Adaptive suppression of threat-history stimuli

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Abstract: The present study investigated whether adaptive suppression mechanisms can be applied to stimuli with a history of threat association. In the experiment, a threat-conditioning task was first used to associate one of two colors—green or cyan—with an electric shock, thereby establishing conditions of threat-history and no-threat-history. Subsequently, in a visual search task, 30 participants reported the orientation of the line inside the target diamond while occasionally being either undistracted or distracted by threat-history or no-threat-history distractors, which appeared across various spatial locations. The results showed that distractors appearing at high-probability locations were effectively suppressed, with suppression being stronger for threat-history distractors than for no-threat-history distractors. These findings indicate that threat history may facilitate visual search through an adaptive attentional suppression mechanism.

Keywords: attentional suppression; threat history; statistical learning

1 Introduction

In our everyday environment, the ability to detect and adapt to statistical regularities plays a fundamental role in guiding attention and behavior. This form of implicit learning, commonly referred to as statistical learning, enables individuals to anticipate the occurrence of events and allocate cognitive resources efficiently, even in the absence of explicit awareness(Fiser & Aslin, 2001; Turk-Browne et al., 2005). Recent research has demonstrated that statistical learning can occur across various domains—visual, auditory, and spatial—and operates automatically in response to environmental structures(Fiser & Lengyel, 2022; Theeuwes et al., 2022).

Although salient distractors typically capture attention(Lin et al., 2024; Theeuwes, 2010, 2025), recent studies have shown that the attentional capture of physically salient distractors (e.g., color and size singletons) can be effectively suppressed when distractors more likely to appear in a specific location in the visual field(Wang & Theeuwes, 2018a, 2018b). Importantly, this suppression is saliency-dependent, meaning that it is adaptively modulated according to the salience of the distractor, with greater suppression applied to more salient distractors(Failing & Theeuwes, 2020; Gong & Theeuwes, 2021). Meanwhile, previous studies have shown that stimuli with a history of threat-related can capture more attention than

neutral stimuli even when presented as task-irrelevant distractors(Anderson & Britton, 2020; Burra et al., 2019; Schmidt et al., 2015; Vuilleumier, 2005; Watson et al., 2019; Zsidó et al., 2023). However, whether adaptive suppression mechanisms apply to emotionally salient, threat-related stimuli remains an open question.

Recent studies using a two-phase design—first establishing location-based suppression with neutral distractors, then introducing threat-related distractors at the same location—have found that suppression either fails to persist(Kim & Anderson, 2021; Ogden et al., 2023) or remains comparable to that for neutral stimuli(Theeuwes et al., 2025; Theeuwes & van Moorselaar, 2025). Notably, there is no evidence that threatening distractors elicit stronger suppression at previously suppressed locations. One possible explanation is that location-based suppression and threat-related suppression were learned in separate phases, potentially limiting their integration. In contrast, the one-phase design—where both types of information are learned concurrently—has been established as a reliable approach for examining adaptive suppression, particularly in studies involving physically salient distractors(Failing & Theeuwes, 2020; Gong & Theeuwes, 2021).

Therefore, the present study used a one-phase paradigm in which both threat-history and spatial information were continuously associated with

distractors. This design allowed participants to concurrently acquire both types of associations, thereby providing a more robust test of the adaptive suppression of these influences. Specifically, we investigated whether individuals are better able to suppress threat-history distractors when these appear at statistically predictable (i.e., high-probability) locations during a visual search task.

2 Method

2.1 Participants

Participants were recruited from the subject pool of Guizhou Normal University. The study was approved by the Committee on Human Research Protection of the School of Psychology, Guizhou Normal University (IRB approval number: GZNUPSY.NO2022E [007]). All participants provided informed consent in accordance with the Declaration of Helsinki. The sample size was determined using G*Power to achieve a power of 0.80 and an alpha level of 0.05. Based on parameters reported by Kim and Anderson (2021) and Le Pelley et al. (2022) regarding the effects of distractor category (threat-history vs. no-threat-history) and distractor location (high vs. low probability), the minimum required sample size was set at 29 participants. We collected data from 33 participants, of whom three were excluded from the final analysis (see details below), resulting in a final sample of 30 participants (17 females, M_{age} = 21, range = 19–27) who

participated in return for monetary compensation.

