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ORIGINAL ARTICLE

# The effects of task-irrelevant threatening stimuli on orienting- and executive attentional processes under cognitive load

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## Abstract

Human visual attention is biased to rapidly detect threats in the environment so that our nervous system can initiate quick reactions. The processes underlying threat detection (and how they operate under cognitive load), however, are still poorly understood. Thus, we sought to test the impact of task-irrelevant threatening stimuli on the salience network and executive control of attention during low and high cognitive load. Participants were exposed to neutral or threatening pictures (with moderate and high arousal levels) as task-irrelevant distractors in near (parafoveal) and far (peripheral) positions while searching for numbers in ascending order in a matrix array. We measured reaction times and recorded eye-movements. Our results showed that task-irrelevant distractors primarily influenced behavioural measures during high cognitive load. The distracting effect of threatening images with moderate arousal level slowed reaction times for finding the first number. However, this slowing was offset by high arousal threatening stimuli, leading to overall shorter search times. Eye-tracking measures showed that participants fixated threatening pictures more later and for shorter durations compared to neutral images. Together, our results indicate a complex relationship between threats and attention that results not in a unitary bias but in a sequence of effects that unfold over time.

Author note: Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

**KEYWORDS**
arousal, emotion, number matrix, task load, visual search, visual working memory

# INTRODUCTION

## Threat prioritization in attention and the underlying networks

Threatening stimuli have often been shown to enjoy an advantage in visual processing (Blanchette, 2006; Lipp, 2006; March et al., 2017; Öhman, 2005; Öhman et al., 2001; Shibasaki & Kawai, 2009; Subra et al., 2017; Zsido et al., 2018), presumably due to the evolutionary advantage that hastened detection of threats confers on one's chances of survival (LeDoux, 2014; LeDoux & Daw, 2018; Öhman & Mineka, 2003). Our attentional systems appear to be biased to quickly detect and perceive threatening stimuli in our environment in order to allow our nervous system to swiftly begin the appropriate behavioural response to the threat (Mobbs et al., 2015; Roelofs, 2017; Soares et al., 2017).

The *attentional biases for threat* (ABT) framework is useful for understanding the information-processing peculiarities associated with threats (and may also contribute to a better understanding of the aetiology and maintenance of specific phobias and anxiety disorders). There are three components of the ABT framework (Cisler & Koster, 2010): (1) delayed disengagement from the threat (also termed as attentional dwell time), (2) facilitated attention to the threat (attentional capture), and (3) attentional avoidance, which is also termed 'vigilance-avoidance' (Mogg et al., 2004). Importantly, a recent review of ABT by McNally argued that there is a crisis in this field because the reliability of the methods used to study ABT are quite poor and because ABT might not apply uniformly across individuals as was assumed by previous literature (McNally, 2018).

The root cause of these reliability concerns could be that the often-used paradigms in this field are not measuring the components of the ABT they intend to, or perhaps they are tapping into more than one component at a time (Cisler et al., 2009; Koster et al., 2004; Mogg et al., 2008). For instance, imagine a dot-probe paradigm wherein a participant detects a target that sometimes appears in the same spatial position as a threatening cue, and sometimes in a different position. Speeded detection of the target when it coincides with the location of the threat, in this example, could be the result of facilitated attention to the dot-probe and/or delayed disengagement from the threat. In a paradigm like this, it is impossible to disentangle these two potential explanations because the threat *coincides* with the target itself.

Prior studies (Dolcos et al., 2020; Mogg & Bradley, 2018) began to tease apart the processes involved in ABT by relying on clinical, behavioural, and neuroimaging results. This body of work suggests that the two key components that need to be assessed are *salience* or stimulus-driven orienting (i.e., the salience network, spanning the amygdala, the insula, and frontal regions of the brain) and the *executive control* of attention (i.e., the executive control network, spanning frontal and parietal regions). These networks, which correspond to different aspects of cognitive control, align well with prior eye-tracking studies (Miltner et al., 2004; Mogg et al., 2000; Waechter et al., 2014) that have utilized attentional capture and dwell time metrics. To date, most empirical studies of threat detection have used task-*relevant* threatening stimuli in their manipulations, and that is problematic because bottom-up and top-down processes overlap considerably in such designs. That is, if the target item is a threatening object, it can affect performance via its bottom-up salience but also in a top-manner due simply to the observer having the item in mind to begin with. Thus, any effects of the threat cannot be said to have been solely influenced by the salience of the stimulus or one's own attentional control settings.

A possible (but seldom used) solution to this methodological concern is to disentangle the primary task from the emotional stimuli, for instance by using *task-irrelevant distractors* (Cisler & Koster, 2010; McNally, 2018). By using task-irrelevant distractors, it is possible for both networks to be examined separately (Calvo & Castillo, 2005). When the stimulus is task-irrelevant, both involuntary capture of attention by the stimulus (salience) and suppression of the stimuli (executive control) can be measured separately (Richards et al., 2012).

In one such behavioural study (De Cesarei & Codispoti, 2008), participants performed an auditory discrimination task while viewing task-irrelevant emotionally charged stimuli. The stimuli were manipulated on some trials by either reducing their size or applying a low-pass spatial filter (i.e., making the image blurry). The results showed a similar interference effect of the emotionally charged images for both intact and manipulated stimuli. This finding – which, crucially, isolated the effects of salience by using task-irrelevant distractors – suggests that attentional capture by affective stimuli seems not to be contingent on high-resolution information (e.g., large, clear pictures) but can also be influenced by only as much information as is necessary to allow a categorization of picture content. This finding is also in line with more recent studies demonstrating conflict effects for task-irrelevant emotionally charged faces and places (Zinchenko et al., 2017).

Some prior work on task-irrelevant emotional stimuli has also been conducted using eye movement and EEG measures. Eye-tracking data has demonstrated that emotionally charged stimuli selectively capture covert attention (Fernández-Martín et al., 2017), and that such stimuli are processed better, and draw covert attention, outside the focus of overt attention (Calvo et al., 2015). Further, EEG data also suggest that threatening stimuli (specifically, angry faces) are attentionally prioritized, an effect that is especially pronounced under conditions of high task difficulty (Bretherton et al., 2017; Burra et al., 2016, 2017). There is also a well-described phenomenon called *fear bradycardia* – also termed *freezing* or *attentive immobility* – that results in increased selective attention towards the threat, inhibited locomotion that can also be observed in eye-movements, and potentiation of the protective startle reflex (Rösler & Gamer, 2019; Szeska et al., 2021). Nevertheless, such results are difficult to interpret in terms of the ABT because they either used mixed emotional stimuli or only a very specific type of threatening stimuli and have not measured behavioural or eye-movement responses. Therefore, the specific circumstances under which threats are perceived – and the manner in which threat detection affects attentional processing – are not well enough understood. It is clear from prior work that to fully understand the effects of threatening stimuli on attentional processing, task-irrelevant stimuli should be used.

