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Aversive conditioning, anxiety, and the strategic control of attention

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ABSTRACT

What we pay attention to is influenced by both reward learning and aversive conditioning. Although early attention tends to be biased toward aversively conditioned stimuli, sustained ignoring of such stimuli is also possible. How aversive conditioning influences how a person chooses to search, or the strategic control of attention, has not been explored. In the present study, participants learned an association between a colour and an aversive outcome during a training phase, and in a subsequent test phase searched for one of two targets presented on each trial; one target was rendered in the aversively conditioned colour (CS+) and the other in a neutral colour (CS-). Given the distribution of colour stimuli in the search array, it was more optimal to search for and report a target in one of the two colours on some trials. Our results demonstrate that participants were biased away from the CS+ target, which resulted in non-optimal search on some trials. Surprisingly, rather than accentuate this bias, greater state anxiety was associated with a stronger tendency to find and report the CS+ target. Our findings have implications for our understanding of the learning-dependent control of attention and abnormal attentional biases observed in high-anxious individuals.

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Introduction

The richness and complexity of many real-world environments exceed the representational capacity of the brain's perceptual system, requiring that we selectively process only a fraction of the available information at any one moment in time. In this respect, stimuli compete for representation in the brain, and attention serves as the mechanism by which this competition is biased in favour of a particular stimulus (Corbetta & Shulman, 2002; Desimone & Duncan, 1995). Although goals and intentions play a strong role in determining what an observer attends to (Folk et al., 1992; Wolfe et al., 1989), attention can at times be involuntarily drawn to certain objects. Physically salient stimuli (e.g. bright, colourful; see Theeuwes, 2010), previously reward-associated stimuli (e.g. Anderson et al., 2011) and aversively conditioned stimuli (Anderson & Britton, 2020; Schmidt et al., 2015) all have heightened attentional priority, with the latter two cases reflecting the influence of prior experience on the allocation of attention (Anderson et al., 2021). In the case of threatening stimuli, threat-related attentional biases are typically elevated in participants with high anxiety (see Bar-Haim et al., 2007, for a review).

Although rewarding and aversive outcomes have dissociable influences on motivated behaviour, with reward promoting approach behaviour and aversive outcomes promoting avoidance behaviour (Chen & Bargh, 1999; Guitart-Masip et al., 2012; Krieglmeyer et al., 2010), the involuntary orienting of attention to stimuli associated with either of these outcomes is supported by a common underlying mechanism of attentional control (Kim & Anderson, 2019, 2021, 2023a, 2023b; Kim, Nanavaty, et al., 2021). It appears

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that the attention system prioritises stimuli that are motivationally salient or pertinent for survival, in a manner that does not distinguish between positive and negative valence. Reward, however, interacts with goal-directed attention to enhance the processing of task-relevant stimuli (Esterman et al., 2017; Kiss et al., 2009; Pessoa & Engelmann, 2010; Small et al., 2005). It was recently shown that when individuals can choose which of two simultaneously-presented targets to find and report, one of which was previously associated with reward, they are biased to report the previously reward-associated target even when doing so reflects a suboptimal attentional strategy (Lee et al., 2022), potentially reflecting a habit-like effect on goal-directed attention (see also Clement & Anderson, 2023; Kim et al., 2024; Lee & Anderson, 2023). Less is known about how aversive conditioning interacts with the goal-directed or strategic control of attention, and whether it follows a similar pattern to reward-related effects or instead promotes attentional avoidance.

When observers must fixate on different coloured disks to reveal a hidden target in a visual foraging task, covert attention is initially drawn toward disks rendered in a colour associated with shock when fixated (Britton & Anderson, 2021). However, observers are able to resist actually fixating on such stimuli until other disks that cannot trigger shock have been fixated, reflecting an initial biasing influence on attention that quickly transitions to marking a stimulus for overt avoidance (Anderson & Britton, 2020). This suggests that observers can to some degree resist attention to aversively conditioned stimuli, at least after the earliest stage of information processing, mapping onto an early approach followed by later avoidance pattern of orienting sometimes observed for threatening stimuli in a cueing task (e.g. Booth, 2014; Koster et al., 2005; Mansell et al., 1999).

