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Can the processing of task-irrelevant threatening stimuli be inhibited? – The role of shape and valence in the saliency of threatening objects

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ABSTRACT

Numerous studies have demonstrated that attention is quickly oriented towards threatening stimuli, and that this attentional bias is difficult to inhibit. The root cause(s) of this bias may be attributable to the affective (e.g., valence) or visual features (e.g., shape) of threats. In two experiments (behavioral, eye-tracking), we tested which features play a bigger role in the salience of threats. In both experiments, participants looked for a neutral target (butterfly, lock) among other neutral objects. In half of the trials a threatening (snake, gun) or nonthreatening (but visually similar; worm, hairdryer) task-irrelevant distractor was also present at a near or far distance from the target. Behavioral results indicate that both distractor types interfered with task performance. Rejecting nonthreatening distractors as nontargets was easier when they were presented further from the target but distance had no effect when the distractor was threatening. Eye-tracking results showed that participants fixated less often (and for less time) on threatening compared to nonthreatening distractors. They also viewed targets for less time when a threatening distractor was present (compared to nonthreatening). Results suggest that visual features of threats are easier to suppress than affective features, and the latter may have a stronger role in eliciting attentional biases.

1. Introduction

The highly salient nature of threatening stimuli has long been recognized in a variety of psychological literatures. Many studies (Becker et al., 2011; Blanchette, 2006; Coelho et al., 2019; LoBue, 2010; Subra et al., 2017; Williams et al., 2006; Zsido, Csatho, et al., 2019; Zsido, Deak, & Bernath, 2019) have observed faster reaction times to threatening compared to neutral stimuli (across a variety of tasks). Threatening objects are more salient not just when compared to neutral objects but also to stimuli of different valences, such as positive or negative nonthreatening items (Csathó et al., 2008; March et al., 2017; Williams et al., 2006; Zinchenko et al., 2017; Zsido, Bali, et al., 2022). This is likely because the perception of threats is an implicit (i.e., automatic) process that precedes other implicit (e.g., processing of valence) and explicit processes (e.g., evaluation) (March et al., 2018). This initial implicit processing is sensitive to both evolutionarily relevant threats, such as dangerous animals or situations (e.g., snakes, heights), and to acquired ones (e.g., guns, social groups). Hastened detection is made possible via the *brainstem-amygdala-cortex* neural alarm system (Liddell et al., 2005). Through this pathway, stimuli are evaluated without overt effort, resulting in fast orienting behaviors. This can equally occur in and out of attentional focus. In prior work (Bayle et al., 2009), quickened responses to threatening stimuli were observable even when the threatening item was presented in the peripheral visual field. However, to date, we still do not know whether visual features (e.g., shape) of the threatening stimuli alone are sufficient to trigger the hastened processing that precedes all subsequent processing.

According to *general feature detection theory,* threatening stimuli are salient because of their specific *visual* features, such as their shape, movement, or skin pattern (Coelho & Purkis, 2009; Davey, 1995). For instance, an EEG study (Van Strien & Isbell, 2017) showed that close-up pictures of snakeskin patterns elicit larger early posterior negativity compared to lizard skin and bird plumage pictures. Similarly, a recent behavioral study (Berggren, 2022) found delayed reaction times when the color associated with angry expressions reappeared as a task-irrelevant distractor during a visual search task. Colors associated with nonthreatening expressions (i.e., neutral and happy) did not produce the same result.

Shapes associated with various threats also seem to be more salient than other visual features. A curvilinear shape (such as the body of a

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snake) can be considered one of these salient features that is detected automatically, facilitating immediate response to threats. Indeed, multiple studies have shown that curvilinear shapes are detected faster in visual search tasks compared to straight or zigzag lines (LoBue et al., 2014; Van Strien et al., 2016; Wolfe et al., 1992). Adding to the importance of shape as a visual feature, an advantage in processing for downward pointing Vs (which has geometrical resemblance to the heads of snakes) has also been observed (Larson et al., 2007). The advantage of certain visual features strongly associated with threats may be caused by the valence and arousal the shape evokes. Nevertheless, the *general feature detection theory* contends that the initial implicit processing of threats is triggered by visual features such as shape and, therefore, a neutral object that is visually very similar to a threat (such as a worm) should elicit a similar advantage in processing.

By contrast, the *fear module theory* (Mineka & Öhman, 2002; Öhman & Mineka, 2001) postulates that the saliency of threatening objects is due to their *affective features* (i.e., valence and arousal elicited by the stimulus). And according to the *theory of arousal biased competition* (Mather & Sutherland, 2011), emotional arousal is able to modulate cognitive processes and mental representations in order to enhance memory and bias selective attention. Based on these accounts, the initial implicit processing of threats is triggered by the emotional features of the stimuli and, therefore, an emotionally neutral object that is visually similar to a threat should not have the same advantage in processing as an actual threat.

It is certainly possible that particular visual features (such as shape) have an advantage because they evoke the same emotional valence and arousal as the actual threats they are resembling (Anderson & Kim, 2019; Le Pelley et al., 2017; Schmidt et al., 2015). For instance, a previous study (Schmidt et al., 2015) examined the automatic capture of attention by physically salient stimuli and emotionally significant stimuli. Specifically, the authors investigated whether a salient neutral stimulus (a colorful diamond shape), when associated with fear through conditioning, could capture attention in visual search. The experimental procedure involved pairing one stimulus (CS+) with an electrical shock, while another stimulus with the same physical characteristics (CS-) was never paired with a shock. After conditioning, participants performed a target search task, where irrelevant CS+ or CS- stimuli were occasionally presented. The findings revealed that the presence of an irrelevant distractor previously associated with fear significantly impaired search performance compared to a distractor lacking fear association. These results suggest that fear associations learned through conditioning have the power to capture attention, even when individuals attempt to disregard them. However, it is equally important to investigate the ecological validity of these findings (to ensure their applicability and generalizability to real-world contexts) by using natural fear associations instead of conditioned ones.