## Processing of threats in non-central vision

Threatening stimuli often appear outside the direct line of sight, in the periphery of our visual field. From an evolutionary perspective, therefore, threat detection is most important when it allows one to quickly identify something not already under direct inspection. In fact, features (e.g., movement, sinusoid shape) that have been shown to be sufficiently processed in peripheral vision (despite the declining performance of the peripheral visual field relative to central vision) (Carretié et al., 2017; Gao et al., 2017) are the ones identified by prepared learning theories as easily associated with threat due to their predatory relevance (Coelho & Purkis, 2009; Davey, 1995). Threatening stimuli have been shown to have prioritized access to visual processing via the *magnocellular pathway* (Van Strien et al., 2016) and the superior colliculus-pulvinar-amygdala pathway (Almeida et al., 2015; Soares et al., 2017; Wang et al., 2018). These are part of the *brainstem–amygdala–cortex alarm system* that plays a vital role in the quick detection of threatening stimuli in the periphery (Csathó et al., 2008). It has been proposed that when processing capacity is not fully utilized, unattended items are more likely to receive attention (Lavie, 1995). However, a previous review argued that the amygdala responds preferentially to peripheral threatening stimuli only during high cognitive load (Palermo & Rhodes, 2007). Although there are studies (Derakshan et al., 2009; Richards et al., 2012, 2014) showing that the understanding of ABT mechanisms would greatly benefit from paradigms using non-centrally presented threats, the evidence is still scarce about the attentional control impairing effects of threats in parafoveal and peripheral vision.

## Effects of cognitive load

Quickly noticing an unexpected threatening stimulus clearly conveys an evolutionary advantage to the survival of humans, but this is an even more crucial behaviour when a person is experiencing high cognitive load, because that is when our attention tends to lapse more easily (Head & Helton, 2014). To survive, dangerous cues necessitate an interruption of one's focused attention and needs, in order to further investigate new information, even when that information may be irrelevant to the person's primary goals (New & German, 2015). It has been suggested (Bretherton et al., 2017; Pessoa et al., 2005) that whether a study finds that attention modulates the processing of unattended emotional stimuli or not depends on how demanding the task was that was implemented. Introducing cognitive load into an attentional task allows for the investigation of automaticity and how exposed attentional processes are to task-irrelevant threatening stimuli (Cisler & Koster, 2010).

According to the *load theory of attention* (de Fockert et al., 2001; Lavie, 2010), distractor interference is severe in high compared to low cognitive load tasks. Neuroimaging evidence supports this contention, showing that amygdala responses to task-irrelevant emotionally charged stimuli are more robust under high load (Pessoa et al., 2005). However, previous findings on the relationship of cognitive load and attentional bias for threats are mixed, and the volume of studies remains scarce to date. Some studies found that working memory (WM) manipulations have no effect on the interference of emotional face distractors (Berggren et al., 2012; Pecchinenda & Heil, 2007). Other studies (Bretherton et al., 2017; Holmes et al., 2014; Petrucci & Pecchinenda, 2016) have shown that depletion of cognitive control resources increases the potential for task-irrelevant threat cues to capture and hold attention. Nonetheless, most of this prior work has exclusively used faces as emotional stimuli and therefore did not extend the findings to stimuli that pose a larger threat than that conveyed by an unhappy expression. Further, though it has been established that threats receive prioritized attention, prior work has not investigated whether threatening stimuli are particularly distracting when they are task irrelevant. Thus, we still have much to learn about how threat detection operates, particularly under conditions of varying cognitive load (Gomes et al., 2017) and varying conditions of task relevance.

## The present study

In the present investigation, our overarching goal was to test the effects of task-irrelevant unattended threatening stimuli on the two key components of ABT during varying conditions of cognitive load with behavioural and eye-tracking measures. To do this, we utilized the *number matrix* paradigm (Zsido et al., 2018, 2019) whereby participants have to search through an array similar to a chessboard, filled with numbers starting from one to a pre-established amount (that can be varied to manipulate task difficulty). The use of this task allows us to test the differential effects of parafoveally and peripherally presented task-irrelevant threat distractors on performance. Additionally, the paradigm offers a convenient way to manipulate the searcher's cognitive load (and thus task difficulty) by simply increasing the numbers present in the search array. The difficulty of the number matrix task can be varied by decreasing or increasing the numbers that are presented in the matrix. As the amount of numbers presented in the matrix increases, visual clutter increases because more digit cells are entered into the same overall search space thereby creating a display that is increasingly complex.[1] Moreover, as the amount of numbers present increases, the mental workload of the searcher increases because the participant has to keep track of information for a longer period of time (i.e., what number has already been found and which target number is next).

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[1] This, according to previous research (Forster & Lavie, 2008, 2009), could also result in a perceptual load effect. However, previous studies (De Fockert, 2013; Tsal & Benoni, 2010) arguing a dilution model instead of perceptual load also pointed out that if the target is clearly distinguished from the distractor, there is no perceptual load effect. In fact, when dilution was separated from perceptual load, they found results that are consistent with those found regarding cognitive load (Tsal & Benoni, 2010). Moreover, some recent experiments (De Fockert, 2013; Fitousi & Wenger, 2011; Lleras et al., 2017) questioned the usefulness of the perceptual load theory because they found that attentional capture by the distractors increased with increasing perceptual load; a pattern better explained by the cognitive load theory.

As such, with this task, we can separate the components of ABT more directly than in other paradigms. Finding the first number (i.e., 1) is a simple visual search task of looking for a target among distractors guided by the features of that target, and therefore primarily requires attention orienting (Wolfe, 2021; Wolfe et al., 2011). Although one constantly needs to match the target to a template stored in WM, we argue that this behaviour relies comparatively more on bottom-up processing than top-down processing because the primary determinant of behaviour is the difference in appearance between the number one and the other distractor numbers in the array. Manipulating task difficulty by adding more numbers to the array increases the interference from other digits because there are more distractors; therefore, we argue that this affects bottom-up processing comparatively more than top-down processing, and thus this task allows us to partially separate these two networks of interest.

By contrast, similar to commonly used trail-making tasks, the task of searching through the number array (i.e., beyond the first digit) relies more on top-down processes than bottom-up processes. This is because searching through the rest of the numbers requires the observer to control their attention and constantly maintain their search target and update the information in WM each time a new target digit is found (Kane et al., 2001; Kovacs & Conway, 2016; Unsworth & Robison, 2017). Thus, in this paradigm, looking at performance for finding the first number allows us to examine (primarily but not exclusively) the salience network and performance during search for the other numbers allows us to examine (primarily but not exclusively) the executive control network.

Previous research using the number matrix paradigm with task-irrelevant but centrally presented images found an arousal stimulation effect: threatening pictures with medium arousal level slowed down performance (i.e., led to slower reaction times or lower highest number reached) compared to neutral pictures, while threatening pictures with high arousal level speeded up performance compared to neutral (and medium arousal threatening) pictures. That is, although threatening pictures distracted attention (i.e., search for the first number was slow), thereby hurting performance, the arousal level conveyed by the emotional picture, if high enough, can also facilitate overall visual search performance (i.e., lead to overall faster search times) by speeding the movement of attention over time (Zsido et al., 2018, 2019). By recording gaze data while participants are performing this task, we can measure further behavioural manifestations of ABT, such as the time to first fixation on the threat and during of overall looking times on threat. Moreover, eye-tracking enables us to examine how pronounced gaze behaviour differences are as a function of various levels of arousal.

Bearing this in mind, our *first hypothesis* was that suppression of task-irrelevant information would be harder for more threatening stimuli compared to less threatening and neutral ones. That is, threatening stimuli should be generally harder to suppress resulting in slower reaction times for finding the first number due to faster first fixation of the threat and longer dwell times on distractors. Our *second hypothesis*, in keeping with the arousal stimulation effect, was that we should also find faster *overall* search times in the presence of more threatening stimuli due to the arousing effect of the threats. Our *third hypothesis* was that suppression of task-irrelevant information for threatening stimuli would be harder for pictures appearing closer to foveal vision, but that this would be mediated by the cognitive load of the task; that is, that under high compared to low load there would be an overall larger effect of distractor interference. Thus, we expected to find the behavioural and eye-tracking pattern described in the first and second hypotheses more pronounced in trials where the threatening distractor was closer to the matrix and the task was more difficult.

