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The role of state anxiety in salience-driven distractor processing: evidence from singleton detection and feature search

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ABSTRACT

Salient but irrelevant distractors automatically capture attention in singleton detection search but not in feature search, due to the different search strategies adopt by observers. While state anxiety has been associated with increased salience-driven capture, it remains unclear whether such effects extend to feature search, which relies more on top-down control. The present study addressed this question using an eye-tracking technique, combining the threat of shock with the singleton detection and feature search tasks. Participants were instructed to execute speeded saccades to the target while ignoring a salient irrelevant distractor. To induce state anxiety, unpredictable, unavoidable, and sporadic shocks were administered during threat blocks, while no shocks were administered during safe blocks. The results showed that threat significantly increased oculomotor capture and dwell time on the salient distractor in the feature search task, but had no effect in the singleton detection task. These findings suggest that state anxiety may selectively impair template-based rejection and disengagement mechanisms required for feature search, whereas purely priority-guided selection during singleton detection leaves little room for additional modulation. Our results highlight that task demands determine how threat-induced state anxiety modulates salience-driven capture.

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Anxiety has long been recognised as a key factor influencing cognitive processes, particularly attention (Robinson et al., 2013). Both trait and state anxiety are characterised by prolonged reactions to unexpected threatening information or events, frequently impairing goal-directed attentional control (Eysenck et al., 2007). One prominent manifestation of this impairment is increased distraction by task-irrelevant but salient stimuli. For instance, Gutierrez and Berggren (2020) showed that heightened state anxiety, induced by the anticipation of an aversive noise, potentiated salience-driven attentional capture. This finding was further supported by an eye-tracking study (Kim & Anderson, 2020, see Experiments 4

and 5), which revealed that the threat of shock-induced state anxiety increased initial fixation proportions on a salient distractor.

These findings are consistent with *Attention Control Theory* (ACT, Berggren & Derakshan, 2013; Eysenck et al., 2007), which suggests that anxious states may heighten vigilance to detect potential threats, thereby amplifying bottom-up salience-driven selection, possibly as a result of impaired top-down control (see also Robinson et al., 2013). The research mentioned above predominantly utilised the singleton detection search task (Theeuwes, 1992, 2010). In this task, participants are instructed to search for a unique shape among a homogeneous

visual search array (e.g. a circle among diamonds or vice versa) and respond to the orientation of a line element inside the unique shape. A salient colour-singleton distractor is presented in half of the trials, which typically interferes with performance, suggesting that visually salient stimuli capture attention automatically (Theeuwes, 1992, 2010).

When the search array is heterogeneous and participants are instructed to search for a specific target feature, the salient colour singleton no longer captures attention (Bacon & Egeth, 1994; Luck et al., 2021). Some studies even report that such a distractor attracts less attention than the other non-targets, suggesting top-down distractor suppression (Gaspin et al., 2015, 2017). An alternative account challenges this suppression interpretation. According to the attentional window account (Theeuwes, 2023), the size of the attentional window that observers adopt determines whether a distractor captures attention. Specifically, in singleton detection search, where the target “pops-out” from the background, a large attentional window is adopted resulting in parallel search. Consequently, the most salient item in the display, the distractor, automatically captures attention. In contrast, during feature search, the target is less salient because of the heterogeneity of the display and thus a smaller attentional window is adopted resulting in serial search. Within this small attentional window, the salient distractor is outside and receives less attention without requiring active suppression. Consistent with this explanation, Oxner et al. (2023) observed no difference in processing distractors with non-targets when the non-targets differed in colour from the target.

Liesefeld and Müller (2020, 2023) advance an alternative and more comprehensive account. They propose that singleton detection search engages a strategy known as priority guidance, in which attention is directed toward the most salient item in the visual field based on dimension-specific saliency maps. This allows the distractor to reliably capture attention, by temporarily holding the highest peak in the priority map. In contrast, the heterogeneity of the display in feature search reduces the salience of the target and induces clump scanning. Clump scanning is a more serial search strategy, where attention is directed to localised groups, or “clumps” of items that are processed in parallel and sequentially compared to a top-down template. Attentional capture by the distractor can be avoided either by relying on a feature-specific distractor template for rapid

identification and rejection of distractors, or by relying on a target template to enhance target processing regardless of the presence of a salient distractor (Liesefeld & Müller, 2020).