In a recent study of ours (Zsido, Stecina, & Hout, 2022), we investigated the impact of threat and visual similarity on target discrimination. Participants completed a Rapid Serial Visual Presentation task, where the stream consisted of threatening and visually similar (but nonthreatening) objects. During the task, participants were presented with six pictures under four different conditions: (1) pictures with the same arousal and shape (e.g., hairdryers), (2) pictures with the same arousal but different shapes (guns and snakes), (3) pictures with different arousal but similar shapes (guns and hairdryers), and (4) pictures with different arousal and dissimilar shapes (snakes and hairdryers). After each RSVP stream, participants saw two pictures and had to choose which one appeared in the stream (i.e., the target). Our results showed that when shape was a sufficient feature by which to discriminate the target from the other items in the stream (e.g., a snake among hairdryers), there was no effect of arousal on performance. Thus, shapes associated with threat alone (irrespective of affective value) yielded faster responses. Participants did rely on arousal, however, when all the stimuli in the stream were visually similar (e.g., a snake among worms). Working memory was less impaired in the dissimilar conditions which could have made the discrimination easier. However, this prior study was concerned with the competition for visual working memory resources rather than elucidating the root cause of attentional biases to threats, per se.

Sawaki and Luck (Sawaki & Luck, 2010) more directly addressed attentional biases, though not in the context of threats. These authors propose a hybrid model to describe how the inhibition of an “attend-to-me” signal works when task-irrelevant *visually salient* (but emotionally neutral) distractors are present. The *signal suppression hypothesis* claims that a salient stimulus in the visual field creates its potentially attention-grabbing signal regardless of its relevance to the observer’s goals. This signal, however, can be actively suppressed by the observer before attentional capture with the help of top-down control (Sawaki & Luck, 2010, 2011). In their ERP study (Sawaki & Luck, 2010), participants were looking for a letter in one of two areas of the display; some trials included irrelevant color singletons and in the control trials, all letters were of the same green or red color. This arrangement was organized so that a red salient distractor was presented among green stimuli or vice versa. Task-irrelevant salient singletons did not create signals for attentional deployment (indicated by the N2 posterior contralateral signal) but they did elicit signals of attentional inhibition (indicated by a distractor positivity signal) both in the attended and unattended areas.

In a more recent eye-tracking study (Gaspelin et al., 2017), participants were instructed to report the orientation of a line within a target stimulus, which was placed among distractors of heterogeneous shapes, including one (salient) distractor of a different color. Singleton capture was discouraged by having participants look for the same target shape throughout the whole procedure. Results showed that it was less likely for the first fixation to land on the singleton distractor than on a non-singleton one (Gaspelin et al., 2017; Gaspelin & Luck, 2018). The authors also found that if active suppression of irrelevant singletons was promoted (simply by participants being told to ignore it), overt attentional shifts (i.e., oculomotor capture or direct fixation) to irrelevant salient singletons were less likely to happen than to non-salient distractors. Thus, we are clearly capable of attentional control through goal-directed, top-down mechanisms (Zinchenko et al., 2020). It has been suggested that goal-directed inhibition is capable of down-regulating the emotional reactions caused by the automatic evaluation of emotional (including threatening) cues (Mogg & Bradley, 2018). That said, it has yet to be shown whether or not such signal suppression mechanisms apply to the inhibition of emotionally salient (rather than visually salient) stimuli.

The neural basis of behavioral interference caused by threat cues (and their subsequent inhibition) can be well-observed with tasks whereby threatening stimuli are presented as task-irrelevant distractors. In one such ERP study (Burra et al., 2019), participants were asked to find a specific flower image among other similar flowers and either a neutral (leaf) or a threatening distractor (spider). In each trial, six stimuli were presented in a circle (following a centrally presented fixation cross). Behavioral interference (evidenced by slower RTs and lower accuracy) was larger when a threatening distractor was present compared to when a neutral one appeared. Although ERP results showed a posterior positivity for both distractors (indicating that both threatening and neutral distractors were inhibited by the participants), the inhibition was delayed (i.e., there was a longer offset latency of the P_D) for the spider distractors. The second experiment of the same study (Burra et al., 2019) excluded the possibility that the delayed suppression was due to visual differences between the spider and leaf distractors. In this experiment, although a similar display of six distractors was used, participants completed a foveal task where they had to find a missing pixel on the fixation cross, thereby reducing attention to the peripheral search display. Again, the amplitude of the posterior positivity was the same for the spider and leaf distractors, but the timing of suppression was different. These combined findings suggest that attentional selection and suppression combined, inducing the delay in suppression (Burra et al., 2019). That is, threatening stimuli can be inhibited, but at the cost of a delay relative to neutral distractors. However, we still do not know whether this attentional capture by threats is caused more by visual or affective features. Further, it is unclear how suppression operates across the entire visual field, as prior work did not manipulate the distance between distractors and the target.

In the present study, across two experiments, our overarching goal was to test whether attentional capture by threatening stimuli was more likely the result of the stimuli's visual or affective features. Further, we sought to test whether the distance between a distractor and the target has an effect on attentional orientation or inhibition. This second question is important because it has been previously shown that threatening (compared to neutral) stimuli presented outside the center of vision divert attentional resources otherwise dedicated to foveal processing (Carretié et al., 2017; Soares et al., 2017). On the one hand, visual features (such as shape) associated with threat have been shown to be sufficiently processed in peripheral vision (Gao et al., 2017). On the other hand, in an fMRI study (Almeida et al., 2015), amygdala activation was only observed for true snake pictures and not for fake ones (when both were presented in the periphery).

In Experiment 1, we used behavioral measures (reaction times and accuracy) in a visual search paradigm; and in Experiment 2 (as an extension of Experiment 1), we recorded eye movements to provide more insights into the underlying mechanisms responsible for attentional biases towards threats.[1] Our first hypothesis was that threatening objects (when employed as task-irrelevant distractors) are hard to inhibit primarily because of their affective features. Therefore, we predicted that distractors with affective features would have greater interference on task-performance, and that participants would fixate on them more (and for longer) compared to visually similar distractors without affective features. Our second hypothesis was that this effect would be independent of the distance between the distractor and the target when the distractor had affective features, but that when distractors were emotionally neutral (but visually similar to threats), the effect would decrease as the distance between targets and the distractor increased.

2. Methods

In Experiment 1, we used a standard visual search task similar to a previously published experiment (Hout et al., 2015). Participants had to locate a neutral target from a general category (i.e., a lock or butterfly) among scattered photographs of real-world neutral objects (e.g., a ball, a doll, a dog). In half of the trials, one of the distractors was a "special distractor" belonging to either a *threatening* category (snake, gun) or a *nonthreatening* category that was visually similar to the threatening categories (worm, hairdryer). For ease of exposition, the latter category will be referred to as nonthreatening distractors. Participants did not have knowledge about this manipulation. We also manipulated the distance between the target and the special distractor by having it presented close to or far from the target location. Experiment 2 was an extension of Experiment 1 that added the monitoring of eye-movements. In Experiment 1, participants completed the task in small groups (but at separate computer stations) and we only recorded reaction times (RTs). In Experiment 2, participants were assessed individually, and we recorded their eye-movements throughout the task.

