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ORIGINAL ARTICLE

Attentional avoidance of threatening stimuli

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Abstract

Aversive conditioning has been shown to influence the control of attention, such that aversively conditioned stimuli receive elevated priority. Although aversively conditioned but task-irrelevant distractors are known to capture attention during speeded search in rapid orienting tasks, it is unclear whether this bias extends to situations where orienting can be more deliberate. We demonstrate that punishment, via electric shock, does not give rise to oculomotor capture by shock-associated stimuli during a foraging task; rather, such aversively conditioned stimuli are actively avoided when searching through a display. On the other hand, even during a foraging task, we found some evidence for a covert attentional bias to threat. Our findings indicate that the previously described effects of aversive conditioning on visual search may not generalize beyond the initial glance and can be suppressed when conditions allow for more deliberate search strategies. More generally, our findings reveal that sustained attentional avoidance of aversively conditioned stimuli is possible during active search.

Introduction

Detection and processing of danger-related visual stimuli enhances reproductive fitness; thus evolutionary theories of fear posit that threatening stimuli are disproportionately prioritized by the visual system (Öhman & Mineka, 2001), thereby facilitating threat detection and the planning of an appropriate motor response. Consistent with this theory, threatening stimuli appear to be prioritized at the early stages of attentional selection (Vuilleumier, 2005; Thigpen, Bartsch, & Keil, 2017). Threatening stimuli (by virtue of association with electric shock, aversive white noise, or monetary loss) are detected more rapidly than neutral stimuli and, when task-irrelevant, delay or impair detection of neutral stimuli (e.g., Bannerman, Milders, & Sahraie, 2010; Koster et al., 2004; Schmidt, Belopolsky, & Theeuwes, 2015; Smith, Most, Newsome, & Zald, 2006; Wang, Yu, & Zhou, 2013; Wentura, Muller, & Rothermund, 2014). In particular, aversively conditioned distractor stimuli may capture attention during visual search, slowing saccades to the target and increasing error rate (Mulckhuyse & Dalmaijer, 2016; Hopkins, Helmstetter, & Hannula, 2016; Nissens, Failing, & Theeuwes, 2017; Anderson & Britton, 2019, in press; for a review, see Mulckhuyse, 2018). Oculomotor attentional capture is defined by initial eye movements more frequently going to an aversively conditioned distractor compared to a neutral stimulus (Theeuwes, de Vries, & Godijn, 2003), whereas covert attentional capture is operationalized as distractor-associated slowing in response to the target or deviation in the trajectory of a goal-directed saccade (Van der Stigchel & Theeuwes, 2007; Mulckhuyse, van Zoest, & Theeuwes, 2008).

Prior studies of the role of aversive conditioning in guiding visual search have typically utilized relatively simple search displays. Participants may be asked to attend a single target while ignoring a single aversively conditioned color singleton distractor (e.g., Mulckhuyse, Crombez, & Van der Stigchel, 2013; Schmidt et al., 2015; Mulckhuyse & Dalmaijer, 2016; Nissens et al., 2017). Given the brevity of the stimulus display and the emphasis on the rapid response in task instructions (e.g., Nissens et al., 2017), participants must initiate saccades rapidly, facilitating stimulus-driven orienting (van Zoest, Donk, & Theeuwes, 2004). The abrupt onset nature of stimuli typical of attentional capture paradigms additionally facilitates stimulus-driven orienting (Yantis & Jonides, 1984; Donk & Theeuwes, 2001). In the majority of attentional capture paradigms, trials end immediately after the participant fixates a non-camouflaged target stimulus. Thus, these paradigms do not address the later time course of attention when a threatening stimulus is present. This absence is significant because, while bottom-up oculomotor capture by affectively salient stimuli is known to

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occur rapidly after stimulus onset (e.g., Mulckhuyse et al., 2008), top-down goal-directed information modulates saccadic behavior increasingly over time (Schmidt, Belopolsky, & Theeuwes, 2017).