Regardless of the exact mechanisms of attentional capture by salient distractors across different search tasks, it remains unclear how these search strategies interact with emotional states, such as anxiety. ACT proposes that anxiety impairs top-down control but strengthens bottom-up attention (Berggren & Derakshan, 2013; Eysenck et al., 2007). Therefore, when the search relies largely on top-down template-guided clump scanning, it may be more susceptible to disruption under anxiety. In contrast, when the search strategy is dominated by salience, as in priority-guided selection, anxiety may further amplify attentional capture in a bottom-up way.

The current study directly tested this hypothesis by combining a threat-of-shock paradigm with the additional singleton task, using eye-tracking to measure attentional capture while manipulating search modes. Specifically, participants completed both a singleton detection task and a feature search task in alternating threat (shock) and safe (no-shock) blocks. According to ACT (Berggren & Derakshan, 2013; Eysenck et al., 2007), elevated state anxiety should affect both search modes, as anxiety increases susceptibility to salient stimuli and impairs top-down attentional control. Therefore, the salient distractor is expected to capture attention more frequently in both conditions, resulting in greater oculomotor capture during threat-of-shock blocks compared to safe blocks.

Method

Participants

Thirty undergraduates with normal or corrected-to-normal visual acuity as well as normal colour vision were recruited. In the singleton detection task, one participant was excluded due to calibration issues, and one was excluded due to insufficient target fixation, resulting in 28 participants (3 males, 25 females; mean age = 19.7 ± 1.38) for the final analysis. In the feature search task, four participants were excluded due to calibration issues, and one was excluded due to insufficient target fixation, resulting in 25 participants (3 males, 22 females; mean age: 19.6 ± 1.41) for the final analysis. A simulation-based power analysis indicated that a sample size of 24

participants was sufficient to detect the effect of interest (see Supplementary material A for details). Each participant received compensation of 25 CNY for their participation. This study was approved by the Ethics Committee of Shaanxi Normal University. The scripts, materials, data and analysis codes for this study can be found at <https://osf.io/7mtu3/>.

Stimuli, design and procedure

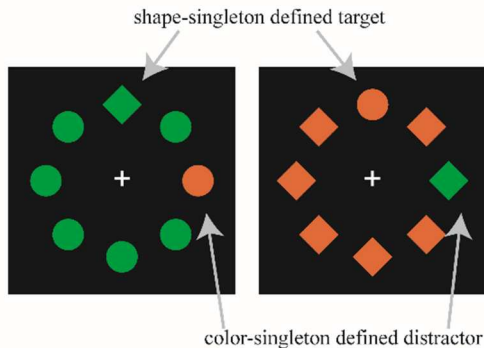
Psychtoolbox (Brainard, 1997) in MATLAB (MathWorks, Natick, MA) was used to present stimuli and collect data. Both the singleton detection task and the feature search task contained a gaze-contingent fixation display, a 1000-ms search array and a 1000-ms blank intertrial interval (ITI; see Figure 1C). The fixation display featured a white cross ($0.51^\circ \times 0.51^\circ$, RGB: [255 255 255], $\text{cd/m}^2 = 78$) at the centre of the screen. The search array consisted of eight filled shapes, evenly positioned on an imaginary circle with a radius of 5.82° around the center of the screen. In the singleton detection task, the search

array comprised seven circles (2.33° diameter) and one diamond ($2.80^\circ \times 2.79^\circ$) or vice versa. The unique shape served as the target. In the feature search task, in addition to a circle and a diamond, the search array included a square ($2.10^\circ \times 2.10^\circ$), a triangle ($2.42^\circ \times 2.10^\circ$), an inverted triangle ($2.42^\circ \times 2.10^\circ$), an oval ($1.86^\circ \times 2.79^\circ$), a pentagon ($2.66^\circ \times 2.54^\circ$) and a hexagon ($2.61^\circ \times 2.28^\circ$).