In Britton and Anderson (2021), participants were motivated to avoid fixating aversively conditioned stimuli, as fixating such stimuli could trigger a shock (the avoidance of shock was a current concern). In the present study, we examined a situation in which one of two targets was rendered in a previously shock-associated colour, and participants had the option to report the digit contained within either this target or a target rendered in a colour that was never paired with shock in a prior training phase. On some trials, the previously shock-associated target was easier to find, and on other trials the other target was easier to find given the distribution of stimuli rendered in that colour. Of interest was whether prior associations with shock would influence how participants chose to search, above-and-beyond how the distribution of colour stimuli influenced the demands of the task. A secondary interest was to explore whether any such influence of aversive conditioning would be modulated by current anxiety, consistent with a modulatory influence of state anxiety on attention reported by Gregoire and Anderson (2024).

Method

Participants

Forty-four participants (25 females, 17 males after two exclusions [see Data Analysis]), between the ages of 18 and 35 years inclusive ($M = 19.0$, $SD = 0.62$) 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 colour vision. All procedures were approved by the Texas A&M Institutional Review Board. Written informed consent was obtained for each participant and all study procedures were conducted in accordance with the principles expressed in the Declaration of Helsinki. The final sample size (see the data analysis section below) yielded power (1-β) > 0.8 with α = 0.05 to replicate the reward bias observed in Lee et al. (2022) ($d_z = 0.45$), and power (1-β) = 0.68 to replicate a correlation of the magnitude reported in Gregoire and Anderson (2024) ($r = .323$).

Apparatus

A Dell OptiPlex 7040 equipped with MATLAB software and Psychophysics Toolbox extensions (Brainard, 1997) was used to present the stimuli on a Dell P2717H monitor. Manual responses were made using a Millikey SR-5 r2 button box. Participants viewed the monitor from a distance of approximately 70 cm in a dimly lit room. Paired electrodes were attached to the left forearm of each participant, and electric shocks were delivered through a BIOPAC linear isolated stimulator under the constant current setting, which was controlled by custom MATLAB scripts.

Stimuli

Each visual search array was composed of 54 coloured squares (each approximately 1.1° × 1.1°) arranged in three concentric rings around the centre of the screen. The inner ring had a radius of 7.3° and consisted of 12 squares, the middle ring had a radius of 10.1° and consisted of 18 squares, and the outer ring had a radius of 13.0° and consisted of 24 squares. Each square in each ring was positioned equidistant from each other and contained a digit between 2 and 9, subtending 0.4° × 0.4°.

Training phase

The training phase comprised a forced-choice version of the adaptive choice visual search (ACVS) task (Irons & Leber, 2016). Each trial consisted of a fixation display (1000 ms), a search array (5500 ms or until response), a feedback display (500 ms), and a blank inter-trial-interval (ITI, 1000 ms). The fixation display consisted of a fixation cross at the centre of the screen. There were two types of search arrays: red and green squares, or blue and green squares (Figure 1(A)). Participants were instructed to search for a target square: a red or blue square containing a digit 2–5. Only one target square was presented on each trial. An equal number of red/blue and green colour squares was presented in the search array on every trial. All red and blue squares that were not the target square contained a digit 6–9. Green boxes were irrelevant to the task and contained a digit 2–9 to prevent participants from searching for a low digit regardless of colour (Irons & Leber, 2016; Kim et al., 2021a). All digits inside non-target squares were assigned randomly using the aforementioned constraints. Participants indicated their response to the digit contained within the target by pressing the button on the button box mapped to that digit (going left-to-right with the left-most button mapped to 2 and the right-most button mapped to 5).