2.1. Participants

The required sample size for this experiment was determined by computing estimated statistical power based on previous studies of singletons and threat suppression (Burra et al., 2019; Gaspelin et al., 2017; Gaspelin & Luck, 2018). The analysis ($f = 0.25$, $1\text{-}\beta > 0.95$, $r = 0.5$) indicated that the minimum required total sample size was 28. In our study, however, we wanted to examine an interaction between two factors which has not been done in these previous studies. Thus, our goal was to oversample, and we therefore collected data in one-week increments until the required sample size was exceeded. In Experiment 1, a total of 49 students (mean age = 19.9, SD = 1.52) participated.

The required sample size for Experiment 2 was determined based on the results (i.e., interaction effects) of Experiment 1. Estimated statistical power was computed with $f = 0.40$, $\beta > 0.95$, $r = 0.5$; the analysis indicated that the minimum required total sample size was 12. In Experiment 2, a total of 23 students participated (mean age = 20.1, SD = 1.43). Again, we sought to oversample (collecting data in one-week increments) because we collected eye-tracking data while in Experiment 1 we only observed behavioral results. Thus, both studies were adequately powered.

All participants were right-handed and reported normal or corrected-to-normal vision and normal color vision. Data from one participant in both experiments was excluded because of failure to follow instructions. All participants were recruited through university mailing lists and received course credit for participation. Data was collected in Hungary, at designated laboratories in the building of the Institute of Psychology, University of Pécs. Our research was approved by the United Ethical Review Committee for Research in Psychology of Hungary and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided written informed consent.

2.2. Experimental stimuli and design

We created a visual search task using images downloaded from the Massive Memory Database (Brady et al., 2008; Hout et al., 2014) as neutral distractors and targets, and sourced a total of 64 images from the internet and from a previous study (Zsido, Stecina, & Hout, 2022) as special distractors. Half of these were threatening (snakes, guns) and the other half were nonthreatening (worms, hairdryers) objects. All images were resized to a maximum of 100 × 100 pixels (2.17° visual angle), maintaining the original proportions. For each trial, the 1920 × 1080 resolution screen was divided into four quadrants and each quadrant was divided into a 3 × 3 matrix of 9 equal-sized cells. Images were placed in 8 of the 9 cells (per quadrant; total set size was 32) quasi-randomly[2]; image locations were randomly jittered within each cell in keeping with prior research (Hout et al., 2015; Hout & Goldinger, 2010, 2012, 2014) to give the appearance of scattering. This gave the overall appearance (to the participant) of a random assortment of pictures that was nevertheless controlled to ensure equal distribution of images across the screen, with no overlap of items (see Fig. 1). Half of the trials were target-present and half were target-absent.

The crucial manipulation was that in half of all trials, a "special" distractor appeared in the form of a threatening or non-threatening (but visually matched) object. We selected the threatening and non-threatening stimuli to be as visually similar as possible in terms of overall shape, pose, color, texture, luminance, image sharpness, and visual complexity. The images were then judged by a group of 20 independent students; pictures flagged as not visually similar were not used in the experiments. We also manipulated the distance between the target and this special distractor (on target-present trials) by locating the item in different parts of the matrix. There were very slight overlaps between the distance conditions because the cells, just like the screen,

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[1] Due to a technical issue with the software used to record the experiment, we could not reliably extract button press results in Experiment 2, which precludes us from presenting them in this paper.

[2] Images appeared random to the participants but were generated following a nonrandom sequence. That is, we fixed the place of the target and special distractors, then filled up the rest of the cells with distractors. Special distractors were selected in a way that only one exemplar per category could appear and all categories were cycled through evenly across trials.

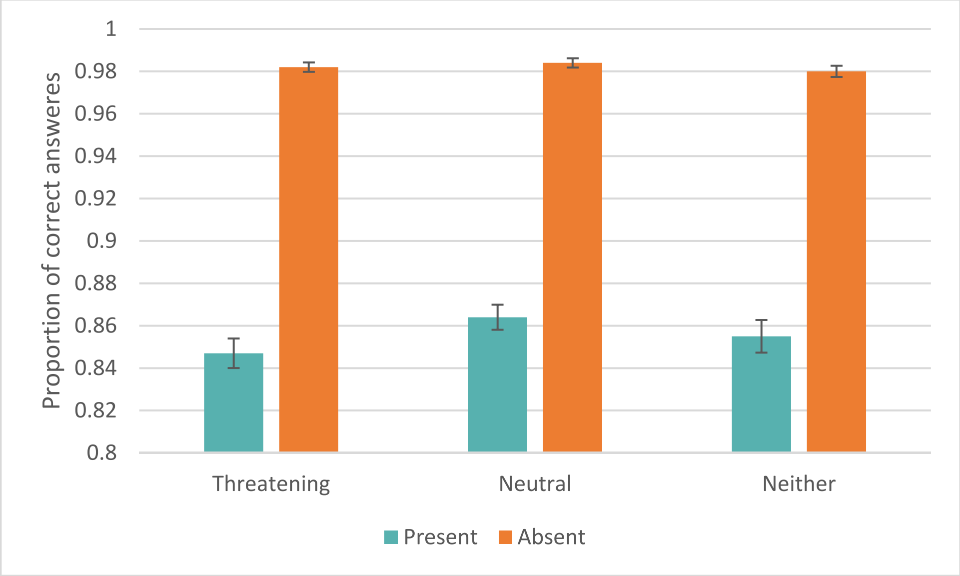

Fig. 1. The progression of events in a trial structure is shown in the top panel. First, a fixation cross was shown, then the visual search task was displayed until the participants indicated they had resolved their decision by pressing the spacebar. Last, a separate screen allowed them to indicate their present/absent decision. The bottom panel shows sample trials with special distractors sampled from the gun, hairdryer, snake, and worm conditions (clockwise starting from the top-left panel). Across panels can also be seen the various trial types: target-absent, target-present distractor close, target-present distractor far, and target-present distractor far, moving clockwise from the top-left panel). Please note that while we highlighted targets with green squares and distractors with red circles for better visibility here, they were not used during the experiment. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

were rectangular (meaning that the diagonal diameter of the cells was greater than their height) and the objects jittered in each cell. In the close condition, targets and special distractors were placed in neighboring cells; the distance between the center of the target and the distractor thus fell between 4.02° and 8.04°. In the far condition, targets and special distractors were placed two to four cells away from each other; the distance here ranged between 6.69° and 19.93°. (For a more detailed description of the sampling conditions, see Supplementary Material 1.)