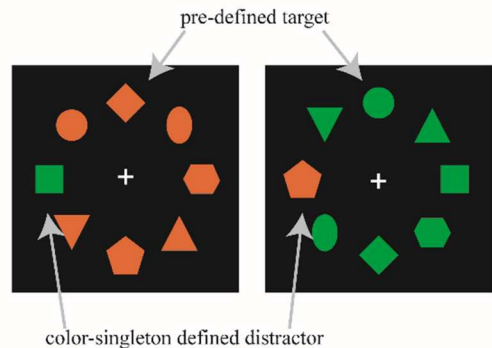
On distractor-absent trials, all shapes were displayed in either red (RGB: [244 74 18], $\text{cd/m}^2 = 78$) or green (RGB: [22 159 0], $\text{cd/m}^2 = 78$). On distractor-present trials, one non-target shape was presented in a different colour than the rest, acting as a colour-singleton distractor. Other non-targets in this study are termed “fillers”. All possible combinations of target and distractor positions were equally represented. Additionally, on distractor-absent trials, the target appeared in all positions within the search array an equal number of times.

Each trial began with the presentation of a fixation cross, which remained visible for 2000-ms or until the participant’s eye position was detected within 0.7° of

A) Singleton detection



B) Feature search



C)

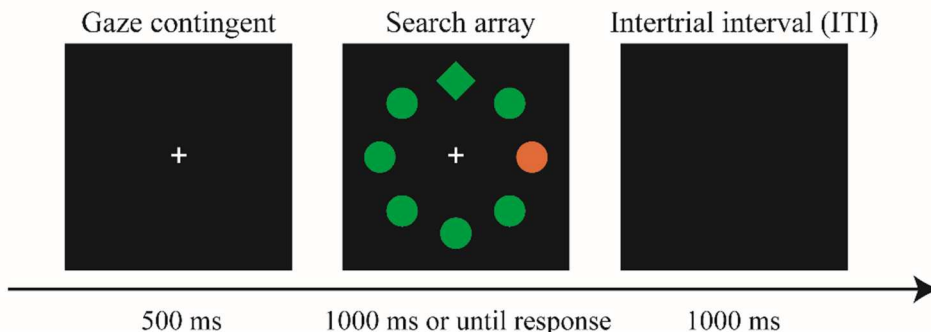


Figure 1. The additional singleton task.

Note: Panel A shows the Singleton detection task, panel B the Feature search task. C depicts a trial in the Singleton detection search task.

the centre of the cross for a continuous 500 ms. Subsequently, the search array appeared for 1000 ms or until fixation on the target occurred. Participants were instructed to saccade promptly and directly to the target. In the singleton detection task, the target was the unique shape, whereas in the feature search task, the target was pre-defined as either a diamond or a circle and remained constant throughout the block. A 1000-ms blank screen was then displayed. Participants were given a customisable rest interval after every 40 trials.

The experiment included four types of blocks: safe singleton detection, threat singleton detection, safe feature search and threat feature search. Each type had 2 blocks with 80 trials each, totalling 640 trials. A text before each block indicated whether it would be safe or threat. A cue before each block in the feature search task showed the target shape. The features of the target and distractor (shape and colour) were randomly assigned for each participant in each block and remained constant throughout the block. Within each block, there were 24 distractor-absent trials and 56 distractor-present trials. The order of blocks (safe first or threat first) and the order of tasks (singleton detection first or feature search first) were counterbalanced across participants. Prior to the formal task, participants underwent a practice phase consisting of 10 trials with no time limit followed by 24 trials with a 1000-ms limit.

In the threat blocks, participants were subjected to shocks during the ITIs, with two to four shocks randomly delivered during each threat block. On average, participants received a total of 5.54 shocks during singleton detection and 6.32 shocks during feature search. The shock intensity for each participant was individually pre-determined (see Supplementary material B).

At the end of each block, participants rated their subjective anxiety level for that block on a scale of 1 to 7 (1 indicating not anxious at all, 7 indicating extremely anxious). Electrodermal activity (EDA) was recorded for each participant (see Supplementary material B). Paired *t*-tests on anxious ratings and EDAs showed an enhanced state anxiety during threat blocks (see Supplementary material C, Figure S1), indicating a successful manipulation of the threat of shock.

Eye-tracking recording and data analyses

Eye-tracking was conducted using the EyeLink 1000 Plus system (SR Research Ltd., Ottawa, Ontario,

Canada), with a head position stabilised by a manufacturer-provided chin rest (SR Research Ltd.). Prior to each task, eye position was calibrated via a 9-point calibration method, with manual drift correction performed by the experimenter when necessary. Real-time monitoring of the *x* and *y* positions of the eyes in relation to the eight stimulus positions was carried out during the presentation of the search array, enabling online fixation coding.