Does the elevated priority that underlies aversively conditioned attentional capture exert a sustained influence, with stimulus-threat associations exerting a persistent biasing effect on selection when present in a display? Or is this bias transient and largely constrained to the earliest stages of visual information processing, such that participants could perform deliberate goal-directed search while effectively ignoring aversively conditioned stimuli? Attentional capture by physically salient (Donk & van Zoest, 2008; van Zoest et al., 2004; see also Anderson & Kim, 2019) or reward-associated stimuli (Anderson & Kim, 2019; Failing et al., 2015; Pearson et al., 2016) can be reduced or avoided by sufficiently delaying the initial saccade, consistent with the suppression of selection bias over time by goal-directed mechanisms. Findings concerning attentional capture by aversively conditioned stimuli are more mixed, with some reporting a persistent bias (Mulckhuyse et al., 2013, Experiment 1; Schmidt et al., 2017) and others reporting attenuation or even reversal of the bias over time (Le Pelley et al., 2018; Mulckhuyse et al., 2013, Experiment 2; Nissens et al., 2017).

Typical attentional capture tasks, such as those described above, do not speak to the more deliberate and sustained visual search more common in real-world situations. This more deliberate search process has previously been modeled using foraging tasks (e.g., Chukoskie, Snider, Mozer, Krauzlis, & Sejnowski, 2013), in which participants select multiple stimuli in turn, one of which conceals a hidden target. The effect of aversive conditioning on eye movements in this paradigm has not been explored. In the present study, we investigate the effects of aversive conditioning on visual search and stimulus selection over time in a foraging task. Participants fixated differently colored disks in an attempt to locate a target camouflaged behind one of the disks. Each color was equally likely to reveal the target when fixated. On 50% of trials, one color could yield a shock if fixated. Because the shock was delivered immediately and unavoidably upon fixation, as in Anderson & Britton (2019, in press), the optimal strategy was to avoid fixating an aversively conditioned disk until only aversively conditioned disks remain to be explored, thereby reducing the number of shocks received. If heightened attentional priority of aversively conditioned stimuli is sustained throughout visual search, as it is for previously identified targets (Cain & Mitroff, 2013), participants should preferentially fixate the aversively conditioned color over the first several fixations, before selecting other stimuli. If, on the other hand, the attentional priority of aversively conditioned stimuli is short-lived and can be overcome during visual foraging, participants should be able to avoid fixating the aversively conditioned color.

Experiment 1

Methods

Participants

Thirty-three participants (18–21 years of age, M = 18.8, 25 female) were recruited from the Texas A&M University community. Data collection was considered complete the week that the target of 32 participants was reached, which would provide $\beta > 0.90$ (computed using G*Power) to detect an oculomotor bias for each individual fixation using the effect size for oculomotor capture by threat of $d = 1.4$ reported in Nissens et al. (2017) and $\alpha = 0.00625$ to account for multiple comparisons across fixations (see "Data analysis"). All participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants were compensated with course credit. All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki.

Apparatus

Stimuli were generated using MATLAB 2017 (MathWorks, Natick, MA, USA) and Psychophysics Toolbox extensions (Brainard, 1997), then presented on a Dell P2717H monitor linked to a Dell OptiPlex 7040 (Dell, Round Rock, TX, USA). Participants viewed the monitor from a distance of 70 cm in a dimly lit room. An EyeLink 1000 Plus desktop-mount eye tracker (SR Research, Ottawa, Ontario, Canada) at 1000 Hz monitored participants' right eye position. Electric shocks were administered to participants' left forearms via paired electrodes (EL500, BioPac Systems, Goleta, CA, USA) linked to an isolated linear stimulator (STMISOLA, BioPac Systems) set to constant current and controlled by custom MATLAB scripts.