One of the two target colours, which alternated across participants, was associated with electric shock (conditioned stimulus, CS+). Participants received an electric shock 500 ms after the termination of the search array (i.e. immediately upon termination of the feedback display) on 60% of trials in which the target was rendered in the shock-associated colour. In contrast, participants never received an electric shock following a search array in which the target was rendered in the other colour (CS-). If participants responded with a number other than the target number, feedback consisted of the word "Missed". If participants did not make a manual response within the 5500-ms time limit, feedback consisted of the

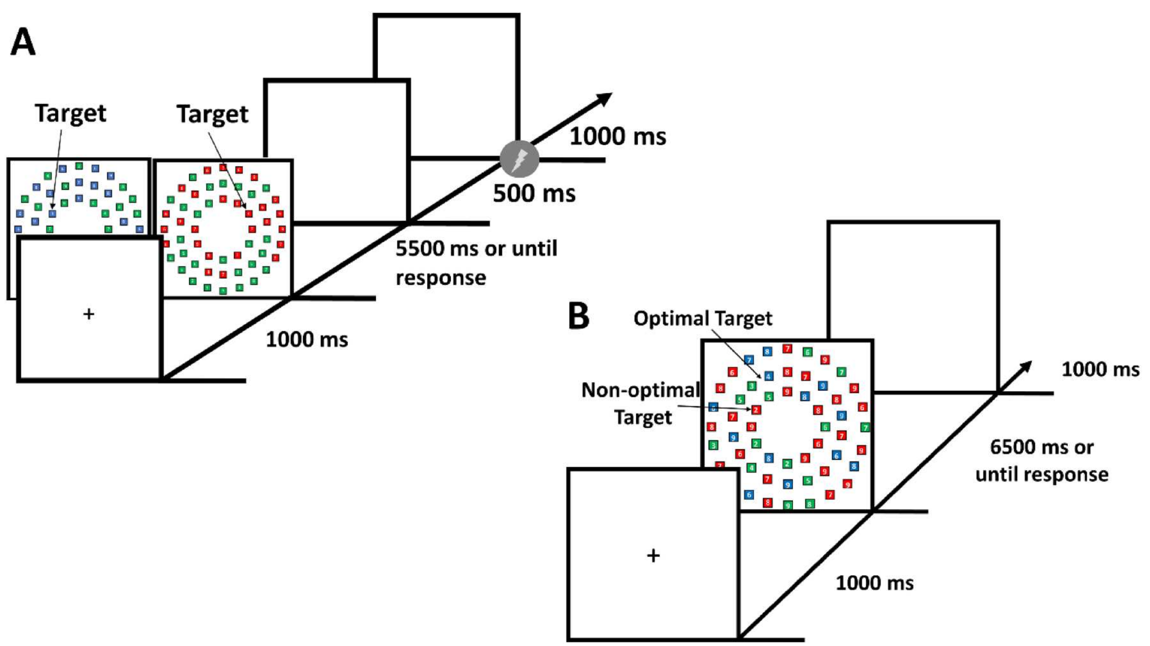

Figure 1. Sequence of trial events. (A) Example training phase trial with each of two search array types shown. When the target was rendered in the shock-associated colour, participants received a mild electric shock 60% of the time regardless of their performance. (B) Example test phase trial. Of interest was whether the experience of aversive outcomes during the training phase influences which of the two targets participants find and report.

words "Too Slow;" otherwise, the feedback display was blank. The delivery of electric shock was not contingent upon task performance and was predicted only by the CS+ colour. Each block of trials in the training phase was 60 trials long (18 CS+ trials with shock delivered, 12 CS+ trials without shock delivered, and 30 CS- trials) and participants completed a total of three blocks with a short break between each. The trials within each block were presented in a random order.

Test phase

The test phase was identical to Lee et al. (2022) and consisted of a fixation display (1000 ms), search array (6500 ms or until response), and ITI (1000 ms) (Figure 1(B)). There were three trial types corresponding to three distributions of red and blue boxes: CS+ optimal (13 CS+ colour boxes, 27 CS- colour boxes, 14 green boxes), CS- optimal (13 CS- colour boxes, 27 CS+ colour box, 14 green boxes), and neutral trials (18 CS+ colour boxes, 18 CS- colour boxes, and 18 green boxes). Participants were not informed about the different colour distributions used. Each trial contained two targets: a red and blue box with a digit 2–5. The digit within each target was different, such that which digit participants reported was diagnostic of which colour target they had found. Participants only needed to report one of the two targets, and they were free to select which to find and report on each trial. The button-digit mapping was the same as in the training phase.