For the target, we measured whether the first fixation was on it and the saccade latency to it (SLC). For the distractor, we measured whether the first fixation was on it (oculomotor capture, see Theeuwes et al., 2003) and the dwell time on it (see Supplementary material B for details). These measurements were then submitted to generalised linear mixed models (GLMMs) or linear mixed models (LMMs) with the *lme4* package (Bates et al., 2015) in R (R Core Team, 2013). First fixation on the target and SLC were analysed with Block (safe, threat), Trial Type (distractor-absent, distractor-present) and Task (singleton detection search, feature search) as fixed effects. First fixation and dwell time on the distractor were analysed with Block and Task as fixed effects. The random-effect structures for all (G)LMMs included by-participant random intercepts. The degrees of freedom were estimated using the Satterthwaite approximation, and *p*-values were obtained from the *lmerTest* package (Kuznetsova et al., 2017). In cases where significant fixed effects were identified, post hoc analyses were conducted using the *emmeans* package (Searle et al., 2012), with *p*-values adjusted using the Bonferroni method for multiple comparisons.¹

Results

Figure 2 shows the proportions of first saccades directed to the target, distractor, and fillers in each condition. For the analyses, we first focused on the proportions of correct saccades in which participants initially fixated on the target.

Initial saccades to the target: distractors influenced fixations and latency only in the singleton detection task; threat had no effect

The GLMM analysis (see Figure 3 left panel) showed a significant main effect of Trial Type, evidenced by higher first fixation proportions on the target when the distractor was absent compared to when it was

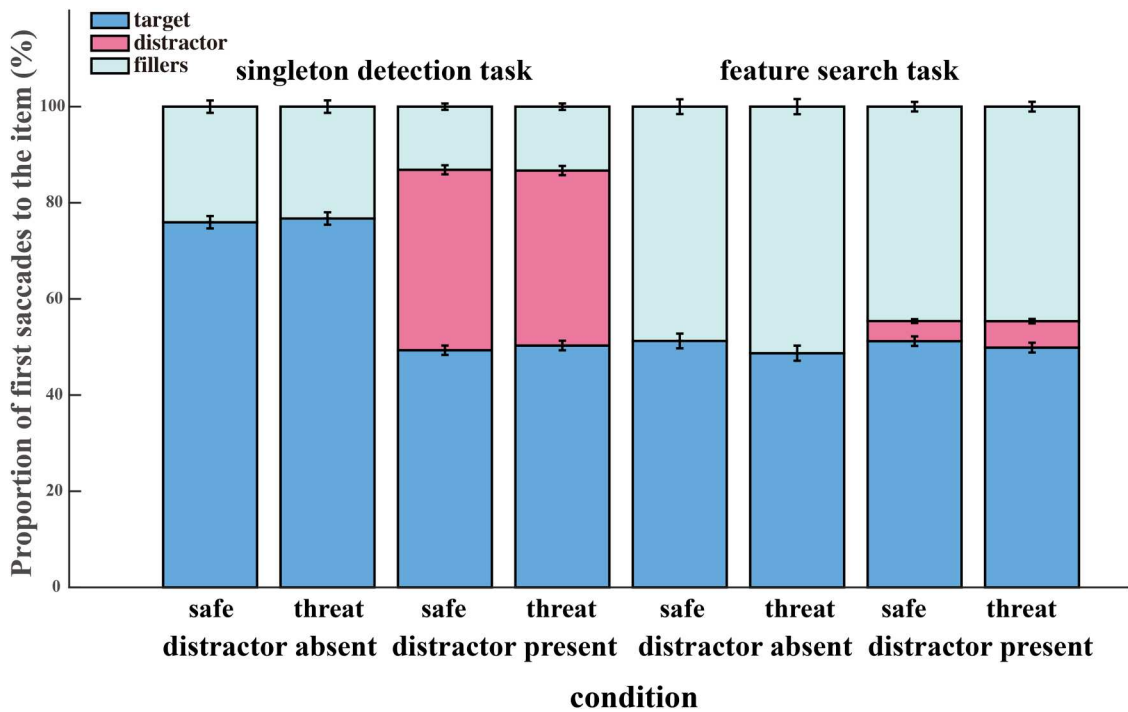


Figure 2. Descriptives of first fixation proportions to the target, distractor and fillers.