# METHODS

## Present experiment

Similar to our prior work (Zsido et al., 2019), we manipulated the intensity of the threats and included two types of threat content (animals and objects) in our study. The primary difference from our previous studies was that instead of presenting threatening and neutral images as background pictures (or directly preceding the matrices), we placed the pictures beside the matrix in two possible positions (near/

parafoveal and far/peripheral). Furthermore, we manipulated task difficulty (cognitive load) by using both easy matrices (compromised of only numbers from 1 to 10) and hard matrices (compromised of numbers from 1 to 35). Thus, we employed a 2 × 2 × 3 design with Task Difficulty (easy, hard), Distractor Eccentricity (near, far), and Threat Intensity (neutral, moderate, high) as within-subject factors.

## Participants

The sample comprised 44 volunteers (30 women) who were undergraduate students of the university in which the data were collected. Their mean age was 21.5 (*SD* = 2.97). We also obtained state (*M* = 8.05, *SD* = 3.08) and trait anxiety (*M* = 13.0, *SD* = 4.15) using the abbreviated version of the Spielberger State and Trait Anxiety Inventory (Zsido et al., 2020), and found that our participants were representative of the standards of the country. The required sample size for this experiment was determined by computing estimated statistical power ($f = 0.40$, $\beta > 0.8$) based on previous studies (Zsido et al., 2018, 2019) that implemented a similar paradigm (specifically, by using the average effect size for the main effect of Threat Intensity across five experiments). The analysis indicated a required total sample size of 7. With a more conservative approach that used a smaller effect size to estimate the sample size needed ($f = 0.25$, $\beta > 0.95$), the required sample size was 23; thus, even with a conservative approach, our study was adequately powered. Further simulation-based posteriori power evaluation using the power contour estimation method (Baker et al., 2020) showed that even with the relatively low trial count of our design, the experiment reach 80% power for all behavioural and eye-tracking measures (required sample size varied between 27 and 41, trial count per condition varied between 2 and 8). All participants were right-handed and reported normal or corrected-to-normal vision. None of the participants reported having been diagnosed with anxiety disorder or undergoing treatment in the past or at the time of the experiment. Data from two participants were excluded because of failure to follow instructions. Our research was approved by the local ethics committee and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided informed consent.

## Experimental stimuli

The visual search task consisted of searching for numbers (sequentially) in matrices that were created using a special matrix generator program (freely accessible from http://baratharon.web.elte.hu/nummatrix/). In the easy task, the numbers ranged from 1 to 10 and were randomly distributed amongst the rectangles. In the hard task, the numbers ranged from 1 to 35. Each number appeared only once in a given matrix. The size of the matrices both in the easy and hard tasks was 700x700 pixels (17.55° x 17.55°). In the easy task, the matrix contained 10 white rectangles, the width and height of which varied from 150 to 300 pixels (visual angle of 3.79° to 7.57°). In the hard task, there were 35 white rectangles and 3 to 6 black ones. The black rectangles were randomly distributed amongst the white ones and were added simply to maintain the same overall global shape in the search area. The width and height of the rectangles varied from 70 to 230 pixels (visual angle of 1.51° to 4.98°). Both the matrices and rectangles within had a 2-pt black border drawn around them. All the rectangles contained a number printed in black in 32-pt Tahoma font.

For each trial, a task-irrelevant picture appeared in one of the eight possible spatial positions. These included a combination of each of the four corners of the screen and a proximity measure that designated how close to the search matrix the picture was presented (near/parafoveal vs. far/peripheral; 12.5° and 24° from the centre of the matrix, respectively). The pictures used in this experiment as task-irrelevant distractors were taken from a previous study (Zsido et al., 2019). The pictures were sourced from the International Affective Picture System (Lang et al., 1997) and the Nencki Affective Picture System (Marchewka et al., 2014), and were selected based on their valence and arousal ratings provided by the authors of the picture systems.[2] Pictures were selected from three threat intensity levels (neutral,

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[2] Emotional picture ratings can be found in Zsido et al. (2019) which is the source of the images used here.

moderate, high) and we selected pictures (in equal proportions) from across animal and object categories. Thus, each category consisted of 16 pictures, resulting in 48 pictures in total. The images were equalized on low-level perceptual features using the Spectrum, Histogram, and Intensity Normalization and Equalization (SHINE) Matlab toolbox (Willenbockel et al., 2010). The images did not differ in visual complexity based on log JPG file size measures (Donderi & McFadden, 2005; Forsythe et al., 2011). For a more detailed description of the images used and the process of controlling for confounding variables see (Zsido et al., 2019). Finally, we resized the images to 300x225 pixels (visual angle of 7.57° to 5.68°).

Participants took part in 96 trials in total, evenly split across easy and hard conditions.[3] The trials within each difficulty condition included a 2 (eccentricity: near, far) × 4 (corners of the screen) × 3 (intensity levels) × 2 (object categories) factorial. See Figure 1 for exemplars of the final stimuli set. Difficulty was blocked, and presentation order was counterbalanced across participants. The two blocks were administered in a single testing session that lasted approximately 70 mins; participants took a short break in between blocks.

## Apparatus and procedure

The stimuli were presented on a 23-inch TFT colour monitor, with a resolution of 1920 × 1080, 16:9 aspect ratio, a refresh rate of 60 Hz, and colour depth of 16.7 M. Stimuli were presented using Tobii Studio. Eye-movements were recorded using a Tobii Pro TX300 (developed by *Tobii Technology AB*, *Danderyd*, *Sweden*) at a sampling rate of 300 Hz (binocular). A five-point calibration was completed before the experiment. Calibration accuracy was checked manually and repeated if it was not judged to be successful (i.e., if a test fixation was determined to be further than a 2.25° radius around any of the five points) by the experimenter. To minimize head movements and increase precision of the tracker, participants placed their heads on a forehead and chin rest throughout the experiment. Behavioural responses were recorded via the mouse of the computer.

The experiment was conducted in a dim and quiet room. Participants were seated at a distance of approximately 60 cm from the monitor. They received both oral and written task instructions. First, they completed a series of six practice trials, after which they were given another opportunity to ask questions. If they indicated that they understood the task fully, the experiment began. Each trial started with a white fixation cross presented for 1000 ms on a black background. Then, the number matrix appeared in the centre of the screen simultaneously with an image in one of the eight possible positions; the background was black. Participants' task was to locate the numbers in ascending order starting with the number one, and to indicate each find by clicking on the numbers using the computer mouse. The number matrix was presented for a predefined amount of time – 10 s in the easy task and 35 s in the hard task – or until the participant located the last number. The number matrices used were randomized across participants and trials.

## Statistical analyses

Eye-tracking data was processed with Tobii Studio to obtain fixation measures and durations using the default settings. No further pre-processing was implemented. The pictures and the rectangles of number 1 and number 10 in the number matrix were defined as Areas of Interest.

Statistical analyses were performed using the JAMOVI Statistics Program version 1.0 for Windows (Jamovi Project, 2018). We first identified and removed outlier trials, defined as those greater than ±2 standard deviations of the group mean (resulting in removal of less than 1% of all the collected

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[3] The reason that the number of trials per condition was to some degree low is that a high number of repetitions would have caused habituation to the emotional content, resulting in a decreased effect of the emotional variables over time.