2.3. Procedure

In Experiment 1, stimuli were presented and randomized using PsychoPy v3.0 software (Peirce, 2007). Data were collected in smaller groups, on up to 10 computers simultaneously (with identical hardware and software profiles) in a quiet room. Participants were seated in separated work-station booths, at approximately 60 cm in front of 21.5-inch LCD monitors with a resolution of 1920 × 1080, 16:9 aspect ratio, a refresh rate of 60 Hz, and color depth of 16.7 M. Experimental sessions were monitored by one research assistant. After verbal and written instructions, everyone completed a test-run of 10 trials (5 target-present, 5 target-absent) which were excluded from analysis. Participants could each ask questions before collectively starting the experiment. Participants completed two blocks of trials; in one block the search target was a lock and in the other it was a butterfly (order of blocks was counterbalanced across conditions).

Each trial started with a black fixation cross on white background appearing for 500 ms. Then, a search array was presented; participants were (earlier) instructed to react as quickly as possible and press the spacebar when they found the target or decided it was absent. After pressing the spacebar, the search array disappeared, and a question appeared on a blank screen prompting participants to report if they saw the target or not (‘y’ for ‘yes I saw the target’ and ‘n’ for ‘no I did not see the target’). Participants could give a yes/no answer by pressing the designated key respectively, without having to hurry. We used this response method similar to several previous studies (Hout et al., 2015; Hout & Goldinger, 2010, 2012, 2014) in order to separately (and more accurately) measure RTs, and to avoid mistakes stemming from mixing up the response keys. Participants were given the opportunity to take a couple of minutes of rest between the two blocks if they felt it was necessary. Each session of data collection lasted between 30 and 45 min.

In Experiment 2, the same stimuli were presented as in Experiment 1, presented on a 23-in. TFT color monitor, with a resolution of 1920 × 1080, 16:9 aspect ratio, a refresh rate of 60 Hz, and color depth of 16.7 M. Stimuli were presented using Tobii Studio Gaze Analysis Software. Eye-movements were recorded using a Tobii Pro TX300 at a sampling rate of 300 Hz. A five-point calibration was completed before the experiment. Calibration accuracy was checked manually and repeated if it was not judged to be successful by the experimenter. To minimize head movements and increase the precision of the tracker, participants placed their heads on a forehead and chin-rest throughout the experiment. Data was collected one participant at a time and participants were seated in a small, dark room, approximately 60 cm away from the screen. The procedure and the task were identical to Experiment 1. The sessions lasted approximately 40 to 50 min per participant.

2.4. Statistical analyses

Statistical analyses were completed using JAMOVI Statistics Program v2.0 (Jamovi Project, 2022). In Experiment 1, we examined RT and accuracy. Further, we computed Balanced Integration Scores (Liesefeld & Janczyk, 2019) which aim to control for the speed-accuracy trade-offs that are very common in visual search tasks and those using reaction time (RT) measurement in general. Balanced Integration Scores (BIS) integrates RTs and accuracy to show the relative performance and relative difficulty of the task (or condition). BIS is calculated by subtracting the standardized RT from the standardized proportion correct (PC) values (BIS = zPC–zRT). Lower BIS indicates worse performance and a harder task. In Experiment 2, we examined eye-tracking measures; in particular, the likelihood of fixation (i.e., the percentage of trials where the participant fixated the special distractor at least once) and total fixation duration on the special distractor (only including trials when there was at least one fixation). In all analyses presented here we focus on target-present trials (correct responses only). Regarding eye-tracking data, all trials with a special distractor present were analyzed. The minimum gaze time required for an eye movement to count as a fixation was set to 50 ms (the default setting for Tobii systems). Total fixation times were calculated on a trial-to-trial basis. Further analyses comparing *special distractor present and absent*, as well as *target present and absent trials* can be found in Supplementary Material 2.

We first identified and removed outlier trials, defined as those greater than ±2 standard deviations of the group mean (resulting in removal of <1 % of all the collected data) in each trial for each participant. We then checked to ensure that the distribution of the variables did not deviate significantly from a normal distribution (Saphiro-Wilk $ps < 0.05$). We performed 2 × 2 repeated measures ANOVAs to test the effect of Distractor Type (threatening, nonthreatening) and Distance from the Target (close, far) on performance and oculomotor measures. Statistical results are presented in tables rather than embedded in the text to make the description of the results easier to follow. Our dataset (including computed study variables) is available on the Open Science Framework: https://osf.io/5pazw/.

3. Results

3.1. Experiment 1

3.1.1. Accuracy

We began by examining accuracy to test our prediction that distractors with affective features would result in greater interference to task-performance compared to visually similar distractors without affective features. See Table 1 for all statistical results, and Supplementary Material 3 for the descriptive statistics. This question is tested via the main effect of Distractor Type, which was not significant.[3] Next, we tested our second hypothesis that this effect will be independent of the distance between the distractor and the target when the distractor had affective features, but that when distractors were emotionally neutral (but visually similar to threats), the effect would decrease as the distance between targets and the distractor increased. The main effect of Distance was significant; participants were less accurate when a special distractor was close to the target compared to when it was far. Fig. 2 shows the significant interaction between Distractor Type and Distance. For threatening distractors, the position of the distractor relative to the target did not affect the results. For nonthreatening distractors, participants were less accurate when the distractor was close to the target compared to when it was far.

3.1.2. Reaction time

We next examined reaction times to test our hypothesis that distractors with affective features would have greater interference on task-performance compared to visually similar distractors without affective features. See Table 1 for all statistical results, and Supplementary Material 3 for the descriptive statistics. Here, the main effect of Distractor Type was significant.[4] Participants were slower to find the target when there was a threatening distractor present compared to when a nonthreatening distractor was present. The main effect of Distance was also significant; participants were slower to find the target when a special distractor was close compared to when it was far. Then, we tested our second hypothesis that this effect will be independent of the distance between the distractor and the target when the distractor had affective features, but that when distractors were emotionally neutral (but visually similar to threats), the effect would decrease as the distance between targets and the distractor increased. The interaction between Distractor Type and Distance was significant. As shown in Fig. 3, the effect of distance was not significant for threatening targets, while nonthreatening distractors slowed participants when they appeared close to the target.