2.2 Apparatus

Screen luminance and color were measured and calibrated using the PsyCalibrator toolkit and SpyderX (Lin et al., 2023), and the calibrated parameters were applied during the stimulus presentation phase of the experiment. An Lenovo computer running MATLAB (2020b) and Psychtoolbox 3.0 generated the stimuli on a 21.5-inch LCD screen with a resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. All stimuli were presented on a black background (RGB: 5, 5, 5) at a viewing distance of 72 cm. All data supporting the findings are openly available via the Science Data Bank (https://www.scidb.cn/anonymous/VlpqNm55).

2.3 Task, Stimuli, and Procedure

Shock work-up task: A multi-channel electrical stimulator (type: SXC-4A, Sanxia Technique Inc., Beijing, China) was attached to participants' left wrist delivered through a pair of Ag/AgCl surface electrodes. Shock intensity was individually calibrated for each participant to reach a level rated as highly annoying but not painful—specifically, a score of 8 on a subjective discomfort scale ranging from 0 to 10.

Threat conditioning task: As visualized in Figure 1A, the threat conditioning task consisted of three phases: habituation, acquisition, and

extinction(Bach et al., 2023). In each trial, one of two colors—green (RGB: 0, 73, 0) or cyan (RGB: 0, 71, 71)—was randomly assigned as the CS+ (CsP, paired with electric shock) or CS− (CsM, not paired with shock), with color-condition assignments counterbalanced across participants. Throughout all phases, participants were instructed to passively observe the stimuli without making any responses. The habituation phase included 4 trials: 2 CS+ trials (no shock) and 2 CS− trials. Each trial began with a 500 ms white fixation point, followed by an 8000 ms CS presentation. The acquisition phase consisted of 16 trials: 8 CS+ (6 with electrical stimulation, 2 without) and 8 CS−. The trial structure was identical to the habituation phase, with inter-trial intervals (ITIs) randomly varying from 9000 to 15000ms. Electrical shocks in CS+ trials were administered at the intensity determined during the shock work-up task. No shocks were administered in the remaining CS+ or any CS− trials. The extinction phase included 40 trials: 20 CS+ and 20 CS−, all without electrical stimulation. Trial structure and ITIs remained consistent with the acquisition phase.

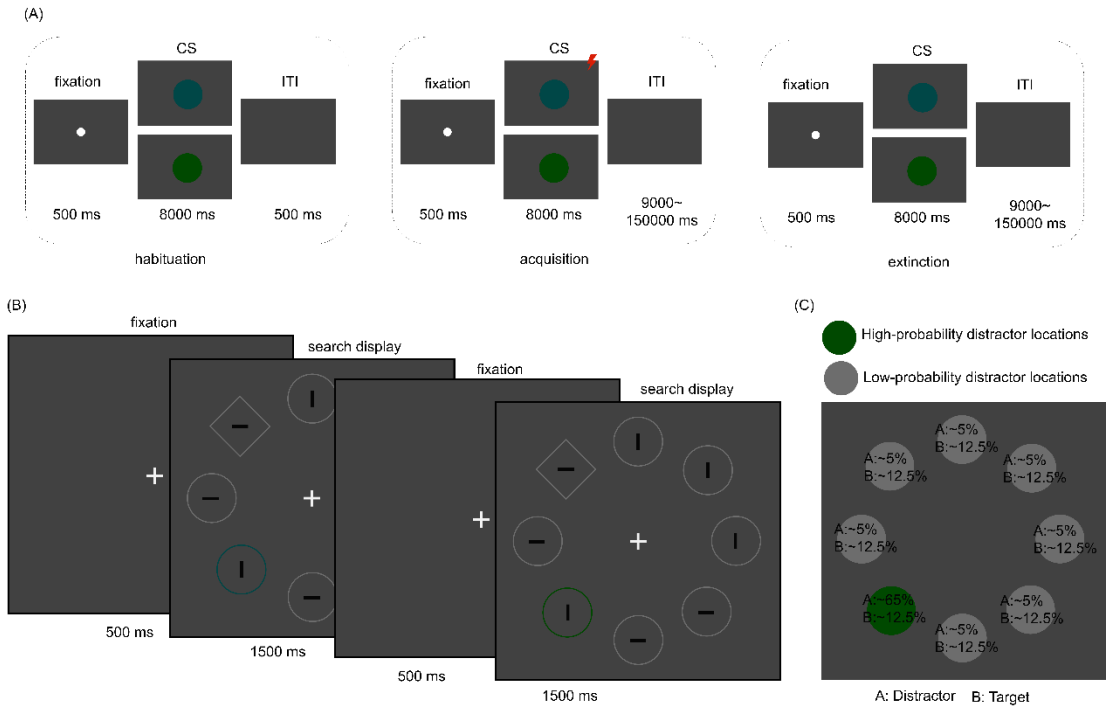
Visual search task: As visualized in Figure 1B, each trial began with a central fixation cross presented on a black background. After 500 ms, a search display appeared and remained on screen until response or a 1500 ms timeout. The display contained eight equally spaced shapes (one diamond and seven circles), arranged on an imaginary circle (radius = 4.5°)