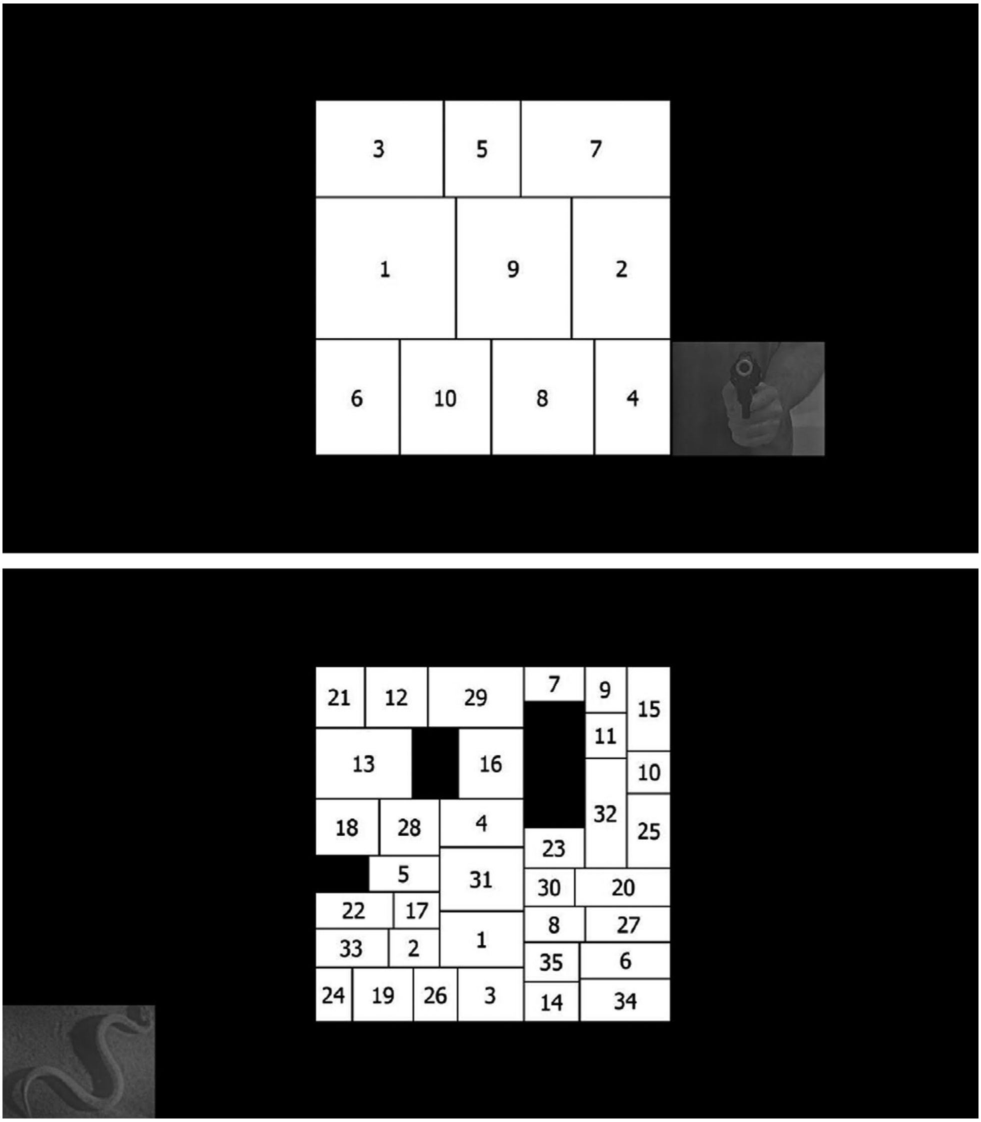

**FIGURE 1** Illustrative examples of the stimuli used in this study. Top: during the easy task, a high threat object is presented as a task-irrelevant distractor in near (parafoveal) position. Bottom: in the hard task condition, a task-irrelevant (animal) distractor is presented in the far (peripheral) position. Please note that this is just an illustration of the final stimuli used; the IAPS and NAPS pictures were replaced due to copyright issues

data) for each subject. We then checked to ensure that the distribution of the variables did not deviate significantly from a normal distribution (Saphiro-Wilk $p$s > .05). Sphericity assumptions were also met for ANOVAs.

We used 2 × 2 × 3 repeated-measures analysis of variances (*r*ANOVA) with Task Difficulty (easy, hard), Distractor Eccentricity (near, far), and Threat Intensity (neutral, moderate, high) as within-subject factors. Our behavioural measures included examining RTs (in seconds) for the time needed to *find the number 1*, and the total *search times* (in seconds) for finding numbers 1 through 10 (search times were truncated in the hard condition to match the easy condition). Search times were the difference between RT for finding number 10 and RT for finding number 1. We used eye-tracking to examine first *decision time* (i.e., time elapsed between the first fixation on the number 1 and when the mouse was clicked, measured in seconds), *attentional capture* time (i.e., time of the first fixation on the task-irrelevant picture, measured in seconds), and *attentional dwell time* (i.e., total fixation time on the task-irrelevant picture, measured in seconds).

Main effects and interactions are reported separately, paired with relevant follow-up ANOVAs or t-tests to further investigate significant interactions.[4] Effect sizes are also presented: partial eta squared ($\eta_p^2$) for the ANOVAs and Cohen's d (*d*) for the t-tests. Tukey corrections were used to account for multiple comparisons.

# RESULTS

## Main effect of Threat Intensity

### Behavioural data

*Finding number 1*

The main effect of Threat Intensity ($F(2,80) = 3.44$, $p = .037$, $\eta_p^2 = 0.079$), indicates that RTs were longer for the moderate ($M = 1.68$, 95% CI = 1.60–1.75) compared to the high threat ($M = 1.62$, 95% CI = 1.54–1.69) and neutral ($M = 1.62$, 95% CI = 1.54–1.70) conditions. However, pairwise comparisons were not significant (moderate-high: $t(40) = 2.30$, $p = .061$ and moderate-neutral $t(40) = 2.24$, $p = .070$).

*Search time (1->10)*

We found a main effect of Threat Intensity ($F\ (2,86) = 4.92$, $p = .009$, $\eta_p^2 = 0.103$), and pairwise comparisons revealed that search time was slower when the image was neutral ($M = 11.80$, 95%CI = 11.10–12.50) compared to when it was moderately threatening ($M = 11.30$, 95% CI = 10.60–12.00; $t(43) = 3.08$, $p = .008$), but the effect was only marginally significant for the difference between neutral and highly threatening distractors ($M = 11.40$, 95% CI = 10.70–12.10; $t(43) = 2.03$, $p = .09$).

### Eye-tracking results

*Decision time (nr1)*

The main effect of Threat Intensity was not significant ($F(2,82) = 2.25$, $p = .112$).

*Attentional capture*

The main effect of Threat Intensity was significant ($F(2,86) = 7.91$, $p < .001$, $\eta_p^2 = 0.155$), indicating that the first fixation occurred sooner for neutral ($M = 5.74$, 95% CI = 4.86–6.61) compared to highly ($M = 7.07$, 95%CI = 6.20–7.94; $t(43) = 3.14$, $p = .007$) and moderately ($M = 7.30$, 95% CI = 6.43–8.17; $t(43) = 3.69$, $p = .001$) threatening images, while the latter two did not differ ($t(43) = .56$, $p = .843$).

*Attentional dwell*

The main effect of Threat Intensity ($F(2,86) = 2.24$, $p = .112$) was not significant.