Stimuli

Each trial began with a fixation display against a black background, which remained on the screen until a fixation was registered within 2.8° of the center of the fixation cross (see Fig. 1). Participants then viewed a search array. The search array consisted of eight colored disks, two of which were red, two blue, two green, and two white, against a black background. Stimuli were not matched for luminance. Each disk was approximately 3° in diameter. Disk locations were randomly determined on each trial, but disks were never spaced more closely than 6.5° edge-to-edge and their centers fell at least 10° from the edges of the screen. On each trial

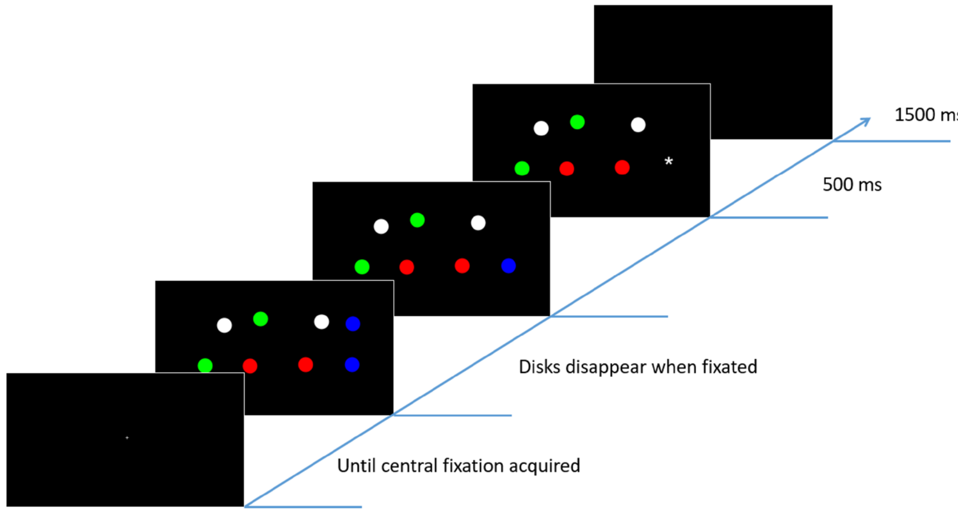

Fig. 1 Sequence and time course of trial events. The target was a star occluded by a randomly selected disk (counterbalanced across trials). When fixated, each disk disappeared. The trial continued until the target was found

half of the disks were located above the horizontal meridian, and half (independently) fell to the left of the vertical meridian. The target was a small star, which was occluded by one of the disks on each trial.

Design and procedure

Participants first completed an eight-trial practice block with no shock component (otherwise identical to the search task). Shock intensity was then calibrated: participants were informed that the shock was meant to be "unpleasant, but not painful", and the shock intensity was increased by 1 milliamp (mA) from a baseline of 8 mA (or decreased if requested, which did not occur in this experiment) until the participant first reported experiencing mild pain. The shock intensity was then decreased by 1 mA to achieve a level that was just below the self-reported pain threshold of the individual. Participants completed seven blocks of the search task. Each block consisted of 48 trials, for a total of 336 trials. The experiment lasted approximately 1 h. Eye position was calibrated at the beginning of each block using a 9-point display.

Participants were instructed to fixate each disk in turn to find the hidden target "as fast as possible". After fixation was registered within a 3.5° diameter region of interest around a disk for a continuous period of 500 ms, the fixated disk disappeared. Each trial continued until the target was revealed. The target then remained on the screen for 1500 ms. Trials were counterbalanced such that within a block, each color revealed the hidden target equally often.

One of the four colors was aversively conditioned, counterbalanced across participants. Participants were informed that they might receive a shock "depending on where you look". Half of trials, selected randomly, were shock-eligible; on these trials, one of the two disks of the aversively conditioned color was randomly selected. Upon fixating this disk, participants received a shock. No indication was given which trials were shock-eligible and which of the two aversively conditioned stimuli would deliver shock upon fixation. Given the counterbalance, on three trials per 48-trial block the shock-linked disk also covered the target, making shock unavoidable. On all trials on which the aversively conditioned color did not hide the target (75% of all trials), shock could be avoided entirely if participants never fixated the aversively conditioned color. The optimal strategy was, therefore, to avoid fixating the aversively conditioned color until all other color disks had been selected first.