3.1.3. Balanced integration score

Finally, we examined BIS to help interpret the confluence of accuracy and RT. The main effect of Distractor Type was nonsignificant. The main effect of Distance was significant; the task was harder when a special distractor was close compared to when it was far. The interaction between Distractor Type and Distance was also significant. Fig. 4 shows that the effect of distance was not significant for threatening targets, while nonthreatening distractors only made the task harder for participants when they appeared close to the target.

Taken together, our first hypothesis was not entirely confirmed as we only found evidence of distractors with affective features having greater interference on task-performance compared to visually similar distractors without affective features when examining RTs but not when examining accuracy and BIS. However, our second hypothesis was confirmed insofar as the performance of participants was worse when a special distractor was close to the target or a threatening distractor was present, while the task was easier with a nonthreatening target presented far from the target.

3.2. Experiment 2

3.2.1. Likelihood of fixation on distractors

We began eye-tracking analysis by examining the likelihood of fixation on distractors to test our first prediction that participants would fixate on distractors with affective features more compared to visually similar distractors without affective features. See Table 2 for all statistical results, and Supplementary Material 3 for the descriptive statistics. The main effect of Distractor Type was not significant. Our second hypothesis was that this effect would be independent of the distance between the distractor and the target when the distractor had affective features, but that when distractors were emotionally neutral (but visually similar to threats), the effect would decrease as the distance between targets and the distractor increased. The main effect of Distance was significant; participants were more likely to fixate the special distractor when it was close to the target compared to when it was far from it. Fig. 5 shows the significant interaction between Distractor Type and Distance. Participants were more likely to look at both threatening and nonthreatening distractors when they appeared closer to the target. But this effect of distance was greater for nonthreatening compared to threatening distractors. There was no difference between the two types of distractors in the far condition.

3.2.2. Total fixation time on distractor

We next examined total fixation time on distractors to test our first prediction that participants would look longer at distractors with affective features more compared to visually similar distractors without affective features. The main effect of Distractor Type was significant. As displayed in Fig. 6, participants fixated nonthreatening distractors longer compared to threatening ones. Our second hypothesis was that this effect will be independent of the distance between the distractor and the target when the distractor had affective features, but that when distractors were emotionally neutral (but visually similar to threats), the effect would decrease as the distance between targets and the distractor increased. The main effect of Distance and the interaction between Distractor Type and Distance were not significant.

In sum, the results contradict our first hypothesis because

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[3] Further analyses comparing special distractor present and absent trials did not show a significant difference in accuracy between trials with affective feature distractors, visually similar distractors, and trials without such distractors. We present the analytic details in Supplementary material 2.

[4] Further analyses comparing RTs on special distractor present and absent trials showed that participants were slower when a distractor with affective features was present compared to trials with a visually similar distractor. The difference between the affective feature distractor and no special distractors present conditions, and the two neutral conditions did not differ from each other. We present the full analysis in Supplementary material 2.

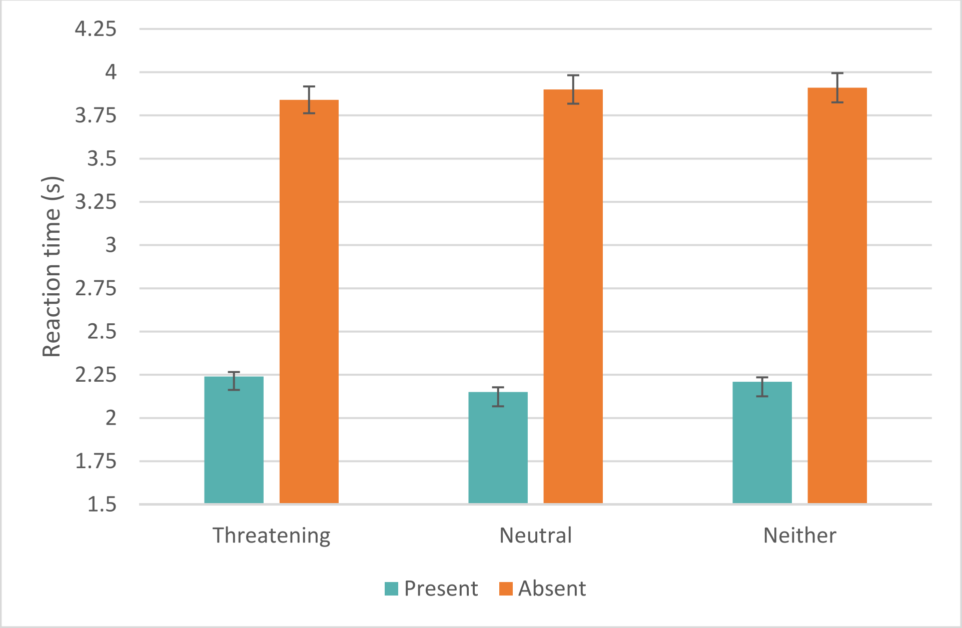

Fig. 2. Performance on the task as measured by the accuracy of identifying the target (when a special distractor was present). Findings are presented across Distractor Type (green and orange bars) and Distance from the Target. Error bars represent one standard error of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