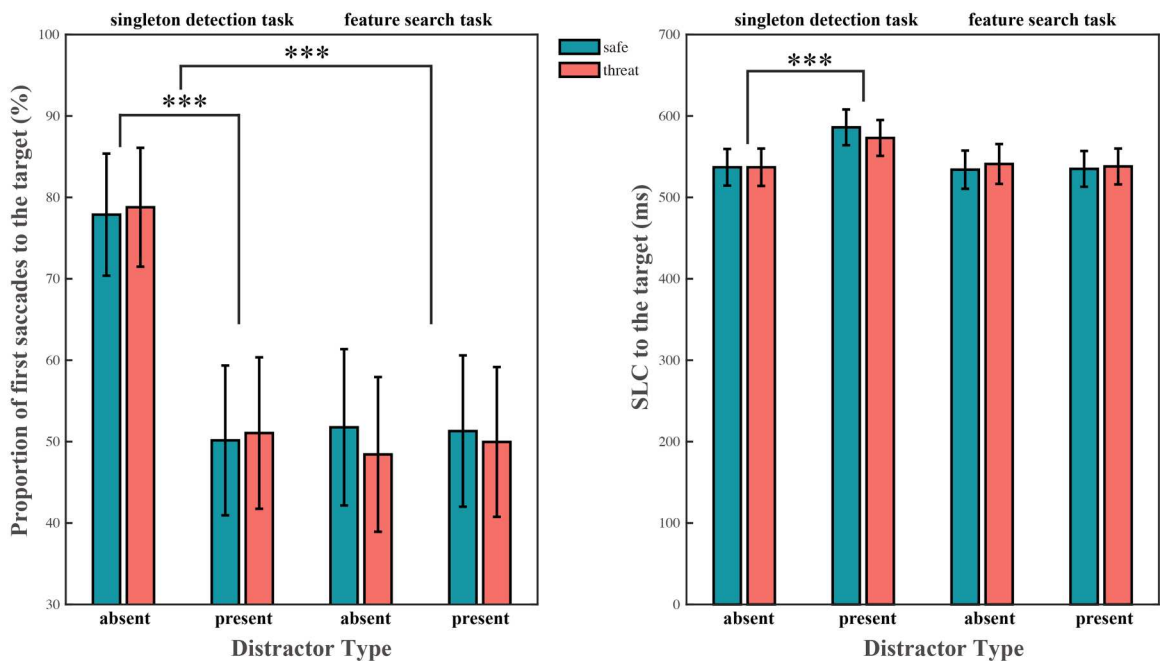


Figure 3. First fixation proportions on the target (left) and the saccade latency to the target (right).

Note: The specific values are based on marginal estimates by emmeans function. Error bars indicate the 95% confidence intervals of the marginal estimates. *** $p < .001$.

present, $\beta = 1.256$, $SE = 0.083$, $z = 15.114$, $p < .001$. The main effect of Task was also significant, with higher first fixation proportions on the target during the singleton detection task than during the feature search task, $\beta = 1.193$, $SE = 0.097$, $z = 12.252$, $p < .001$. Furthermore, a significant interaction between Trial Type and Task was observed, $\beta = 1.243$, $SE = 0.113$, $z = 10.993$, $p < .001$. Subsequent analyses revealed a significant decrease in first fixation proportions on the target when the distractor was present compared to when it was absent in the singleton detection task, $\beta = -1.261$, $SE = 0.059$, $z = 21.217$, $p < .001$, but not in the feature search task, $\beta = 0.021$, $SE = 0.055$, $z = 0.377$, $p = .707$. However, the interaction was not modulated by threat, $\beta = 0.078$, $SE = 0.162$, $z = 0.478$, $p = .633$.

Then we focused on the saccade latency (SLC) of correct saccades in which participants initially fixated on the target. The LMM analysis (see Figure 3 right panel) showed a significant main effect of Trial Type, due to longer saccade latency to the target in distractor-present than in distractor-absent trials, $\beta = 49.208$, $SE = 6.747$, $t(7664.44) = 7.294$, $p < .001$. The interaction effect of Trial Type and Task was also significant, $\beta = -48.939$, $SE = 10.109$, $t(7663.66) = -4.841$, $p < .001$. Post-hoc analyses revealed increased saccade latency

to the target when the distractor was present compared to when it was absent in the singleton detection task, $\beta = 42.56$, $SE = 4.80$, $t(7679) = 8.864$, $p < .001$, but not in the feature search task, $\beta = -1.12$, $SE = 5.49$, $t(7679) = -0.203$, $p = .839$. Furthermore, threat did not modulate the interaction effect, $\beta = 10.530$, $SE = 14.556$, $t(7663.40) = 0.723$, $p = .469$.