Data analysis

Fixations on a disk that were registered more than 1500 ms after the previous disk fixation were excluded from analysis ($M = 4.95\%$ of fixations per participant, $SD = 3.87\%$), as these fixations were likely delayed by poor tracking quality and might not have reflected participants' first choice. One participant was replaced after registering 2.5 SDs over the mean number of fixations cut using this criterion (see, e.g., Anderson, 2016; Sali et al., 2018), suggesting generally poor tracking quality.

We assessed fixation order by color, specifically examining the percentage of trials on which the shock-associated color was fixated first, second, and so on. The aversively conditioned color could be fixated up to twice per trial. Preliminary analysis was conducted by submitting trial percentages by fixation to a repeated-measures ANOVA with Greenhouse–Geisser correction due to violation of assumed sphericity. As no interaction between block and fixation order was found (see "Results"), data were pooled across blocks for each participant, and the probability of fixating an aversively conditioned color disk was compared against chance (25%) separately for each fixation made. One-sample

t tests were conducted in SPSS using a Bonferroni adjusted α level of 0.00625.

To determine whether first fixations were slower on an aversively conditioned color than on a neutral color, a measure of covert attentional bias, RT to first disk fixated was submitted to a two-way repeated-measures ANOVA. Type of stimulus fixated (aversively conditioned vs. neutral) and block were entered as within-subjects variables. As we observed no interaction between block and stimulus type, we again pooled the data across blocks. A paired-samples t test was conducted in SPSS using an α level of 0.05.

Results

Overt attentional bias

The results of the present study clearly demonstrate a bias against fixating aversively conditioned stimuli. As block did not interact with the probability of fixating an aversively conditioned stimulus, $F<1$, and in keeping with prior studies (e.g., Anderson & Britton, 2019, in press; Le Pelley et al., 2018; Mulckhuyse et al., 2013; Mulckhuyse & Dalmaijer, 2016; Pearson et al., 2016; Schmidt et al., 2015, 2017), we collapsed fixation data across blocks. For each fixation, with the exception of the first, the percentage of fixations made to the aversively conditioned color differed significantly from chance ($ps<0.00625$; see Fig. 2). The second through sixth fixations were made to an aversively conditioned stimulus less frequently than chance, whereas the seventh and eighth fixations were made to an aversively conditioned stimulus more frequently than chance, indicating that participants tended to exhaust other options before fixating the aversively conditioned color. The absence of an interaction with block suggests that participants avoided the aversively conditioned color consistently throughout the experiment, rapidly learning the contingency, consistent with prior reports (Nissens et al., 2017; see also Failing et al., 2015).

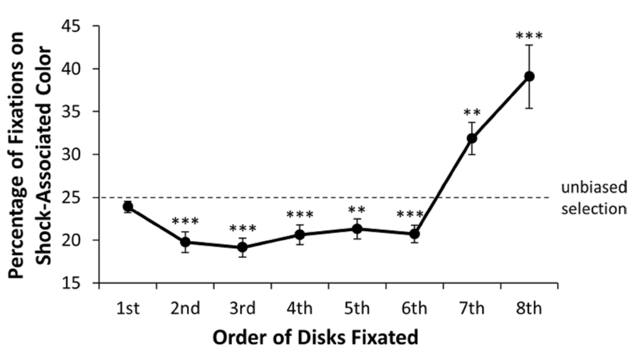

Fig. 2 Percentage of fixations on an aversively conditioned color by fixation order. Error bars represent the SEM. $^{**}p<0.005$, $^{***}p<0.001$

Covert attentional bias

In our analysis of RT to first fixation, block did not interact with stimulus condition (aversive vs. neutral), $F<1$; thus we again pooled data across blocks. Initial fixation latencies on the aversively conditioned stimuli (M = 295 ms, SD = 47 ms) were shorter than those to neutral colors (M = 303 ms, SD = 49 ms), $t(32)=2.07$, $p=0.047$, $d=0.36$.