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[4] Main effects and interactions that were not relevant to answer our primary hypotheses were moved to Method S1 so as to keep the main text as straightforward and concise as possible.

## Interaction between threat intensity and distractor eccentricity and task difficulty

### Behavioural data

*Finding number 1*

The three-way interaction was significant (F(2,80) = 4.61, $p$ = .013, $\eta_p^2$ = 0.103) showing that the manipulated factors had a different effect during the easy and difficult tasks. If we isolate the easy trials, we find a two-way interaction between Threat Intensity and Distractor Eccentricity (F(2,80) = 4.47, $p$ = .014, $\eta_p^2$ = 0.100). When the image was near to the matrix we found an inverse linear trend for Threat Intensity and RT (F(2,80) = 3.50, $p$ = .035, $\eta_p^2$ = 0.08); that is, participants were faster when more threatening images were presented. This effect was not significant when the image was farther away (F(2,80) = 2.43, $p$ = .095). For the difficult trials, the Threat Intensity and Distractor Eccentricity (F(2,80) = 4.85, $p$ = .010, $\eta_p^2$ = 0.108) interaction was also significant. When the image was near to the matrix (F(2,80) = 8.53, $p$ < .001, $\eta_p^2$ = 0.176), participants were slower when the image was moderately threatening compared to neutral and highly threatening conditions. See Figure 2 for the interaction and Appendix 1 for the descriptive statistics.

*Search time (1->10)*

The two-way interaction between Distractor Eccentricity and Threat Intensity (F(2,86) = 1.41, $p$ = .250), and the three-way interaction between Task Difficulty, Distractor Eccentricity, and Threat Intensity (F(2,86) = .76, $p$ = .470) were not significant. See Figure 2 for the interaction and Appendix 2 for the descriptive statistics.

### Eye-tracking results

*Decision time (nr1)*

The three-way interaction was not significant (F(2,82) = 1.98, $p$ = .145). The Threat Intensity and Distractor Eccentricity (F(2,82) = 3.66, $p$ = .030, $\eta_p^2$ = 0.08) interaction showed that the Threat Intensity effect was only significant when images were near to the number matrix (F(2,80) = 8.49, $p$ < .001, $\eta_p^2$ = 0.172) such that decision time was slower in the moderate threat condition ($M$ = 1.53, 95%CI = 1.43–1.62) compared to high threat ($M$ = 1.39, 95%CI = 1.29–1.48; $t$(41) = 2.75, $p$ = .020) and neutral ($M$ = 1.32, 95%CI = 1.23–1.41 $t$(41) = 4.03, $p$ < .001) conditions. The latter two did not differ ($t$(41) = 1.28, $p$ = .410). The Threat Intensity effect was not significant when distractors were located farther away (F(2,82) = .158, $p$ = .854). See Figure 3 for the interaction and Appendix 3 for the descriptive statistics.

*Attentional capture*

The three-way interaction was not significant (F(2,86) = 0.48, $p$ = .622). The interaction between Distractor Eccentricity and Threat Intensity was not significant (F(2,86) = 0.03, $p$ = .970). See Figure 4 for the interaction and Appendix 4 for the descriptive statistics.

*Attentional dwell*

The three-way interaction was significant (F(2,86) = 6.37, $p$ = .003, $\eta_p^2$ = 0.129). Isolating the easy task condition, we found no significant main effects or interactions. By contrast, when looking at the hard task condition, the interaction between Distractor Eccentricity and Threat Intensity was significant (F(2,86) = 5.85, $p$ = .004, $\eta_p^2$ = 0.120). Here, the Threat Intensity effect was significant when the image appeared in a far position (F(2,86) = 8.01, $p$ < .001, $\eta_p^2$ = 0.157), indicating that participants looked at neutral images longer ($M$ = .58, 95%CI = 0.51–0.65) compared to high ($M$ = .43, 95%CI = 0.36–0.50; $t$(43) = 3.43, $p$ = .003) and moderate ($M$ = .43, 95%CI = 0.35–0.50; $t$(43) = 3.50, $p$ = .002) threats, while

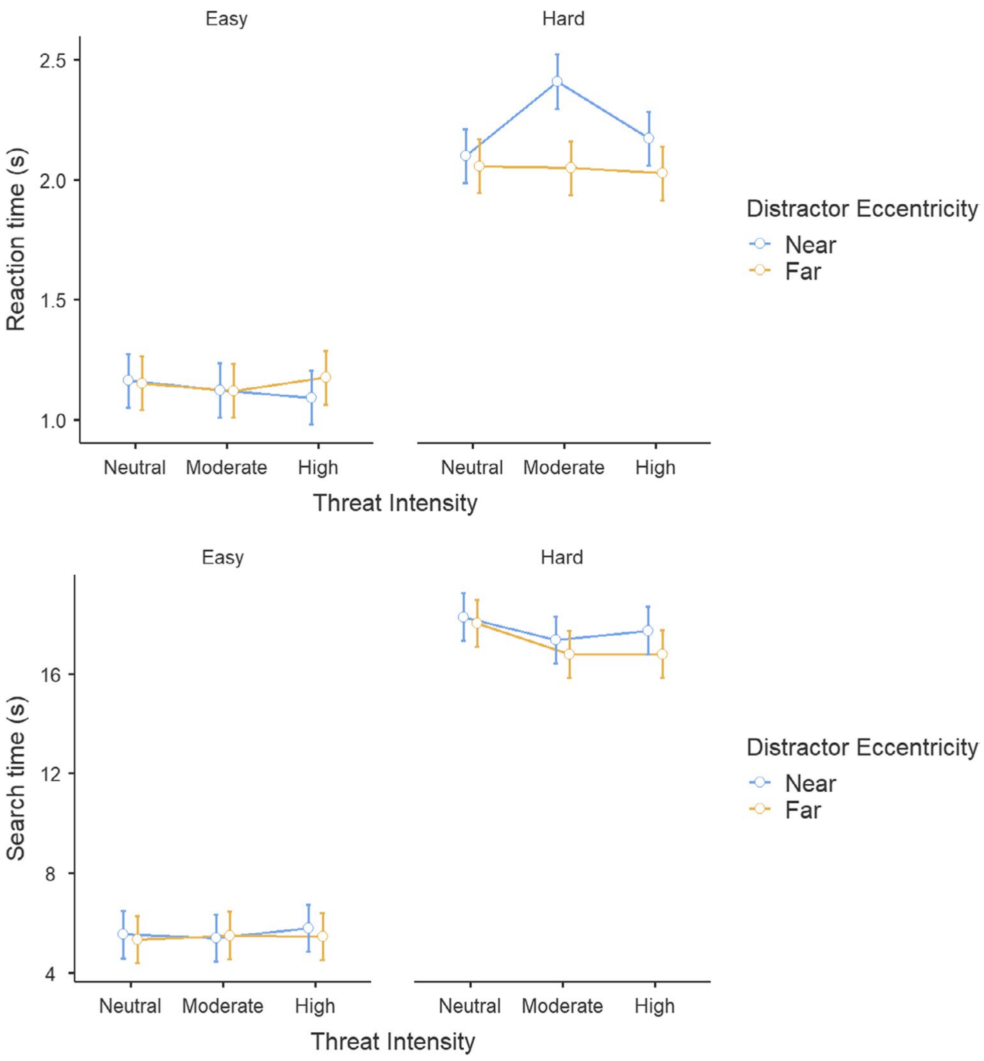

**FIGURE 2** Reaction times for finding the first number and for finding all the numbers in top and bottom panels, respectively. Findings are presented across Threat Intensity levels using separate plots for the easy and hard conditions (left and right panels, respectively) and for the near and far Distractor Eccentricities (blue and yellow lines, respectively). Error bars represent 95% confidence intervals

the latter two did not differ ($t(43) = 0.14$, $p = .989$). See Figure 4 for the interaction and Appendix 5 for the descriptive statistics.

