibrated intensity) immediately upon the eye tracker registering a fixation on the distractor (CS+). The CS+ color (red or blue) was counterbalanced across participants. Trials were presented in a random order.

Procedure

The experiment consisted of a 20-trial practice block with no shocks followed by five blocks of 108 trials each. Prior to the experiment task, the intensity of shock was calibrated to achieve a level that was "unpleasant, but not painful" (e.g., Schmidt et al., 2015a, Schmidt, Belopolsky, & Theeuwes, 2017). Specifically, the intensity of a 2-ms shock was gradually increased from 8 mA until the participant first noted that the shock was painful, at which point the intensity was reduced by 1 mA and confirmed as unpleasant, but not painful. Eye position was calibrated prior to each block of trials using nine-point calibration and was manually drift corrected by the experimenter as necessary (the need for which was evident when acquiring initial fixation at the outset of each trial). Participants were instructed to fixate ("look directly at") the unique shape, and were informed that sometimes they would receive a shock depending on where they looked. Participants were not informed of which color predicted shock, as such instruction to try to ignore a feature can ironically produce a bias to initially orient to that feature (Moher & Egeth, 2012).

Data Analysis

We recorded which of the six shape stimuli was initially fixated on each trial. Fixation of a stimulus was registered if eye position remained within a region extending 0.7° around the stimulus for a continuous period of at least 50 ms (100 ms on the target to trigger the termination of the stimulus array). Percentage of initial fixations on a distractor was taken over all trials within the respective condition. On distractor-absent trials, in order to quantify the probability of initially fixating a distractor for the sake of comparison, one of the nontargets was dummy-coded as the critical distractor on each trial using the same parameters that were used to define the position of the critical distractors on distractor-present trials (i.e., same counterbalance of position relative to the target position). Response time was measured from the onset of the display until a fixation on the target was registered; from the registered response time 100 ms was subtracted to yield the time at which eye position first entered into the region of the target.

Results

A fixation on the target was registered within the timeout limit on 98.1% of all trials. An analysis of variance with distractor condition (absent, CS−, CS+) as a factor revealed a main effect of the manipulation, $F(2, 54) = 39.00$, $p < .001$, $\eta_p^2 = 0.591$ (Figure 1B). Replicating attentional capture by physically salient stimuli (Theeuwes, 1992), the CS+ and CS− distractors were both significantly more likely to be the first stimulus fixated compared with a nontarget on distractor-absent trials, ts > 6.68, ps < 0.001, ds > 1.26. Importantly, participants were also significantly more likely to initially fixate a CS+ distractor compared with a CS− distractor, $t(27) = 2.52$, $p = .018$, $d = 0.48$. Unsurprisingly, given that reorienting attention from the distractor takes time, the same pattern of results was evident in response time (406, 447, and 457 ms, for the absent, CS−, and CS+ distractor conditions, respectively), $F(2, 54) = 58.51$, $p < .001$, $\eta_p^2 = 0.684$; CS+ versus CS−: $t(27) = 2.66$, $p = .013$, $d = 0.50$.

Discussion

The present study provides clear and compelling evidence that signals for threat are preferentially attended automatically. Fixating the CS+ directly resulted in a shock on some trials (with 50% probability), which was delivered immediately upon fixating the stimulus. It was therefore explicitly counterproductive to fixate the CS+, which was made salient to participants from the immediacy of the feedback. The adaptive response in this context is to do everything possible to suppress eye movements to the CS+. In spite of this, participants were more likely to fixate the CS+ relative to a neutral CS−. Our results corroborate and extend the findings of Nissens et al. (2017), providing direct evidence for the automaticity of the attentional bias to threat.

Our findings also speak to the role of punishment in the control of eye movements. Punishment plays a general role in extinguishing behaviors that result in its delivery (e.g., Church, 1963). In the present study, this role for punishment in curbing behavior—in this case oculomotor behavior—was pitted against the influence of cue-based associative learning and its role in facilitating threat detection (e.g., Mulckhuyse, 2018; Schmidt et al., 2015a; Wang et al., 2013). Oculomotor capture was not high in our task (the CS+ was fixated on less than 20% of trials), such that participants had ample opportunity to learn that suppressing overt attention to the CS+ avoided shock, whereas fixating the CS+ but not the CS− reliably resulted in an immediate shock. That participants failed to adaptively adjust their behavior to this contingency is striking. In this sense, our findings suggest that the associative aspects of aversive conditioning influence the attention system more powerfully than does punishment learning, causing the punished behavior to be potentiated rather than extinguished when the two sources of learning compete against each other.

The findings of the present study fit into a broader literature examining the role of associative learning in the control of attention (Le Pelley, Mitchell, Beesley, George, & Wills, 2016). In particular, stimuli previously associated with reward also capture attention, in a manner that is hypothesized to be similarly automatic (see Anderson, 2016, for a review). The similarities and differences between these two influences on the attention system, particularly with respect to the underlying neural systems involved (Anderson, 2019), are largely unexplored and reflect a promising direction for future research.

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