Discussion

Participants fixated preferentially on neutral stimuli when possible. On the seventh and eighth fixations of a trial, when most of the options had been exhausted, participants fixated the shock-associated stimulus at a rate greater than chance; on all other fixations except the first, participants avoided aversively conditioned stimuli, fixating the aversively conditioned color less frequently than chance. This pattern indicates that participants can suppress overt attention to an aversively conditioned stimulus on second and later fixations and are not necessarily biased to select an aversively conditioned stimulus on the initial fixation if allowed to respond more deliberately. At the same time, initial fixation latencies for aversively conditioned stimuli were faster than for neutral stimuli, suggesting an initial covert attentional bias that was subsequently suppressed prior to initiating an eye movement on most trials.

Experiment 2

In Experiment 1, we demonstrated that participants can avoid fixating aversively conditioned stimuli during foraging. As outlined in the Introduction, we interpret this avoidance as arising from the demands of the task, which allow more deliberate selection from among multiple potential targets without an explicit time limit. However, an alternate account might attribute this lack of capture to the potential task-relevance of the aversively conditioned stimulus. That is, in prior research demonstrating attentional capture by aversively conditioned stimuli, the aversively conditioned stimulus is typically task-irrelevant on all trials and participants are instructed to ignore it (e.g., Anderson & Britton, 2019, in press; Nissens et al., 2017); this is done to strengthen the argument in favor of the automaticity of threat-driven attentional capture (Anderson, 2018). However, it is known that intent to ignore a feature-defined stimulus can ironically direct more attention to the stimulus, an "attentional white bear" effect (Cunningham & Egeth, 2016; Moher & Egeth, 2012). Therefore, one potential alternative explanation for the difference between our findings and those of prior single-target search studies (Anderson & Britton, 2019, in press; Nissens et al., 2017) is that in those prior studies, the stimulus-shock contingency strongly motivated participants to ignore the shock-associated stimulus, which made this stimulus more likely to capture overt attention. Conversely, in our experiment, shock-associated stimuli could also conceal the target and, therefore, were not task-irrelevant.

To resolve this issue, Experiment 2 presented one of two explicitly task-irrelevant non-target color singletons, one of which resulted in a shock upon fixation, during a foraging task without explicit time pressure. If participants show no bias toward the aversively conditioned stimulus, oculomotor capture by threat can be avoided during foraging even when participants are explicitly motivated to ignore the aversive stimulus.

Methods

Participants

Sixteen new participants [18–34 years of age, M = 22.9, 6 female (1 no response)] were recruited from the Texas A&M University community. Data for one participant were replaced because the participant was unable to complete the study due to poor tracking. Given that the present experiment used physically salient distractors, the attentional priority of which is short-lived (Donk & van Zoest, 2008; van Zoest et al., 2004), we powered our study to specifically detect an overt attentional bias toward or away from the aversively conditioned stimulus specifically on the initial fixation. We estimated the effect size as the average for the overt attentional bias evident in Nissens et al. (2017) and Anderson and Britton (2019, in press), which both showed evidence of increased probability of initial fixation on a shock-associated distractor. The sample size of $n = 16$ provided $\beta > 0.9$ using $\alpha = 0.05$ for the single comparison on the first stimulus fixated (computed using G*Power). All participants reported normal or corrected-to-normal visual acuity and normal color vision. Participants were compensated with course credit or money (10 USD). All procedures were approved by the Texas A&M University Institutional Review Board and conformed with the principles outlined in the Declaration of Helsinki.

Apparatus

The apparatus was identical to that used in Experiment 1.