Threat increased oculomotor capture and dwell time on the distractor in the feature search task, but has no impact in the singleton detection task

The GLMM analysis showed a significant main effect of Task on first fixation proportions on the distractor (see Figure 4 left panel), with higher proportions in the singleton detection task than in the feature search task, $\beta = 2.786$, $SE = 0.112$, $z = 24.762$, $p < .001$. There was also a significant interaction between Block and Task, $\beta = 0.323$, $SE = 0.149$, $z = 2.160$, $p = .031$. Further analyses revealed a significant increase in first fixation proportions on the distractor during the threat compared to the safe condition in the feature search task, $\beta = 0.264$, $SE = 0.137$, $z = 1.932$, $p = .027$, but not in the singleton detection task, $\beta = -0.059$, $SE = 0.061$, $z = -0.970$, $p = .834$.

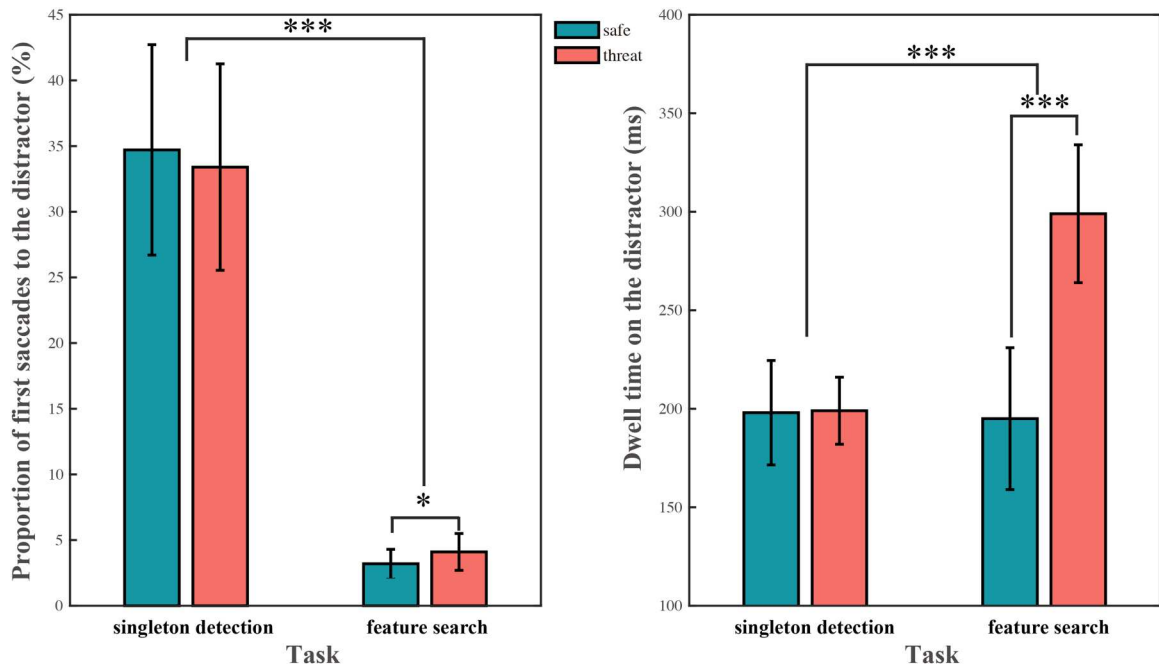


Figure 4. Comparisons on first fixation proportions on the distractor (left) and the dwell time on the distractor (right).

Note: The specific values are based on marginal estimates by emmeans function. Error bars indicate the 95% confidence intervals of the marginal estimates. * $p < .05$, *** $p < .001$.