# DISCUSSION

Despite the importance of understanding how attention is prioritized and allocated to threatening images, it has been suggested that there is a crisis in this field (McNally, 2018), particularly with respect to the ABT framework because the underlying processes are not fully understood, and the reliability of the measures used to investigate this framework has been called into question. Therefore, in this study, we sought to examine the two key components of ABT: salience and the executive control of attention (Dolcos et al., 2020; Mogg & Bradley, 2018). We did this by using a recently introduced paradigm that

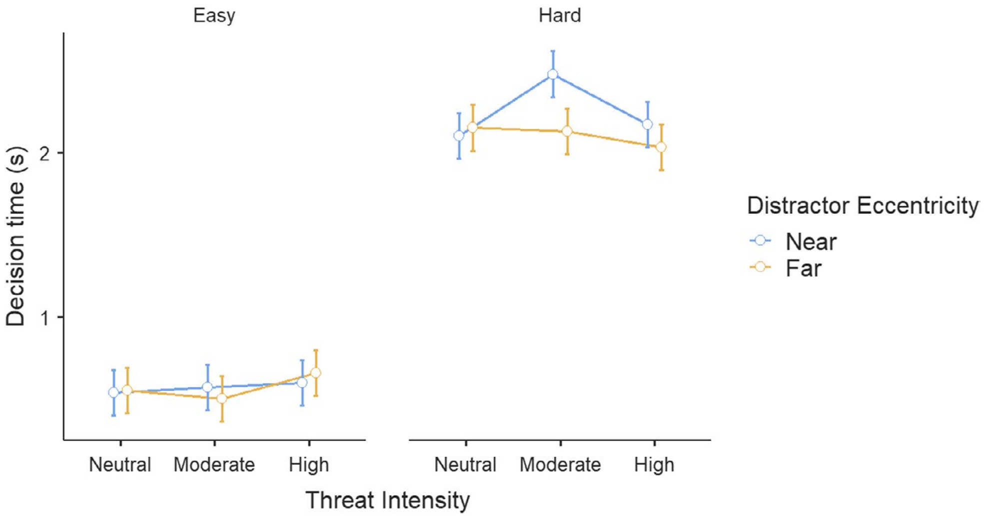

**FIGURE 3** Decision time (elapsed time from first fixation to first click) on the number one. Findings are presented across Threat Intensity levels using separate plots for the easy and hard conditions (left and right panels, respectively) and for the near and far Distractor Eccentricities (blue and yellow lines, respectively). Error bars represent 95% confidence intervals

is suitable for addressing these networks separately. Further, we circumvented the problems associated with using task-relevant threats (Cisler & Koster, 2010; McNally, 2018) by employing task-irrelevant distractor images that varied in emotional intensity. Using task-irrelevant images allowed us to tease apart the effects of threat on salience and the executive control of attention. The images appeared either near to the main task (in a parafoveal position) or farther away from the main task (in a peripheral position). We manipulated the distance of the images to investigate whether threatening stimuli might have a greater advantage in capturing attention compared to other stimuli when viewed outside of central vision. Finally, we manipulated the cognitive load of the task by increasing its difficulty. We sought to test whether distractor interference is as effective during low cognitive load as it is during high cognitive load (de Fockert et al., 2001; Lavie, 2010). Generally speaking, our results supported the *load theory of attention* (de Fockert et al., 2001; Lavie, 2010); that is, task-irrelevant interference was only present when the task was difficult, not when it was easy.

In the easy – that is, low cognitive load – task, we had two key results. First, when the image was close to the matrix, participants were faster to find the first number but slower to complete the search task in the presence of more threatening distractors. Better performance for finding the number one is in line with the previously documented *arousal stimulation effect* (Zsido et al., 2018, 2019); that is, the arousal level conveyed by the emotional picture seems to facilitate visual search performance. However, we may have expected, therefore, the same effect for overall search performance – that is, participants completing the entire task faster in the presence of more threatening distractors – but that is not what we found. One explanation could be that the presence of a threat was detected quickly without an overt shift of attention (Cave & Batty, 2006; Fernández-Martín et al., 2017), which in turn alerted the visual system (Fang et al., 2016; Schupp et al., 2003) hastening performance for finding number one due to an overall benefit from increased arousal. This finding is in line with previous physiological studies (Calvo et al., 2015; De Cesarei & Codispoti, 2008; Fernández-Martín et al., 2017). Further, it supports the *vigilance-avoidance theory* (Mogg et al., 2004; Wentura et al., 2000); that is, the spatial position of the threatening picture may have been inhibited and orienting attention to a *different* spatial position was thereby comparatively enhanced. The finding of shorter fixation durations for threatening compared to neutral images may support this explanation. Nevertheless, the constant need to suppress a spatial position and avert attention might have imposed extra demands on the executive control network. The fact that we found contradictory evidence to the general attention-grabbing nature of threats (based on