Stimuli

Stimuli were identical to those in Experiment 1, with the following exceptions. All discs presented were grey, except for a single orange or blue distractor on distractor-present trials. Stimuli were matched for luminance. The distractor never concealed the target.

Design and procedure

The study design was identical to Experiment 1, with the following exceptions. Participants were told that the target could only ever be hidden by a grey circle and that they should ignore blue and orange stimuli. They were again told that shocks would be administered "depending on where you look". One-third of trials had no distractor (all circles were grey); on distractor-present trials, the distractor was equally often orange or blue. One distractor color was aversively conditioned, counterbalanced across participants. Upon 50 ms of fixation on the aversively conditioned distractor, participants immediately received a shock, after which the distractor disappeared; every such fixation resulted in a shock, such that fixation on the aversively conditioned distractor was 100% predictive of shock.

Data analysis

The probabilities of fixating the aversively conditioned distractor and the neutral distractor over successive fixations were computed in the same manner as in Experiment 1, with particular emphasis on the initial fixation. Given that the stimuli of interest were always task-irrelevant, a measure of covert attentional bias is provided by latency to fixate a grey stimulus (i.e., RT) on distractor-present trials when overt attentional capture is avoided. Given that no interactions with block were observed in Experiment 1, and in keeping with prior research (e.g., Anderson & Britton, 2019, in press; Le Pelley et al., 2018; Mulckhuyse et al., 2013; Mulckhuyse & Dalmaijer, 2016; Pearson et al., 2016; Schmidt et al., 2015, 2017), data were collapsed across block prior to conducting the planned comparisons.

Results

Overt attentional bias

Aversively conditioned distractors were initially fixated on 10.3% of trials and neutral distractors on 10.2% of trials, an insignificant difference, $t(15) = 0.12$, $p = 0.904$, with the Bayes Factor indicating moderate evidence in favor of the null hypothesis, $BF_{01} = 3.89$ (Rouder et al., 2009). As expected, distractor fixations very seldom occurred after the initial fixation, with an average of 1.4 such fixations summed over all fixations (2–8) for both distractors.

Covert attentional bias

For trials on which a grey stimulus was fixated first, aversively conditioned distractors were associated with increased RT (M = 434 ms) compared to neutral distractors (M = 423 ms), $t(15) = 2.02$, $p = 0.031$ (one-tailed), $d = 0.51$. As would be expected from salience-driven attentional capture (Donk & van Zoest, 2008; van Zoest et al., 2004), both distractors slowed RT compared to distractor-absent trials (M = 402 ms), $t\text{s} > 3.37$, $p\text{s} < 0.005$, $d\text{s} > 0.84$.

Discussion

In contrast to prior reports using single-target search under time pressure (Anderson & Britton, 2019, in press; Nissens et al., 2017), and consistent with the findings from Experiment 1, initial fixations were not biased toward aversively conditioned stimuli. This is in spite of the fact that fixations on the distractor always resulted in electric shock. Unlike in Experiment 1, subsequent fixations were not biased away from the aversively conditioned distractor, but such fixations were in general very infrequent, suggesting efficient oculomotor avoidance. Although distractor fixations were generally not frequent in our experiment, the total number of shocks delivered using this procedure exceeded that which has been shown to produce a significant attentional bias toward aversively conditioned stimuli (e.g., Schmidt et al. 2015). Replicating Experiment 1, and consistent with the learning of the color-shock contingency, a covert attentional bias was evident for the shock-associated distractor, additionally slowing saccades to a task-relevant stimulus. Altogether, the results of Experiment 2 demonstrate that the ability to avoid oculomotor capture by aversively conditioned stimuli is not contingent upon such stimuli being potential targets, and by extension, that the difference between our pattern of results and that of prior studies (Anderson & Britton, 2019, in press; Nissens et al., 2017) cannot be explained by a difference in the relationship between aversively conditioned stimuli and task goals.