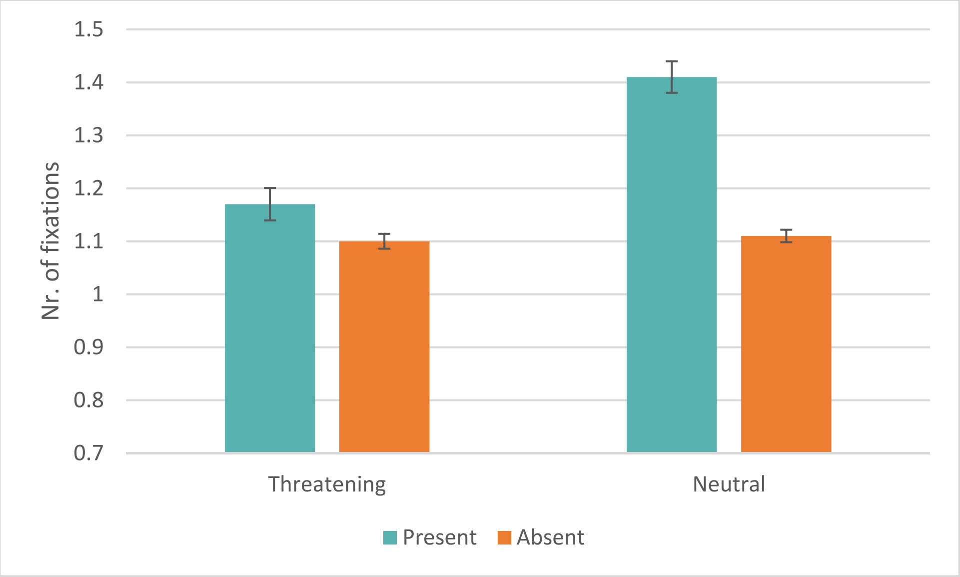

Fig. 3. Performance on the task as measured by the RT for finding the target (in seconds) on trials in which a special distractor was present. Findings are presented across Distractor Type (green and orange bars) and Distance from the Target. Error bars represent one standard error of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

participants were more likely to fixate and looked longer at nonthreatening compared to threatening distractors. Further, we could not confirm our second hypothesis either as both fixation likelihood and time decreased when special distractors were presented far compared to close to the target, and there was no difference between the two types of special distractors in the far condition.

4. Discussion

A large body of prior research (Becker et al., 2011; Blanchette, 2006; Coelho et al., 2019; Csathó et al., 2008; LoBue, 2010; March et al., 2017; Subra et al., 2017; Williams et al., 2006; Zsido, Csatho, et al., 2019; Zsido, Deak, & Bernath, 2019) has shown that threatening stimuli are highly salient, and thus, tend to be detected faster and more efficiently than neutral objects or those that elicit different emotions. Current theories (Coelho & Purkis, 2009; Davey, 1995; LoBue, 2014; Mather & Sutherland, 2011; Zsido et al., 2018) seem to disagree on whether this advantage is caused by the visual or emotional features of the objects. The result of more recent studies (Burra et al., 2019; Sawaki & Luck, 2010; Zsido et al., 2022) suggests that investigating the efficiency of inhibition could help resolve the debate. Thus, in the present study, we used task-irrelevant distractors that were either threatening or nonthreatening but visually similar to threats (and these items were placed near or far from the target of search). The goal of our study was to

Table 1
Detailed statistical results for Experiment 1 (accuracy, reaction time, and BIS) with main effects, interactions, and follow-up simple effects.

Measurement	Effect	df	F/t	p	η^2p
Accuracy	Distractor Type	1,48	0.822	0.369	0.017
	Distance	1,48	13.679	< 0.001	0.222
	Interaction	1,48	9.294	0.004	0.162
	Simple main effects				
	Threatening Close – Threatening Far	48	−0.380	0.706	
	Threatening Close – Nonthreatening Close	48	1.615	0.113	
	Threatening Far - Nonthreatening Far	48	−3.551	< 0.001	
	Nonthreatening Close - Nonthreatening Far	48	−4.494	< 0.001	
Reaction time	Distractor Type	1,45	5.32	0.026	0.106
	Distance	1,45	5.58	0.023	0.110
	Interaction	1,45	5.74	0.021	0.113
	Simple main effects				
	Threatening Close – Threatening Far	45	−0.159	0.874	
	Threatening Close – Nonthreatening Close	45	0.120	0.905	
	Threatening Far - Nonthreatening Far	45	3.900	< 0.001	
	Nonthreatening Close - Nonthreatening Far	45	3.009	0.004	
BIS	Distractor Type	1,47	2.57	0.116	0.052
	Distance	1,47	12.39	< 0.001	0.209
	Interaction	1,47	8.64	0.005	0.155
	Simple main effects				
	Threatening Close – Threatening Far	47	−0.349	0.729	
	Threatening Close – Nonthreatening Close	47	1.085	0.283	
	Threatening Far - Nonthreatening Far	47	−4.074	< 0.001	
	Nonthreatening Close - Nonthreatening Far	47	−4.204	< 0.001	

test how these salient but task-irrelevant stimuli capture attention in a visual search task, and to explore whether the affective or visual features of the stimuli were more influential in the biasing of attention. While we are interested in visual features generally, the present research is just the first step of discovering their potential effects. There are a number of variables that would fit the category of visual features such as pose, skin texture, fangs/teeth, color. Thus, our findings here can really only be directly applied to the shape feature.

Based on the behavioral measures we found that threatening distractors interfered with the task more compared to nonthreatening ones, and that the influence of threats impacted task performance regardless of their proximity to the search target. By contrast, nonthreatening items were examined for longer (which may be taken as evidence that they were not suppressed) but only affected performance when they appeared close to the target. In sum, these results may indicate that the suppression of neutral stimuli was not necessary because they did not interfere with the task, while threatening stimuli interfered with task performance due to an increase in cognitive load as participants actively inhibited it during the trial. When the special distractor appeared close

Table 2
Detailed statistical results for Experiment 2 (likelihood of fixation and total fixation time on distractors) with main effects, interactions, and follow-up simple effects.

Measurement	Effect	df	F/t	p	η^2p
Likelihood of fixation	Distractor Type	1,23	3.31	0.082	0.126
	Distance	1,23	29.51	< 0.001	0.562
	Interaction	1,23	7.16	0.013	0.237
	Simple main effects				
	Threatening Close – Threatening Far	23	2.785	0.011	
	Threatening Close – Nonthreatening Close	23	−2.696	0.013	
	Threatening Far - Nonthreatening Far	23	0.455	0.654	
	Nonthreatening Close - Nonthreatening Far	23	5.451	< 0.001	
Total fixation time	Distractor Type	1,22	8.42	0.008	0.277
	Distance	1,22	3.59	0.071	0.140
	Interaction	1,22	1.92	0.180	0.080
	Simple main effects				
	Threatening Close – Threatening Far	22	0.672	0.509	
	Threatening Close – Nonthreatening Close	22	−2.980	0.007	
	Threatening Far - Nonthreatening Far	22	−1.160	0.259	
	Nonthreatening Close - Nonthreatening Far	22	2.847	0.009	