centered on fixation. Each shape contained a gray line segment (RGB: [70, 70, 70]) oriented either horizontally or vertically, randomly assigned. Participants reported the orientation of the line inside the target diamond by pressing either the "s" or "k" key, with key assignments counterbalanced across participants. They were instructed to respond as quickly and accurately as possible. In two-thirds of the trials, one non-target shape was replaced by a singleton color distractor (either green or cyan). The threat relevance of each color singleton (i.e., whether it had a threat history or no-threat history) was determined during the prior threat conditioning task. Critically, As visualized in Figure 1C, although the target appeared equally often in all locations, each color singleton distractor was more frequently presented at one specific location, defined as the high-probability distractor location (~65%). The high-probability location was randomly assigned for each participant. Before beginning the formal task, participants completed 20 practice trials and were required to achieve at least 85% accuracy to proceed. The experimental session consisted of 16 blocks, each containing 56 trials: 20 trials with threat-history distractors, 20 with no-threat-history distractors, and 16 distractor-absent trials.

Post-task Awareness Assessment: After completing the visual search task, participants answered a series of questions assessing their awareness of the spatial distribution of distractors. They were first asked whether they

had noticed any spatial imbalance in distractor occurrence. Then, they were required to indicate the location with the highest distractor probability for both the threat-history and no-threat-history distractors.

Figure 1 *Experimental Paradigm*



Note. (A) Example of the threat conditioning task. The task consisted of three distinct phases. *Habituation Phase*: Participants are exposed to the CS+ and CS− without any shocks to establish a neutral baseline. *Acquisition Phase*: The CS+ is followed by the shock on a majority of trials (i.e., 75%), while the CS− remains unpaired. *Extinction Phase*: Both the CS+ and CS− are presented again, but no shocks are delivered. This phase examines how quickly the learned fear response diminishes. (B)Example trial sequence of the visual search task. Each trial began with a fixation display, followed by a search display in which participants indicated the orientation (horizontal or vertical) of the line inside the target diamond. In two-thirds of the trials, one non-target shape was replaced by a singleton color distractor (either green or cyan). (C) Schematic

representation of the spatial regularities of distractor presentation. Percentages at each location indicate the probability of the distractor or target appearing in that location throughout the task. See the online article for the color version of this figure.

2.4 Data recording and Statistics

During the visual search task, participants' response times and accuracy were recorded. Behavioral data analyses were conducted in R using RStudio. Prior to analysis, response time (RT) data were preprocessed according to the following steps: (1) The first two trials of each block were excluded; (2) Trials with incorrect responses were removed; (3) Trials with RTs shorter than 200 ms were excluded; (4) Trials with RTs exceeding ±2.5 standard deviations from the mean were discarded; and (5) Participants with fewer than 70% of total trials remaining after preprocessing were excluded from further analysis.

Following preprocessing, mixed-effects linear modeling of RTs was performed using the lme4 and lmerTest packages(Kuznetsova et al., 2017). In the distractor-absent trials, a mixed-effects linear model was constructed with distractor location probability (LocP) as a fixed factor and RT to the target stimulus as the dependent variable. Subject was included as a random effect to account for inter-individual variability. The model was specified as: $\mathrm{RT} \sim \mathrm{LocP} + (1 \mid \mathrm{Subject})$. In the distractor-present trials, the model included both location probability and distractor category (CS)

as fixed factors, with RT as the dependent variable and subject as a random effect. The model was specified as: $\mathrm{RT} \sim \mathrm{CS} * \mathrm{LocP} + (1 \mid \mathrm{Subject})$. To determine whether differences between conditions or levels were statistically significant, post-hoc comparisons were conducted using the emmeans package, with multiple comparisons corrected using the Tukey method.

To further assess how the development of the learned suppression effect differed between threat-history and no-threat-history distractors, we calculated the proportion of the interference reduction (*P*), as calculated by the formula below, represents the ratio of the reduction in reaction time (RT) from the low-probability location (LPL) to the high-probability location (HPL) relative to the RT at the LPL: $P = (RT_{LPL} - RT_{HPL}) / RT_{LPL}$. A larger value of *P* indicates a stronger learned suppression effect.