General discussion

The present study investigated the effect of punishment on stimulus selection during foraging. Overall, participants consistently suppressed overt attention to aversively conditioned stimuli when such orienting was actively punished, contrary to findings from single-target visual search paradigms performed under time pressure. In Experiment 1, participants fixated preferentially on neutral stimuli when available, with the exception of the unbiased first fixation. In Experiment 2, when the aversively conditioned stimulus was always task-irrelevant, initial fixations again showed no evidence of bias toward the aversively conditioned stimulus, and subsequent fixations avoided task-irrelevant stimuli almost entirely. However, in both studies we observed evidence for a covert attentional bias toward the aversive stimulus influencing the first fixation.

Prior work in multiple-target visual search and foraging tasks suggests that top-down and selection history-related attentional biases, both of which have been extensively characterized in single-target search (e.g., Wolfe, Butcher, Lee, & Hyle, 2003; Awh, Belopolsky, & Theeuwes 2012), persist well beyond the first target selection (e.g., Cain & Mitroff, 2013; Wolfe, Cain, & Aizenman, 2019). Our findings suggest that aversive conditioning, by contrast, does not generalize between single- and multiple-target search, at least when orienting to the aversively conditioned stimulus is directly punished (as in Anderson & Britton, 2019, in press). In this sense, our results are consistent with prior work demonstrating that very early saccades are disproportionately affected by threat-driven oculomotor capture (e.g., Nissens et al., 2017). Involuntary attentional capture is known to be facilitated by time pressure (e.g., Pearson et al., 2016; Anderson & Halpern, 2017), perhaps because participants are less able to tap strategic top-down control mechanisms to inhibit distractor-evoked attentional priority during the selection process. Our study implies that when time limits are removed and motivated participants must decide which among multiple potential targets to select, top-down mechanisms heavily modulate overt attention and allow the organism to completely overcome any overt attentional bias toward aversively conditioned stimuli.

Overt attentional avoidance of threatening stimuli has been previously characterized in the context of clinical anxiety and is typically observed relatively late in visual processing (e.g., Koster, Crombez, Verschuere, Van Damme, & Wiersema, 2006; for a review, see Cisler & Koster, 2010). The vigilance-avoidance hypothesis describes initial capture by threat stimuli, followed by avoidance; in this model avoidance of threat stimuli is a volitional, frontal cortex-mediated attempt to reduce the intense endogenous emotional arousal associated with threat stimuli (Mogg, Bradley, Miles, & Dixon, 2004). In a representative study, Rinck & Becker (2006) demonstrate in a population of spider-fearful participants that negatively valenced stimuli attract more initial fixations than neutral stimuli during free viewing but elicit fewer and shorter gaze durations for the rest of the 1000 ms stimulus presentation period. No effect was seen in nonanxious controls. Attentional avoidance may arise over the course of a trial as top-down goals exert increasing influence over attentional selection.

However, the stimuli used in the majority of prior studies of attentional avoidance present significant interpretational challenges: the attentional bias toward negatively valenced photographs varies depending on the neutral stimulus used (e.g., Hermans et al., 1999), and systematic differences in visual salience between negative and neutral stimuli may confound results within individual studies. Furthermore, photographic stimuli may not be sufficiently threatening to elicit attentional capture or avoidance in healthy participants (see Schmidt et al., 2015). These challenges may speak to why some prior studies of attentional avoidance report avoidance only in low trait anxiety (Sagliano, Trojano, Amoriello, Migliozzi, & D'Olimpio, 2014) while others observe stronger avoidance in high trait anxiety (e.g., Koster et al., 2006). Our study demonstrates that avoidance occurs in healthy participants when overt attention carries an unavoidable and sufficiently intense exogenous cost (in the present study, electric shock), obviating any early bias. Notably, block had no effect on the percentage of fixations on each stimulus, suggesting that the association was acquired very quickly (see also Failing et al., 2015; Nissens et al., 2017).