Due to the colour distribution within the search array, either the CS+ or CS- colour could be less abundant than the other, meaning that there are fewer stimuli rendered in that colour that would need to be searched through. Thus, searching through stimuli rendered in the less abundant colour constitutes the "optimal" search strategy. However, participants were not informed of this strategy. Non-target squares were assigned numbers in the same manner as in the training phase, and performance-related feedback was presented in the same manner following incorrect responses or time outs. Each block of trials in the test phase was 90 trials long (30 trials for each trial type, randomly distributed), and participants completed a total of three blocks with a short break between each.

Contingency awareness test

After the test phase, participants completed a contingency awareness test. To assess awareness of the different colour distributions during the test phase, participants were asked whether they noticed any pattern or regularity in the distribution of the coloured boxes during the test phase and whether they used a strategy for finding a target. If participants reported using a strategy or noticing a difference, we asked participants to explain their strategy or the difference they noticed (typed response). Lastly, to assess awareness of the colour–shock contingencies, participants viewed a series of search arrays from the training phase and were asked how likely they were to be shocked after each array on a scale from 0 to 100%. Participants viewed a total of 24 search arrays, half of which contained a red target and half of which contained a blue target.

Task procedure

After consent, each 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" (e.g. Anderson & Britton, 2020; Grégoire et al., 2022; Gregoire & Anderson, 2024). Following calibration, participants completed the state component of the State-Trait Anxiety Inventory (STAI-state; Ferreira & Murray, 1983) before completing the task. After the STAI-state questionnaire, participants completed practice for the training phase. Practice consisted of 20 trials and participants had to obtain at least 85% accuracy to proceed to the training phase. After the practice, participants completed the three blocks of training. Then, participants performed 20-trial practice for the test phase with the same accuracy criterion. After the practice, participants were explicitly instructed about the absence of the shock in the test phase and completed the three blocks of test phase trials. The task was otherwise identical to Lee et al. (2022), swapping an aversive outcome (shock) with monetary reward. The experiment concluded with the contingency awareness test.

Data analysis

We excluded two participants due to low accuracy in the task (<3 *SD* of the group mean), so 42 datasets were fully analysed. In the test phase, we computed the frequency with which participants reported the CS+ target for each of the three different colour distributions, in addition to mean response time (RT) and accuracy. On non-neutral trials, the frequency of reporting the CS+ target was expressed with respect to optimality, which was the proportion of trials on which the target of the less abundant colour was reported (chance = 50%).

Transparency and openness

The experiments reported in this article were not formally preregistered. Raw data are available at https://osf.io/qmhy3/. We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Results

Training phase

There was no significant difference observed in RT between CS+ target trials ($M = 2.85$ s, $SD = 0.33$ s) and CS- target trials ($M = 2.91$ s, $SD = 0.31$ s), $t(41) = -1.97$, $p = .056$. Neither was there a difference in accuracy in reporting the CS+ target ($M = 90.6\%$, $SD = 6.2\%$) and CS- target ($M = 90.1\%$, $SD = 5.9\%$), $t(41) = 0.61$, $p = .548$.

Test phase

We conducted one-way repeated-measures analyses of variance (ANOVA) on RT and accuracy with trial type (CS+ optimal, CS- optimal, neutral) as a factor. The main effect of trial type was not significant for RT (CS+ optimal: $M = 2.55$ s, $SD = 0.47$ s; CS- optimal: $M = 2.55$ s, $SD = 0.44$ s; neutral: $M = 2.56$ s, $SD = 0.45$ s) $F(2,123) = 0.02$, $p = .976$, nor accuracy (CS+ optimal: $M = 94.4\%$, $SD = 8.17\%$; CS- optimal: $M = 94.7\%$, $SD = 7.51\%$; neutral: $M = 94.6\%$, $SD = 9.02\%$), $F(2,123) = 0.05$, $p = .952$.