3 Results

The present study was designed to examin whether adaptive suppression mechanisms can be applied to stimuli with a history of threat association. Therefore, we first examined whether the spatial distractor imbalance led to a learned suppression effect at high-probability locations during distractor-absent trials. As visualized in Figure 2A, the results showed a main effect of distractor location, $F_{(1, 6655.12)} = 45.08$, $p < 0.01$. Responses were significantly slower, when the target appeared in the high-

probability distractor locations than in the average of the low-probability distractor locations, b = -38.2, SE = 5.69, z = -6.72, d = 0.25. The results indicates a robust learned spatial suppression effect at high-probability locations.

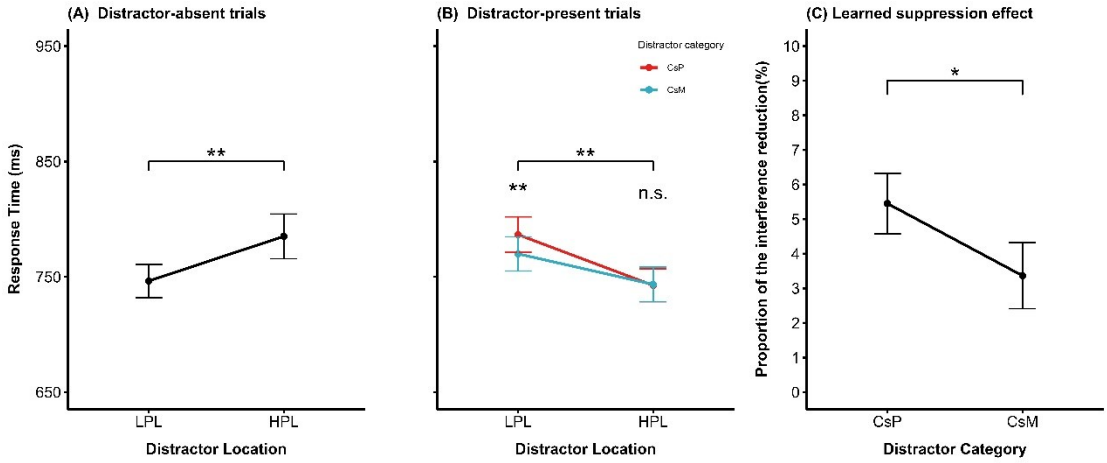
Building on this, we next examined whether the development of this effect differed between threat-history and no-threat-history distractors. As visualized in Figure 2B, the results showed a main effect of distractor location, $F_{(1, 16606.05)} = 177.60$, $p < 0.01$, target search was faster when the distractor appeared at high-probability locations compared to the average of the low-probability locations, b = 35.40, SE = 2.65, z = 13.33, d = 0.22, and a main effect of distractor category, $F_{(1, 16606.06)} = 8.73$, $p < 0.01$, threat-history distractors elicited slower responses than no-threat-history distractors. b = 7.84, SE = 2.65, z = 2.96, d = 0.05. Crucially, there was significant interaction, $F_{(1, 16606.05)} = 10.93$, $p < 0.01$, between these two factors. Further analysis revealed that target search was slower when threat-history distractors appeared at low-probability locations compared to no-threat-history distractors, b = 16.61, SE = 4.29, z = 3.87, $p < 0.01$, d = 0.10, with no difference observed at high-probability locations, b = -0.93, SE = 3.13, z = -0.30, p = 0.99. Target search was faster when distractors appeared at high-probability locations compared to low-probability locations (threat-history distractors: b = 44.14, SE = 3.76, z = 11.73, p <

0.01, $d = 0.27$; no-threat-history distractors: $b = 26.60$, $SE = 3.74$, $z = 7.11$, $p < 0.01$, $d = 0.16$).

Moreover, As visualized in Figure 2C, the results showed that the proportion of interference reduction for threat-history distractors (5.45%) was significantly greater than that for no-threat-history distractors (3.36%), $t_{(29)} = 2.19$, $p = 0.04$, $d = 0.40$.

There was little evidence of explicit awareness of the distractor location regularity. Ten participants reported not noticing that the distractor appeared more or less frequently at a specific location, with an average confidence rating of 4.40 (on a 1–7 scale). The remaining 23 participants indicated that they had noticed a spatial imbalance, with an average confidence rating of 4.26. However, none of these 20 participants correctly identified the high- or low-probability locations as defined in the experiment. These results suggest that the learned suppression effect was unlikely to be driven by explicit awareness.