Prior studies of the vigilance-avoidance model of anxiety suggest that covert attention may remain on the threat stimulus while overt attention is directed elsewhere (Sagliano et al., 2014; for a review, see Weierich, Treat, & Hollingworth, 2008), reducing the endogenous arousal associated with overtly attending threat while continuing to monitor threat. Covert attentional capture by threat signals has also been reported in the general population (Mulckhuyse & Dalmaijer, 2016). Covert attention is typically operationalized as increased response latency, distortion in saccade trajectories, and increased likelihood of errant saccades to the covertly attended stimulus when presented as a distractor (Van der Stigchel & Theeuwes, 2007; Mulckhuyse, Van der Stigchel, & Theeuwes, 2009; Hickey & van Zoest, 2012; Schmidt, Belopolsky, & Theeuwes, 2012; Anderson & Yantis, 2012; Mulckhuyse et al., 2013).

Consistent with a covert attentional bias toward threatening stimuli, we observed in Experiment 1 a reduction in response latency when an aversively conditioned potential target was the first stimulus fixated, suggesting that early competition in the oculomotor system was biased in favor of aversively conditioned stimuli. Likewise, in Experiment 2, participants exhibited increased response latency to fixate a task-relevant stimulus when an aversively conditioned distractor competed for selection, again suggesting a covert attentional bias toward the aversive stimulus. In this way, our study replicates evidence of attentional bias observed in covert attentional capture tasks (e.g., Schmidt et al., 2015), while demonstrating that oculomotor biases towards aversively conditioned stimuli are largely the product of task demands that encourage or require rapid eye movements in response to stimulus onset (e.g., Anderson & Britton, 2019, in press; Mulckhuyse & Dalmaijer, 2016; Nissens et al., 2017) and that the oculomotor biases thus facilitated do not translate to the context of deliberate visual search. The apparent covert attentional bias might explain why the first saccade was not significantly biased away from the aversively conditioned stimuli in the present study. The extent to which participants maintained covert attention on aversively conditioned stimuli after the first fixation, or conversely, suppressed covert attention (Sawaki & Luck, 2010) remains unclear. Future studies in this vein could potentially assess sustained covert attention with concurrent eye tracking and EEG (Weaver, van Zoest, & Hickey, 2017).

Another limitation of this study is that we did not assess trait anxiety as a potential moderator of attentional avoidance within a nonclinical sample, although as noted, prior research on attentional avoidance often shows an effect of trait anxiety (e.g., Sagliano et al., 2014). Similarly, we did not explicitly screen for anxiety disorders or other psychiatric conditions that might influence how threat biases attention, which could be explored in this context. Finally, it should be noted that the probability of attending an aversively conditioned stimulus by chance rises higher than 25% as stimuli are removed from the search display; thus, as the analysis reported for Experiment 1 compares each fixation to a probability of 25%, our calculations may underreport participants' true preference for neutral stimuli.

Conclusions

Our findings demonstrate that in a foraging task without explicit time constraints, oculomotor capture by aversively conditioned stimuli can be avoided when fixating such stimuli is unavoidably punished, although a covert attentional bias towards signals of threat remains. The results indicate that findings of oculomotor capture by aversively conditioned stimuli may not generalize to other visual search tasks, and further suggest that top-down strategic mechanisms trigger attentional avoidance during the course of deliberate visual search under threat. More research is needed to understand the conditions under which aversive outcomes bias attention towards or away from threatening stimuli, along with the potential relationship between covert attentional mechanisms and overt attentional avoidance.

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Data availability statement Raw data and experiment code for both experiments is available on the Open Science Framework (https://osf.io/kgp45/).

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval All procedures were conducted in accordance with the ethical standards of the Texas A&M University Institutional Review Board and with the 1964 Helsinki declaration and its later amendments.

Informed consent Informed consent was obtained from all individual participants included in the study.

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