We next evaluated the probability of reporting the optimal target on CS+ colour optimal and CS- colour optimal trials, in addition to the probability of reporting the CS+ target on neutral trials. We found the percentage of reporting the CS+ target on neutral trials was significantly lower than 50%, $t(41) = -2.10$, $p = .042$, $d_z = -0.33$, indicating a bias against reporting a target in this colour. This bias is also reflected in the optimality of the other two trial types where participants were significantly optimal when the CS- colour was optimal, $t(41) = 2.45$, $p = .018$, $d_z = .38$, while participants were not significantly optimal when the CS+ colour was optimal, $t(41) = 0.02$, $p = .983$ (Figure 2(A)). A Bayes factor analysis (using JASP 0.18.3.0 with default priors) indicated that the null hypothesis was 5.99 times more likely to account for the observed data than the alternative hypothesis that participants were optimal above chance on CS+ optimal trials, $BF_{01} = 5.99$. Lastly, a significant negative correlation between RT and optimality was observed for the CS- colour optimal trials, $r(40) = -.503$, $p < .001$, demonstrating a clear performance advantage associated with engagement of the optimal strategy (Figure 2(B)). No such correlation was observed for the CS+ colour optimal trials, on which participants were generally not optimal, $r(40) = -.157$ $p = .32$.

Next, we analysed the correlation between state anxiety (measured by the STAI-state) and the frequency of reporting a CS+ target. We found a significant positive correlation between state anxiety and the frequency of reporting the CS+ target on neutral trials, $r(40) = .381$, $p = .013$ (Figure 2(C)), in addition to a significant positive correlation between state anxiety and how much more optimal participants were on CS+ colour optimal versus CS- colour optimal trials (also an indicator of preference for reporting the CS+ target), $r(40) = .371$, $p = .016$ (Figure 2(D)). To visualise and better understand the relationship between state anxiety and performance in the task, we divided participants into three tertiles based on STAI-S score (Supplemental Figure 1). Participants in the first and second tertiles exhibited a similar pattern to the overall analysis in which optimality was significantly greater than 50% on CS- optimal trials (1st tertile, $t(13) = 2.53$, $p = .025$, $d_z = 0.68$; 2nd tertile, $t(13) = 2.34$, $p = .036$, $d_z = 0.63$) and the percentage of reporting the CS+ target was significantly below 50% on neutral trials (1st tertile, $t(13) = -2.62$, $p = .021$, $d_z = -0.68$; 2nd tertile, $t(13) = -2.36$, $p = .035$, $d_z = -0.63$). However, participants in the third tertile showed a trend toward the opposite pattern of performance in which they were marginally more likely than chance (50%) to report the CS+ target on CS+ optimal trials, $t(13) = 2.16$, $p = .05$, $d_z = 0.58$, and neutral trials, $t(13) = 1.83$, $p = .090$, $d_z = 0.49$. Correspondingly, participants in the third tertile exhibited significantly higher optimality on CS+ optimal trials, $t(26) = 2.59$, $p = .015$, $d = 0.98$, lower optimality on CS- optimal trials, $t(26) = 2.23$, $p = .034$, $d = 0.84$, and a higher percentage of reporting the CS+ target on neutral trials, $t(26) = 3.32$, $p = .003$, $d = 1.25$ compared to participants in the first tertile (Supplemental Figure 1). That is, across all trial types, more anxious participants were *more* likely to find and report a target rendered in the colour previously associated with shock.