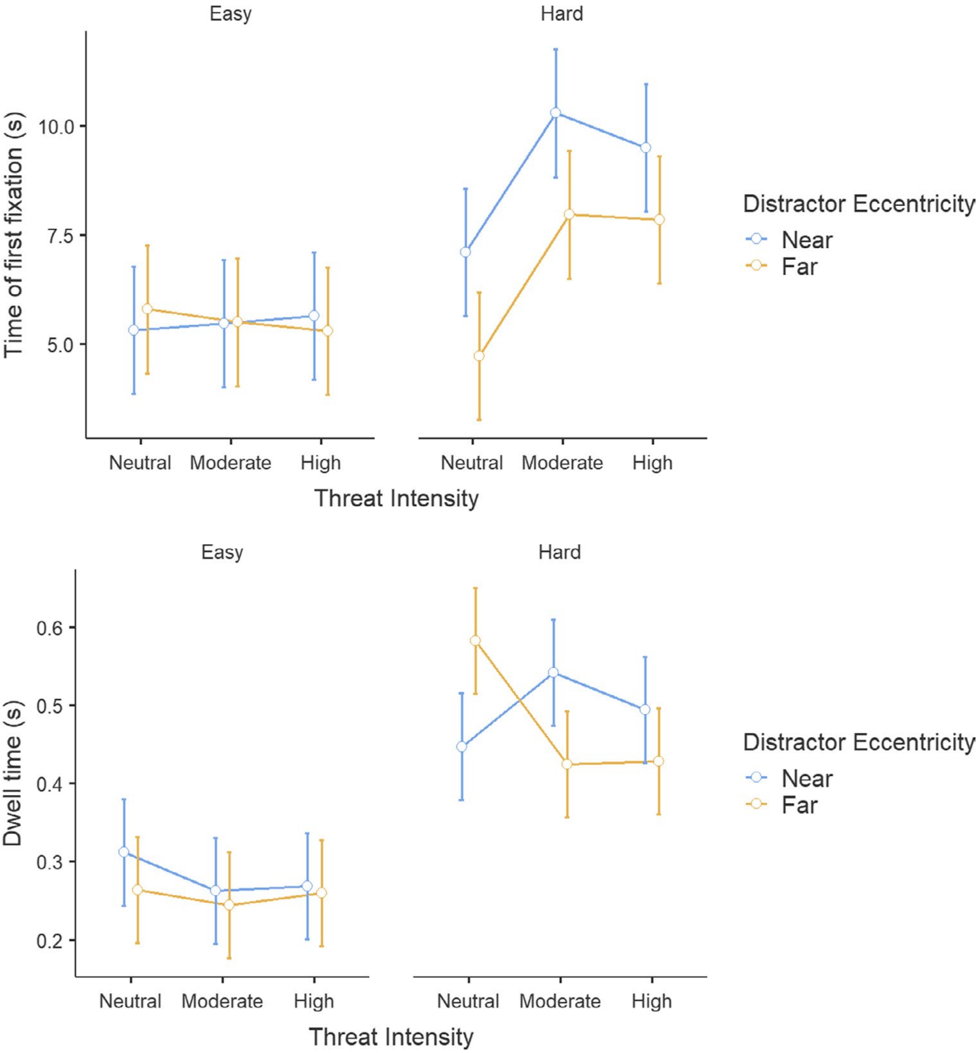

**FIGURE 4** Time of first fixation (on the number one) and distractor dwell time in top and bottom panels, respectively. Findings are presented across Threat Intensity levels using separate plots for the easy and hard conditions (left and right panels, respectively) and for the near and far Distractor Eccentricities (blue and yellow lines, respectively). Error bars represent 95% confidence intervals

the eye-tracking results) might lend further support to this assumption. Accordingly, when participants were conducting the search task, active inhibition of the highly threatening image would be demanding of cognitive resources, resulting in a limited availability of WM resources to complete the primary task (Schmeichel, 2007; Unsworth & Robison, 2017), thus leading to poorer overall performance.

Task performance was largely equivalent across conditions when the task was easy. However, a lack of effects in the easy conditions does not necessarily direct information on the presence or absence of covert attentional shifts (which are not possible to measure by simply monitoring eye gaze). More cognitive resources remained available for control functions during the easy task which could be the reason why the effects of our manipulations were less pronounced during the easy task. Peripheral vision alone could be enough to identify an image as threatening (even if the specific nature of that threat was not recognized) (Calvo et al., 2015; De Cesarei & Codispoti, 2008), resulting in the active inhibition of that spatial position. Previous research has shown that detection of threatening stimuli is prioritized due to its advantage in visual processing via the magnocellular pathway (Van Strien et al., 2016). This is presumably because the processing of the general features strongly associated with threats (e.g., movement, sinusoid shape) does not suffer from the declining performance of the peripheral visual field compared to central vision (Carretié et al., 2017; De Cesarei & Codispoti, 2008; Gao et al., 2017). Therefore, even partial information processed via the magnocellular pathway may trigger the brainstem–amygdala–cortex alarm system (Csathó et al., 2008). That is, the participant may know *that* some threatening object is there but not be aware of what is it *specifically*. Nonetheless, it shall also be noted that we cannot fully out rule the possibility that the results are due to the fact that our sample included healthy individuals (not diagnosed with an anxiety disorder). As McNally (2018) also noted, not all people with an anxiety disorder showed ABT. In contrast, however, it was also shown that patients with mental health issues may have limited control capacity (Cole et al., 2014). Therefore, the homogeneity of the results might mean that our sample of healthy participants could ignore the distractor images (even if they had knowledge of them) and focus on the task.

In the hard – that is, high cognitive load – task, our results were directly in line with that of previous research using a similar paradigm (Zsido et al., 2018, 2019). Here, the presence of a threatening image distracted attention away from the search array, resulting in longer reaction times to find the first number. However, the arousal level difference between the moderate and high threat images are at odds with the extent to which the images are distracting and arousing, resulting in a paradoxical reaction time pattern whereby highly threatening images led to reaction times that were similar to when a neutral image was present (Meyer et al., 2019; Zinchenko et al., 2020; Zsido et al., 2019). The longer decision time when highly threatening images were presented on the periphery could suggest that either the arousal stimulation effect facilitates the performance of the visual system or shortens the movement time once the decision is made. This is in line with previous studies arguing that the visual processing of threatening stimuli is prioritized via the magnocellular pathway and the superior colliculus-pulvinar-amygdala pathway (Almeida et al., 2015; Soares et al., 2017; Van Strien et al., 2016; Wang et al., 2018), possibly due to the evolutionary advantage conferred by being able to quickly and efficiently detect potential dangers outside the direct line of sight. Although the elongated reaction and decision times for threatening compared to neutral stimuli might be in accordance with a freezing response (Rösler & Gamer, 2019), it should be noted that such behaviour is adaptive even in non-anxious participants as a means to facilitate finding an escape from the approaching threat. However, this cannot explain the results regarding higher intensity threats wherein the pattern of the results is better explained by the arousal stimulation effect.

Regarding the overall search time, we found (again consistent with the arousal stimulation effect) that threatening images resulted in faster search performance compared to neutral ones. That is, participants finished finding numbers one to ten faster when the distractor image was threatening. We did not find increased dwell time or faster attentional capture for threatening images, which is consistent with the *signal suppression hypothesis* (Sawaki & Luck, 2010). This hypothesis argues that before the bottom-up processing of a given salient stimulus can be completed, its signal can sometimes be suppressed by top-down control mechanisms, allowing the goal-driven mechanisms to override the item's salience. The suppression is not an automatic process, however, and it is therefore highly dependent on the availability of WM resources (Schmeichel, 2007; Zanto et al., 2011). Therefore, while the suppression of threatening images was nearly absolute in the easy task, in the hard task suppression was weakened because the available WM resources were comparatively more limited.

In sum, our results demonstrate that task-irrelevant distractors are more prone to affect visual cognition during high cognitive load. Further, we showed that the arousal level conveyed by threatening stimuli can compensate for the extent to which they are distracting by facilitating visual search processes when arousal is heightened. Task-irrelevant threatening images are distracting because they tend to trigger the brainstem-amygdala-cortex alarm system in spite of the top-down attentional control, sweeping the attentional focus from the task to the task-irrelevant image. At the same time, the presence of a threat increases the activity in the central arousal systems (Howells et al., 2012) that also arises from the brainstem (Moruzzi & Magoun, 1949). This results in an increased arousal level which may boost participants' overall performance. That is, participant may then find numbers faster, presumably partially due to the increase in WM capacity (Nielson et al., 1996; Sakaki et al., 2019) and faster attentional movements (Bradley et al., 2011; Gomez et al., 2019). The facilitated search performance thus offsets the initial loss of time caused by the distraction of the threatening image.

We also demonstrated that the number matrix paradigm is suitable to use for future studies investigating the orienting and executive control networks of attention. Finally, we found evidence in favour of the vigilance-avoidance hypothesis of the three ABT components, and consequently for the signal suppressing hypothesis.

Future research should include a greater emphasis on the extent to which individual differences interact with the arousal and distracting effects of threats. For instance, the inclusion of anxiety measures – both questionnaire and physiological (e.g., skin conductance) measures – would allow for direct monitoring of whether any of the participants become hyper-aroused because of task difficulty, threat perception, anxiety, or worrying. For this purpose, using valence and arousal as continuous predictor variables instead of dichotomizing them may lead to the better understanding of the results, although the fact that the relationship between these variables and task performance does not seem linear might make this approach less feasible. Moreover, it is clear that individual differences in WM capacity reflect differences in executive attention and cognitive control. Therefore, we must consider that although all of our participants could solve both the easy and hard tasks, it is possible that the relative difference between conditions was not equivalent for all participants. Future work could deal with this potential inequity by assessing individual differences in WM capacity prior to the study, and by adjusting task difficulty for each participant (e.g., by manipulating the volume of numbers to be searched for) such that overall search times are approximately equal across individuals.