Figure 2 *Learned spatial suppression is stronger when threat-history distractors appear at high-probability locations.*



Note. (A) Mean RT in the visual search for distractor-absent trials, as a function of whether the target appeared in the high-probability distractor location versus the average of the low-probability distractor locations. (B) Mean RT in the visual search task as function of distractor location (x-axis) and as a function of distractor category (CsP, CsM). (C) The proportion of reduction in interference (from the LPL to the HPL) for different distractor category. All error bars represent within-subjects standard error of the mean. LPL = low-probability distractor locations; HPL = high-probability distractor locations; CsP = threat-history distractors; CsM = no-threat-history distractors. ** indicates $p < 0.01$, * indicates $p < 0.05$, and n.s. indicates not significant ($p > .05$). See the online article for the color version of this figure.

4 General Discussion

The present study shows that threat-history distractors can be attentionally suppressed, with a stronger suppression effect for threat-related stimuli. First, the results from the distractor-absent trials confirm that participants developed a learned suppression effect at high-probability

distractor locations relative to other locations, consistent with previous research(Failing et al., 2019; van Moorselaar et al., 2020, 2021; Wang et al., 2019). Moreover, our threat conditioning task was effective, as threat-history distractors elicited stronger attentional capture than no-threat-history distractors following conditioning—a pattern consistent with previous studies employing similar methods (Schmidt et al., 2015). Critically, regardless of threat history, distractors appearing at high-probability locations can be effectively suppressed, with the suppression being stronger for threat-history distractors than for no-threat-history distractors.

The current findings extends prior work showing that learned suppression can be saliency-specific (Failing & Theeuwes, 2020) and adaptively modulated depending on distractor properties(Gong & Theeuwes, 2021). While previous research has emphasized the independence of valence learning and statistical learning in shaping attentional priority(Kim & Anderson, 2021; Le Pelley et al., 2022; Ogden et al., 2023), our results provide novel evidence for an interaction between threat valence and spatial regularity: threat modulates the effectiveness and magnitude of learned suppression. This contrasts with findings by Kim and Anderson (2021), who reported additive but independent effects of punishment history and distractor location. A possible reason for this

discrepancy is that our paradigm directly manipulated emotional relevance at the level of distractor category and systematically tested its interaction with spatial suppression.

Moreover, recent studies have shown that fear-associated salient distractors (e.g., spiders or fear-conditioned stimuli) can still be suppressed through statistical learning(Theeuwes et al., 2025; Theeuwes & van Moorselaar, 2025), the present study provides further evidence of an adaptive attentional suppression mechanism that extends to threat-related stimuli. Previous research suggests that controllability influences individuals' attentional bias toward threat stimuli(Bishop et al., 2004; Limbachia et al., 2021; Wood et al., 2015). When threat-related distractors appear at high-probability locations, individuals' sense of control over these distractors is enhanced, facilitating more effective attentional suppression. This pattern is consistent with the notion that the visual system integrates both salience and motivational relevance into a unified priority map(Gaspelin & Luck, 2018; Pearson et al., 2022), and further indicates that the suppression mechanism is not fixed but dynamically modulated by prior affective experience(Anderson et al., 2021).

Although the present study shows that threat history facilitates visual search, several limitations should be acknowledged. First, we did not examine the temporal dynamics of suppression development using neural

measures such as ERP components (e.g., PD or N2pc), which would help identify whether threat modulates early attentional selection or later suppression mechanisms(Gaspelin et al., 2023; Lin et al., 2024; Nobre & Ede, 2023; Zhang et al., 2025). Second, it would be valuable to explore whether passive exposure to threat-related stimuli, as examined in habituation paradigms(Won & Geng, 2020), yields similar modulation of learning-based suppression.

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Conflicts of interest

The authors declare that they have no competing interests.

Ethics approval

The study was approved by the Committee on Human Research Protection of the School of Psychology, Guizhou Normal University (IRB approval number: GZNUPSY.NO2022E [007])

Consent to participate

All participants provided informed consent in accordance with the Declaration of Helsinki.

Consent for publication

The article has been approved by all authors for publication.

Availability of data and materials

All data supporting the findings are openly available via the Science Data Bank (https://www.scidb.cn/anonymous/VlpqNm55).

Code availability

The analysis code supporting this study will be made publicly available on the Science Data Bank after publication.

Authors' contributions

Jingqing Nian served as lead for data curation, formal analysis, and validation and contributed equally to conceptualization, writing–original draft, and writing–review and editing. Yu Zhang served as lead for conceptualization, supervision, and writing– review and editing. Yu Luo served as lead for conceptualization, funding acquisition, supervision, writing–original draft, and writing–review and editing.

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