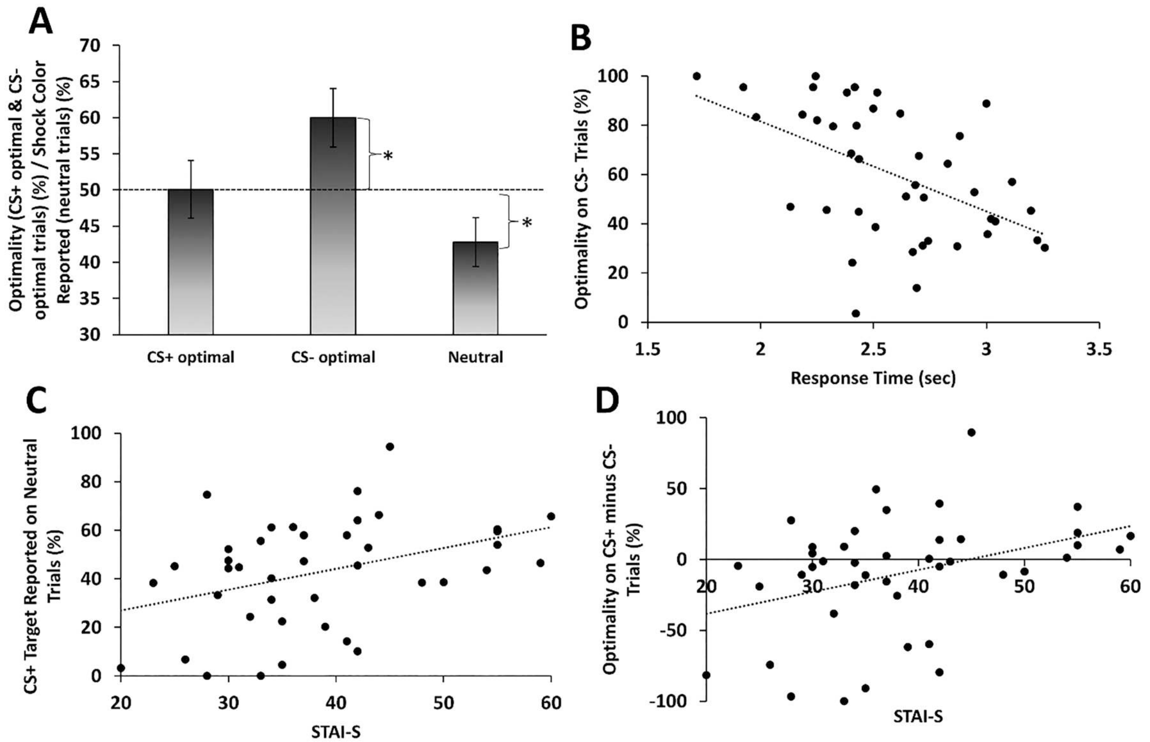

Figure 2. Test phase results. (A) Optimality of target report on CS+ optimal & CS- optimal trials and proportion of trials on which the CS+ target was reported on neutral trials. Error bars depict the standard error of the mean. *$p < .05$. (B) Correlation between optimality of target report on CS- optimal trials and response time. (C) Correlation between the percentage of neutral trials on which the CS+ target was reported and STAI-S score. (D) Correlation between the difference of optimality on CS+ optimal minus CS- optimal trials and STAI-S score.

Contingency awareness test

One participant was excluded from the analysis for failing to complete the contingency awareness test. Out of the 39 participants who answered "Yes" to the use of a strategy, there were only 9 participants who described a strategy to search for the target in the less abundant colour. Nineteen participants reported noticing a difference between the two target colours and seven of them described the unequal distribution of the target colour on some trials during the test phase. Lastly, participants reported that the CS+ target was more likely to be followed by a shock than the CS- target in the training phase (CS+ colour: 56.2%, CS- colour: 34.7%, $p < .001$). However, the difference in reported shock likelihood between CS+ optimal and CS- optimal trials was not significantly correlated with state anxiety, $r(40) = .082$, $p = .608$, the difference in optimality between CS+ optimal and CS- optimal trials, $r(40) = -.088$, $p = .578$, or the probability of reporting the CS + target on neutral trials, $r(40) < .001$, $p = .997$. Thus, while participants displayed some awareness of the colour?shock contingencies, their awareness of these contingencies did not appear to be related to their state anxiety, optimality, or frequency of reporting the CS+ target.

Discussion

On the whole, participants were biased against finding and reporting a target rendered in a colour previously associated with electric shock (CS+). This bias resulted in search performance being significantly above-chance optimal only when the optimal target was not previously associated with shock (CS-); when the optimal target was previously associated with shock, participants searched non-optimally. The extent to which participants engaged the optimal strategy (see Clement & Anderson, 2023; Irons & Leber, 2016; Kim et al., 2021; Lee & Anderson, 2023) on CS- optimal trials came at the benefit of RT, providing independent evidence that it was indeed optimal to search in this way. The bias away from the CS+ target therefore came at the detriment of search performance.