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## CONFLICTS OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## AUTHOR CONTRIBUTION

**Andras N. Zsido:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Funding acquisition (equal); Investigation (equal); Methodology (equal); Project administration (equal); Resources (equal); Software (equal); Supervision (equal); Visualization (equal); Writing – original draft (equal); Writing – review & editing (equal). **Diana T. Stecina:** Conceptualization (equal); Investigation (equal); Methodology (equal); Writing – original draft (equal); Writing – review & editing (equal). **Rebecca Cseh:** Data curation (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – original draft (equal); Writing – review & editing (equal). **Michael C. Hout:** Conceptualization (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Supervision (equal); Writing – original draft (equal); Writing – review & editing (equal).

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

**Method S1** Main effects and interactions that are not the primary focus.

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## APPENDIX 1

### DESCRIPTIVE DATA FOR FINDING THE FIRST NUMBER, PRESENTED SEPARATELY FOR EACH CONDITION. MEAN REACTION TIMES AND STANDARD DEVIATION (*SD*) VALUES ARE PRESENTED IN SECONDS

| | | | | 95% Confidence Interval | |
|---|---|---|---|---|---|
| **Task difficulty** | **Distractor eccentricity** | **Threat intensity** | **Mean** | **Lower** | **Upper** |
| Easy | Near | Neutral | 1.16 | 1.051 | 1.28 |
| | | Moderate | 1.12 | 1.010 | 1.24 |
| | | High | 1.09 | .980 | 1.21 |
| | Far | Neutral | 1.15 | 1.040 | 1.26 |
| | | Moderate | 1.12 | 1.008 | 1.23 |
| | | High | 1.18 | 1.064 | 1.29 |
| Hard | Near | Neutral | 2.10 | 1.987 | 2.21 |
| | | Moderate | 2.41 | 2.297 | 2.52 |
| | | High | 2.17 | 2.059 | 2.28 |
| | Far | Neutral | 2.06 | 1.945 | 2.17 |
| | | Moderate | 2.05 | 1.937 | 2.16 |
| | | High | 2.03 | 1.914 | 2.14 |

## APPENDIX 2

### DESCRIPTIVE DATA PRESENTED FOR THE ELAPSED TIME BETWEEN FINDING THE FIRST AND THE LAST NUMBERS, SHOWN SEPARATELY FOR EACH CONDITION ACROSS BOTH EXPERIMENTS. MEAN REACTION TIMES AND STANDARD DEVIATION (*SD*) VALUES ARE PRESENTED IN SECONDS

| | | | | 95% confidence interval | |
|---|---|---|---|---|---|
| **Task difficulty** | **Distractor eccentricity** | **Threat intensity** | **Mean** | **Lower** | **Upper** |
| Easy | Near | Neutral | 5.53 | 4.58 | 6.48 |
| | | Moderate | 5.39 | 4.44 | 6.34 |
| | | High | 5.79 | 4.84 | 6.73 |
| | Far | Neutral | 5.32 | 4.37 | 6.27 |
| | | Moderate | 5.49 | 4.54 | 6.44 |
| | | High | 5.44 | 4.50 | 6.39 |
| Hard | Near | Neutral | 18.28 | 17.33 | 19.23 |
| | | Moderate | 17.36 | 16.42 | 18.31 |
| | | High | 17.73 | 16.79 | 18.68 |
| | Far | Neutral | 18.03 | 17.08 | 18.98 |
| | | Moderate | 16.78 | 15.83 | 17.73 |
| | | High | 16.79 | 15.84 | 17.74 |

## APPENDIX 3

## DESCRIPTIVE DATA PRESENTED FOR DECISION TIME (ELAPSED TIME FROM FIRST FIXATION TO FIRST CLICK), SHOWN SEPARATELY FOR EACH CONDITION. MEAN VALUES AND STANDARD DEVIATION (*SD*) VALUES ARE PRESENTED IN SECONDS

| Task difficulty | Distractor eccentricity | Threat intensity | Mean | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Easy | Near | Neutral | 0.540 | 0.401 | 0.679 |
| | | Moderate | 0.573 | 0.434 | 0.712 |
| | | High | 0.600 | 0.461 | 0.739 |
| | Far | Neutral | 0.555 | 0.416 | 0.694 |
| | | Moderate | 0.504 | 0.365 | 0.643 |
| | | High | 0.660 | 0.520 | 0.799 |
| Hard | Near | Neutral | 2.102 | 1.963 | 2.241 |
| | | Moderate | 2.477 | 2.338 | 2.617 |
| | | High | 2.171 | 2.032 | 2.310 |
| | Far | Neutral | 2.151 | 2.012 | 2.291 |
| | | Moderate | 2.129 | 1.990 | 2.268 |
| | | High | 2.034 | 1.894 | 2.173 |

## APPENDIX 4

## DESCRIPTIVE DATA PRESENTED FOR THE TIME OF THE FIRST FIXATION, SHOWN SEPARATELY FOR EACH CONDITION ACROSS BOTH EXPERIMENTS. MEAN VALUES AND STANDARD DEVIATION (*SD*) VALUES ARE PRESENTED IN SECONDS

| Task difficulty | Distractor eccentricity | Threat intensity | Mean | 95% confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| Easy | Near | Neutral | 5.32 | 3.87 | 6.78 |
| | | Moderate | 5.47 | 4.01 | 6.92 |
| | | High | 5.64 | 4.19 | 7.10 |
| | Far | Neutral | 5.79 | 4.34 | 7.25 |
| | | Moderate | 5.50 | 4.04 | 6.96 |
| | | High | 5.30 | 3.84 | 6.75 |
| Hard | Near | Neutral | 7.10 | 5.64 | 8.55 |
| | | Moderate | 10.28 | 8.82 | 11.73 |
| | | High | 9.50 | 8.04 | 10.95 |
| | Far | Neutral | 4.73 | 3.27 | 6.18 |
| | | Moderate | 7.96 | 6.50 | 9.42 |
| | | High | 7.84 | 6.38 | 9.30 |

## APPENDIX 5

## DESCRIPTIVE DATA PRESENTED FOR TOTAL TIME SPENT VIEWING, SHOWN SEPARATELY FOR EACH CONDITION. MEAN VALUES AND STANDARD DEVIATION (*SD*) VALUES ARE PRESENTED IN SECONDS

| | | | | 95% confidence interval | |
|---|---|---|---|---|---|
| **Task difficulty** | **Distractor eccentricity** | **Threat intensity** | **Mean** | **Lower** | **Upper** |
| Easy | Near | Neutral | 0.312 | 0.244 | 0.380 |
| | | Moderate | 0.263 | 0.195 | 0.331 |
| | | High | 0.268 | 0.200 | 0.336 |
| | Far | Neutral | 0.264 | 0.196 | 0.332 |
| | | Moderate | 0.244 | 0.176 | 0.312 |
| | | High | 0.260 | 0.192 | 0.328 |
| Hard | Near | Neutral | 0.447 | 0.379 | 0.515 |
| | | Moderate | 0.541 | 0.474 | 0.609 |
| | | High | 0.494 | 0.426 | 0.562 |
| | Far | Neutral | 0.582 | 0.514 | 0.650 |
| | | Moderate | 0.425 | 0.357 | 0.493 |
| | | High | 0.428 | 0.360 | 0.496 |