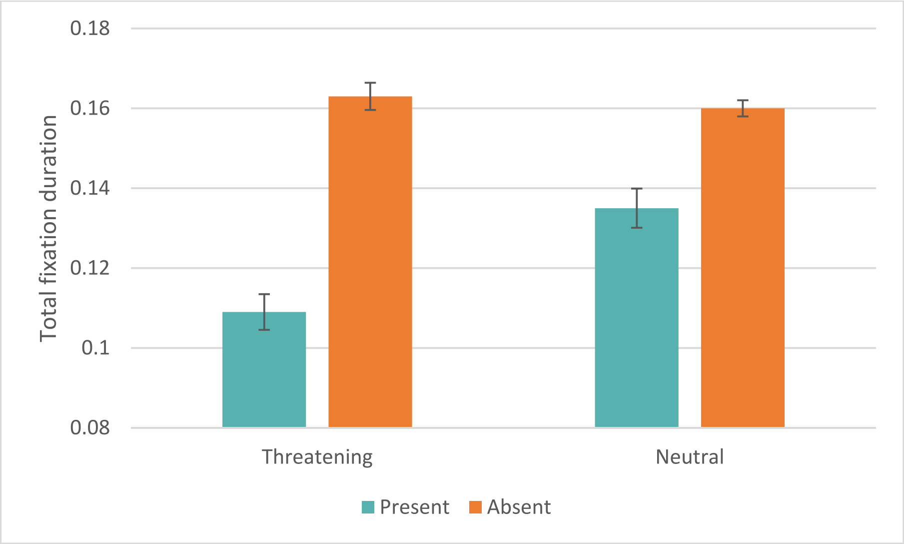

Fig. 4. Performance on the task as measured by BIS for finding the target on trials in which a special distractor was present. Findings are presented across Distractor Type (green and orange bars) and Distance from the Target. Error bars represent one standard error of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

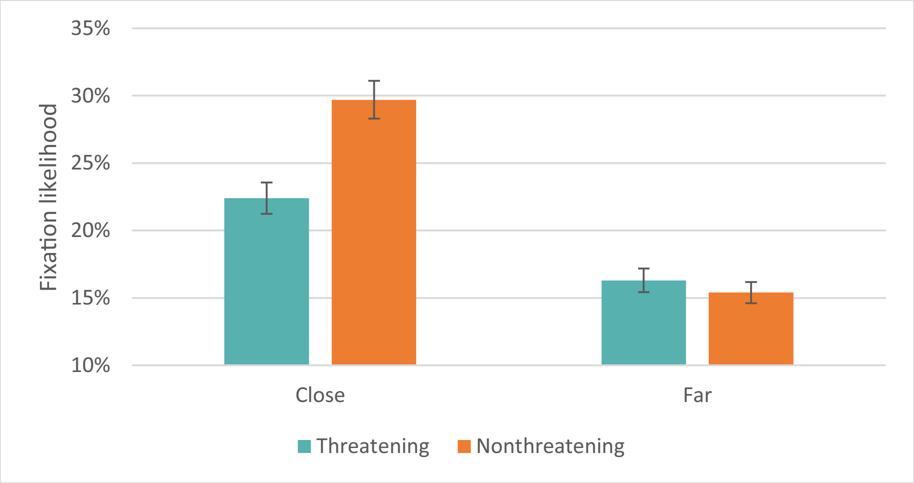

Fig. 5. The likelihood of fixating the special (threatening, nonthreatening) distractor. Findings are presented across Distractor Type (green and orange bars) and Distance from the Target. Error bars represent one standard error of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

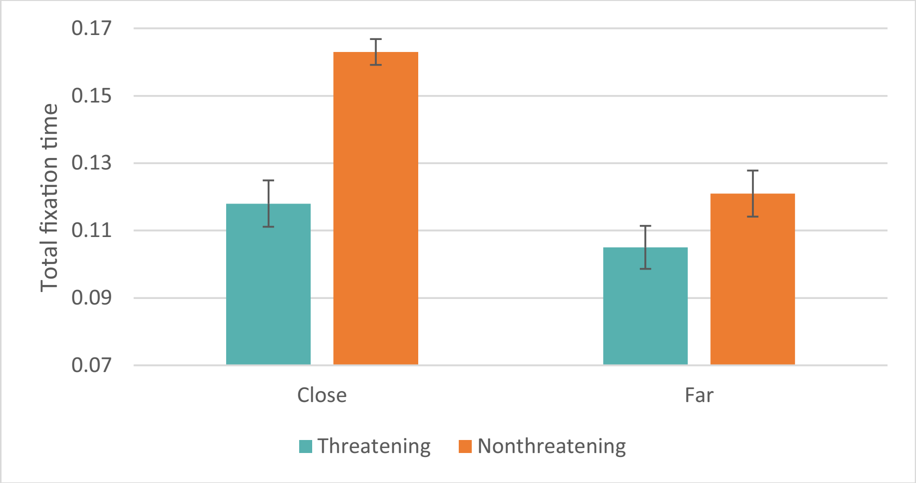

Fig. 6. Total fixation times on the special (threatening, nonthreatening) distractors. Findings are presented across Distractor Type (green and orange bars) and Distance from the Target. Error bars represent one standard error of the mean. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to the target (compared to being positioned further away), we found no difference between threatening and nonthreatening distractors regarding accuracy, RTs and BIS. Thus, the affective and visual features of threat similarly influenced task performance and distracted participants from the task. This may allow us to draw the following conclusions: (1) threatening information does provide an attentional advantage (Blanchette, 2006; March et al., 2017; Öhman & Mineka, 2001; Subra et al., 2017; Williams et al., 2006; Zsido et al., 2018, 2022), one so strong that when presented near to foveation of the target, inhibiting such information without behavioral consequences may not be possible; and (2) threatening information can be ascertained very quickly, with minimal stimulus detail available to foveal vision – in this case, shape similarity was enough to elicit interference.

In previous studies, this latter phenomenon was tested with simple geometric shapes. Downward pointing V stimuli that can be associated with angry faces are reacted to faster and elicit activation in the amygdala (Larson et al., 2007; Larson et al., 2009; Van Strien et al., 2016), and curvilinear shapes and lines are detected faster compared to straight and zigzag lines (LoBue et al., 2014). Thus, shapes that signal threat (similarly to affective features) potentially create an automatic "attend-to-me" signal that is difficult to inhibit, which results in decreased performance (longer RT, lower accuracy) for both threatening and visually similar nonthreatening distractors. However, here we also found that participants fixated on nonthreatening distractors for a longer duration of time. This might indicate that nonthreatening (distractor) objects were ambiguous. They may have created the "attend-to-me signal" (automatically attracting attention) but when participants examined them (i.e., fixated on the distractor), they then realized that no threat was present. Such ambiguity may prompt closer inspection of the object, resulting in more time spent looking at the item. Because the likelihood of fixations was also higher for nonthreatening distractors in the close condition, it is not likely that the longer looking time was due to a delayed disengagement (Sawaki & Luck, 2010, 2011). Rather the ambiguity of the stimuli seems to have prompted a higher number of fixations accumulating in longer total viewing times.