The LMM analysis on the dwell time on the distractor (see Figure 4 right panel) showed a significant interaction effect of Block and Task, $\beta = 101.888$, $SE = 18.053$, $t(2131.55) = 5.644$, $p < .001$. Post-hoc tests revealed a significantly increased dwell time on the distractor during the threat compared to the safe condition in the feature search task, $\beta = 103.62$, $SE = 17.11$, $t(2135) = 6.056$, $p < .001$, but not in the singleton detection task, $\beta = 1.74$, $SE = 5.97$, $t(2135) = 0.29$, $p = .771$.²

Discussion

This study examined how the threat of shock-induced state anxiety influenced salience-driven oculomotor capture in both the singleton detection task and the feature search task. Results showed that during safe blocks, the salient distractor captured attention in the singleton detection task, but not in the feature search task. In the singleton detection task, saccade latency to the target increased in the presence of a distractor and the proportion of correct saccades decreased. In contrast, no evidence of attentional capture was observed in the feature search task, which is in line with previous research (Bacon & Egeth, 1994). These results indicate that participants adjusted their search strategy based on task demands, resulting in attentional capture during singleton detection and no capture during feature search. Increased state anxiety did not modulate saccade latency or proportions of saccades directed to the target in either task. However, it did affect distractor processing differently depending on the task. State anxiety increased oculomotor capture and prolonged dwell time on the distractor in the feature search task, but not in the singleton detection task.

The findings from the feature search task suggest that state anxiety may not have affected the overall search strategy per se, but rather the specific process of rejecting the salient distractor and disengaging from it. This interpretation aligns with Attention Control Theory (ACT), which posits that heightened anxiety simultaneously enhances the processing of salient distractors and impairs goal-directed control (Berggren & Derakshan, 2013; Eysenck et al., 2007; Robinson et al., 2013). In the context of clump-based scanning, effective distractor rejection depends on matching local item groups to a top-down template and rapidly excluding non-matching items (Liesefeld & Müller, 2020). Our results, showing increased

oculomotor capture and prolonged dwell time on distractors under threat, suggest that state anxiety may impair these template-driven rejection and disengagement processes. This would imply that feature search relies more on top-down controlled template-driven rejection and disengagement mechanisms than singleton detection search and hence is more vulnerable to heightened state anxiety.

The lack of effect of state anxiety in the singleton detection task may seem surprising, given previous evidence that anxiety heightens salience-driven attentional capture (Gutierrez & Berggren, 2020; Kim & Anderson, 2020). However, a closer examination of Gutierrez and Berggren (2020) reveals that their task involved a fixed target shape (diamond), which may have encouraged participants to use a singleton detection or a feature search strategy (Leber & Egeth, 2006). Thus the enhanced distractor cost under threat in their study may not solely reflect amplified salience-based priority guidance, but could also indicate that state anxiety disrupted template-based rejection processes associated with feature-guided search. This interpretation is consistent with our findings from the feature search task. One potential explanation for the lack of threat effects in our singleton detection task is carry over, in which threat-induced anxiety might persist into safe blocks in within-subject designs. Indeed, Kim and Anderson (2020) found no difference in oculomotor capture between threat and safe blocks in a within-subject comparison (Experiment 4), but did observe stronger capture under threat in a between-subject comparison (Experiments 4 and 5). However, our data argue against this account. Both subjective anxiety ratings and skin conductance responses were significantly higher in threat than in safe blocks, indicating that anxiety did not transfer from threat to safe blocks. Instead, it is possible that priority guidance in singleton detection is already dominated by salience, leaving little room for further amplification by anxiety. The discrepancies in distractor processing between singleton detection and feature search tasks highlight the complexity of attentional mechanisms under anxiety. The interaction between threat anticipation and attentional control can yield different outcomes depending on task demands and contextual factors.

In summary, heightened state anxiety selectively disrupted distractor processing during feature search, while having no measurable effect during singleton detection. This dissociation highlights the

complexity of the relationship between anxiety and attentional mechanisms, which may be shaped by specific task characteristics. By examining a range of experimental paradigms, researchers can better understand how anxiety influences attentional processes. Such insights may inform the development of more effective interventions for individuals experiencing heightened anxiety.

Notes

1. Depending on which interaction reached significance, *p*-values were adjusted for multiple tests: four tests in the case of a significant two-way interaction and eight tests in the case of a significant three-way interaction.
2. The results remained significant when including participants who had sufficient trials in both the singleton detection task and the feature search task (see Supplementary material D).

Disclosure statement

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

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