The group-level effect we observed is inconsistent with an effect of an involuntary attentional bias for the CS+ colour on the strategic control of attention; such a bias would have been consistent with the effect of aversive conditioning on distractor processing in a speeded visual search task (e.g. Anderson & Britton, 2020; Kim & Anderson, 2021; Schmidt et al., 2015) and the effect of colour-reward associations on the strategic control of attention in the same task (Lee et al., 2022). The observed group-level bias is, however, consistent with the attentional avoidance of aversively conditioned stimuli observed in an attentional foraging task (Britton & Anderson, 2021). It is unclear whether covert attention was initially biased toward the CS+ colour and participants then avoided fixating and/or reporting such stimuli (as in Britton & Anderson, 2021), or whether there was no covert attentional bias and participants merely tended to choose not to search among stimuli rendered in the CS+ colour. It is even possible that they to some degree suppressed CS+ colour stimuli (see Gaspelin & Luck, 2018). What is clear is that, when it comes to the strategic control of attention, observers are inclined to avoid searching for stimuli that formerly predicted an aversive outcome, even when they are informed that no more aversive outcomes will be delivered and searching in this way comes at the expense of more optimal task performance.

It might have been expected that more anxious participants would have been more inclined to avoid reporting a target rendered in the previously shock-associated colour. This would be consistent with how individuals with anxiety disorders tend to avoid stimuli related to their worries (e.g. Hofmann & Hay, 2018; Roberts et al., 2022; Salters-Pedneault et al., 2004). However, we observed the opposite: More anxious participants were in fact *more* likely to find and report a target rendered in the previously shock-associated colour, suggesting an attentional bias toward aversively conditioned stimuli that influenced the strategic control of attention. The overall group-level bias against finding and reporting the previously shock-associated colour was weak, albeit significant, because several more anxious participants exhibited an opposite tendency.

Our findings suggest that heightened attentional biases toward fear-related stimuli in anxious participants may not be as involuntary and automatic as previously assumed, given that in the test phase of the present study, participants needed to search among multiple stimuli of each task-relevant colour and chose when and whether to report the CS+ colour target. Our findings suggest that anxious individuals may to some degree strategically prioritise aversively conditioned stimuli, potentially in an effort to engage in overt threat monitoring (see Mulckhuyse, 2018; Öhman & Mineka, 2001; Vuilleumier, 2005). This bias to strategically attend to threat-related stimuli may have implications for our understanding of the cognitive mechanisms contributing to anxiety disorders and other psychopathology.

More broadly, our findings offer novel insight into seemingly conflicting findings concerning the role of anxiety in threat detection and threat avoidance. Generally, patterns of attentional orienting both toward and away from threatening stimuli are accentuated with high anxiety (Bar-Haim et al., 2007; Booth, 2014; Koster et al., 2005; Mansell et al., 1999), suggesting that anxiety can potentiate a threat-related attentional process. In the present study, the influence that conditioned threat had on attention fundamentally shifted with high anxiety. Whereas participants on the whole tended to avoid attending to stimuli rendered in a threat-related colour, more highly anxious participants showed the opposite tendency. This suggests that anxiety can change the manner in which threat-related stimuli are processed, specifically with respect to how participants choose to search. Such an anxiety-related shift in attentional strategy could help explain why attention can be drawn toward or away from threat-related stimuli in individuals with and without high anxiety across different task contexts, which is a possibility ripe for further exploration.

In conclusion, aversive conditioning influences not only involuntary attentional biases, but also the strategic control of attention. Although observers' attention may be initially biased toward aversively conditioned stimuli (Britton & Anderson, 2021; Kim & Anderson, 2021), they will avoid intentionally attending to such stimuli even when doing so is detrimental to task performance. More anxious participants, however, show the opposite tendency, intentionally prioritising aversively conditioned stimuli, which raises important questions concerning whether preferential processing of aversively conditioned distractors frequently observed in anxious individuals (e.g. Blanchette & Richards, 2013; Gregoire & Anderson, 2024) is in fact to some degree reflective of strategic and intentional attentional processing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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