While both threatening and nonthreatening distractors decreased performance on the behavioral task when presented closer to the target, only threatening (but not nonthreatening ones) did so when presented far from the target. However, the total fixation duration was lower for threatening compared to nonthreatening distractors. In previous studies

(Bayle et al., 2009; Hung et al., 2010), peripheral stimulus presentation resulted in a quicker neural activation (measured by MEG) compared to foveal presentation in emotional compared to neutral stimuli. Indeed, threatening stimuli have been shown (Calvo & Lang, 2005; Csathó et al., 2008; Liddell et al., 2005; Wang et al., 2018) to have prioritized access to visual processing via the brainstem–amygdala–cortex alarm system, which plays a vital role in the quick detection of threatening stimuli in the periphery. This system ensures that the automatic alert response to threatening stimuli is also present for threatening stimuli that fall outside of the center of attention (Bayle et al., 2009; Hung et al., 2010; Rigoulot et al., 2011, 2012). Previous studies proposed that the processing of the visual features strongly associated with threats (such as sinusoid shape) does not suffer from declining performance in the peripheral visual field (compared to foveal visual processing (Carretié et al., 2017; De Cesarei & Codispoti, 2008; Gao et al., 2017). Such information may trigger the brainstem–amygdala–cortex alarm system, drawing the focus of attention, and thereby resulting in a quick orientation to the stimulus. However, our results are in line with a previous fMRI study (Almeida et al., 2015) showing that the amygdala activation was only observed for true snake pictures and not for fake ones (the stimulus was snake shaped but not a real snake) when presented in the periphery. This might be because both this and our study presented threatening and visually similar nonthreatening stimuli in the same experiment, while previous studies used only one stimulus type per participant. It seems that visual features can be more easily inhibited in the periphery compared to affective features (Burra et al., 2019). Hence, when the stimulus is actually a threatening item, it causes a greater behavioral interference.

Our results showed that performance (indicated by accuracy, RTs, and BIS) decreased for threatening compared to nonthreatening stimuli regardless of the distance between target and distractor. The pairwise comparisons of the behavioral measures indicated that the difference between threatening close and threatening far conditions was nonsignificant; similarly the difference between threatening close and nonthreatening close conditions were nonsignificant. In contrast, performance improved when the nonthreatening distractor appeared far from the target compared to nonthreatening distractor close to the target and threatening distractor far from the target. When the stimulus was nonthreatening, active suppression of it possibly required fewer resources compared to a threatening stimulus (Bradley et al., 2007; Schupp et al., 2006). This might explain the fact that such distractors interfered less with the completion of the main task. Further, presumably participants fixated on these items for a longer period of time because their spatial positions were not under active inhibition. On the other hand, shape similarity might be an ambiguous source of information before one takes a closer look at the stimulus to evaluate it, so the higher oculomotor capture and longer fixation times may be a result of an automatic reorientation for reassurance (Calvo & Lang, 2005).

Nevertheless, in our study, we only found evidence of prioritized access to visual processing (i.e., production of behavioral interference) when threatening information came from affective valence, not visual features alone. However, in the distractor absent-present analysis (presented in Supplementary material 2) the main effect of Distractor type was nonsignificant. While this comparison showed no difference between trials with nonthreatening but visually similar to threatening distractors and trials without special distractors, the difference was only evident between threatening and nonthreatening but visually similar trials (not between trials with threatening distractors and trials without special distractors). Thus, these findings are not yet conclusive, and as our study was not designed to be powered for such a comparison, further studies will be needed to clarify the current findings. In sum, it seems that visual features which signal threat are easier to inhibit than actual affective valence when shown outside of central vision.

Although our findings are novel, we should acknowledge certain limitations in the current investigation. First, participants conducted a free visual search, and the foveal position of the special distractors were therefore not fixed. Consequently, we can only interpret our findings in light of their relative distance from the target. Second, the task design preclude us from conducting a more fine-grained analysis of the eye movements such as the destination of the first saccade on a trial as past studies have examined (Gaspelin et al., 2017; Hamblin-Frohman et al., 2022) However, those studies used a small number of objects (4 or 6) with stimuli presented equidistant from fixation while the visual display in the present study was more complex (with 32 objects per trial) and the distance between target and distractors greatly varied. Third, we used eye-tracking methodology[5] which is only capable of recording overt eye-movements. Future experiments should employ other methodologies (such as EEG or MEG) to more fully understand the processes of inhibition during covert attention. Thus, we encourage conceptual replication of our work using other techniques. Finally, in the present investigation we focused on directly comparing two types of distractors (threatening and visually similar nonthreatening). Adding new conditions (e.g. dissimilar nonthreatening and other emotional categories than threat) would be interesting and would probably improve the generalizability of the results.

Taken together, our findings suggest that the inhibition of affective features of threatening information is not (or is only partially) possible regardless of whether such an item appears inside or outside of attentional focus. Threatening stimuli induced behavioral interference, but participants fixated on them less often. This possibly suggests that their spatial position was actively suppressed, diverting cognitive resources away from the main task. In contrast, visual features of threat only interfered with the main task when appearing closer to the focus of attention. Outside of it, the visual features seem to be inhibited more easily but produce more orienting eye-movements (compared to affective features) presumably because they were quickly dismissed as nonthreatening, and their spatial position was therefore not inhibited.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2024.104150.

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CRediT authorship contribution statement

Diána T. Pakai-Stecina: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing. **Michael C. Hout:** Conceptualization, Formal analysis, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Cintia Bali:** Investigation, Project administration, Software, Visualization, Writing – review & editing. **Andras N. Zsido:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

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[5] One limitation here is that we were unable to verify replication of the RTs due to a mishap with data collection.

Data availability

Our dataset (including computed study variables) is available on the Open Science Framework: https://osf.io/5pazw/?view_only=63bbe6f6aacb45ed8b052495df556783.

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