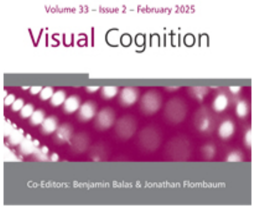

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Multimodal task-irrelevant threat information and their effects on visual search tasks

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ABSTRACT

We investigated the effect of threatening distractors on attentional executive control. While previous visual search studies found that task-irrelevant threatening stimuli are harder to ignore than neutral or other valenced stimuli, they have only used static pictures that do not resemble real-life threat encounters. Therefore, this study extends the scope by using multimodal stimuli (audiovisual, muted videos, pictures), threatening and neutral, as task-irrelevant distractors. Our results showed that participants spent more time searching for the first target number when presented with a threatening compared to a neutral picture, and participants were faster in picture modality compared to both audiovisual and muted video stimuli (regardless of valence). Furthermore, participants completed the task (i.e., found all numbers) faster in the threatening muted video compared to neutral one but threatening audiovisual distractors resulted in worse performance compared to neutral audiovisual ones. We found no significant correlation between participants' self-reported fear and anxiety levels and the behavioural measures. These results suggest the complex interplay between emotional condition and sensory modality in attentional processes, emphasizing the differential effects of threat across visual and audiovisual contexts.

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Task-irrelevant distractors; multimodal stimuli; number matrix task; visual search; visual working memory

A variety of previous studies found that threatening stimuli are more salient than other emotional categories, making them more difficult to ignore, i.e., threatening stimuli capture attention more readily and disengagement from them is harder compared to neutral and other emotional stimuli (Blanchette, 2006; Cisler et al., 2009; Koster et al., 2005; LoBue & Matthews, 2014; March et al., 2017; McNally, 2019; Mogg & Bradley, 2004, 2018; Mulckhuyse, 2018; Öhman et al., 2001; Subra et al., 2018; Zsido et al., 2023). Visual search paradigms are effective for studying attentional processes because they can be adapted to study different aspects of selective visual processing (Krummenacher et al., 2010). For example, threatening emotional stimuli easily attract attentional resources. While this often leads to better adaptive actions, it can be detrimental if the emotional information is unrelated to the task and must be ignored (Dolcos et al., 2020; Garcia-Pacios et al., 2015). Attentional biases towards threat are frequently discussed in terms of attentional priority maps and biased competition(Desimone & Duncan, 1995). In this model, multiple stimuli compete for processing, with selection depending on both bottom-up salience and top-down goals. Threatening stimuli tend to gain an advantage in this competition due to their high evolutionary relevance. However, their ability to capture attention can be affected by perceptual demands or competing sources of salience. Consequently, it has been argued (Calvo & Castillo, 2005; Cisler & Koster, 2010; McNally, 2019; Richards et al., 2012) that task-irrelevant distractors should be used in threat research to disentangle their effects on bottom-up (attentional grab) and top-down (executive attentional control) processing. Both bottom-up and top-down processes contribute to perception and attention to threatening stimuli (Ochsner et al., 2009). Bottom-up processes tend to respond to immediate stimuli and processes are driven by external stimuli (Katsuki & Constantinidis, 2014).

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Consequently, bottom-up factors, such as the salience of a stimulus, tend to enhance neural responses to fearful stimuli (Ochsner et al., 2009). In contrast, top-down processes involve cognitive control and interpretation and are internally guided by factors such as prior knowledge, conscious plans, and current goals (Katsuki & Constantinidis, 2014). Consequently, top-down factors, such as attentional load, can reduce these responses (Hsu & Pessoa, 2007). However, the vast majority of research investigating the effect of threat stimuli on attention has used static pictures. In everyday life, however, we rarely encounter real threats as static pictures. Instead, they often include dynamic and multimodal aspects such as motion and sound, which may have different or more pronounced effects on cognitive processing and attentional control. These modalities place different demands on the attentional system, thereby altering the manifestation of threat-related biases. Models of attention, such as attentional capture and disengagement (Fox et al., 2002; Koster et al., 2006; Mogg & Bradley, 2018), suggest that static images may trigger the early orienting and delayed disengagement effects more effectively. However, dynamic or multisensory stimuli may override or suppress the influence of emotional content due to their increased load or salient motion cues (Lavie, 2010; Talsma et al., 2010; Wolfe, 2021). Furthermore, dual-process models posit that bottom-up salience (e.g., motion or intensity) and top-down control (e.g., task goals) compete for attentional resources (Desimone & Duncan, 1995; Kahneman, 1973). In dynamic conditions, bottom-up salience from movement or audiovisual synchrony may dominate, leaving less room for threat characteristics to guide attention. Furthermore, objects that appear to be moving rapidly toward us (looming stimuli) have a particularly strong and distinctive impact on our attention. When these stimuli are charged with emotional salience or threat, this effect becomes even stronger. Dynamic stimuli, even without conscious effort, draw our attention quickly often outperforming static visual stimuli (Fernández-Folgueiras et al., 2021; Lin et al., 2009). Looming stimuli that combine more than one sensory system (visual and auditory) results in increased attentional capture, suggesting enhanced sensitivity to approaching threat via multiple sensory channels (Cappe et al., 2009; Maier et al., 2004). Similarly, the load theory of attention suggest that distractor interference is greater in high compared to low cognitive load tasks (De Fockert et al., 2001; Lavie, 2010). Applying this theory to the processing of threats suggests that the modality and sensory richness of the stimuli (e.g., audiovisual versus static) may influence attentional capture by altering perceptual load.

A key question is whether the emotional salience of threat remains influential when competing with the perceptual salience of dynamic, multisensory distractors. The present study contributes to existing research by investigating how task-irrelevant audiovisual and static threatening information affects visual search performance. It extends previous research focusing on static stimuli by investigating how dynamic and multimodal stimuli affect attentional control systems. In the effort to investigate modality and threat effects on attention, a matrix-number task was employed used in previous research (Zsido et al., 2022). We maintained the neutral and threatening stimuli while introducing three different modalities: audiovisual, muted video and picture. We presented the number matrix in the centre of the screen with a distractor stimulus appearing in one of the 4 corners of the number screen, close to the number matrix. Participants searched for numbers in ascending order (starting from 1) in a matrix, with task-irrelevant emotional distractors presented close by. This paradigm offers an attentional capture measure by computing the time it takes to find the first target number, with sustained attention or executive control measured by the time to find number 10. With three stimulus modalities incorporated – audiovisual, muted video and picture – we sought to study how the emotional stimulus format acts on visual search performance. We selected weather-related stimuli for both the threats (e.g., storms, lightning, and tornadoes) and neutral conditions because they are ecologically valid and represent real-world dangers that are inherently dynamic and multimodal. In contrast to other commonly used threat categories (e.g., angry faces, snakes or spiders), weather events can be naturally presented in static, dynamic and audiovisual formats. This enabled us to create stimuli that closely matched across different formats, providing a unique opportunity to test how the format of a stimulus influences attentional capture and control.

Overall, we propose that participants will find it more difficult to suppress the threatening task-irrelevant information. Previous studies suggest that threatening stimuli capture attention rapidly than neutral stimuli by increased fixations on the threat-related cues (Pakai-Stecina et al., 2023; Trujillo et al., 2021). Additionally, static images – while common in laboratory settings – and may not fully engage perceptual and emotional processes characteristic of real-world experiences (Sonkusare et al., 2019). Unlike static stimuli, dynamic and audiovisual stimuli engage multiple senses at once, which activates broader neural networks and potentially shifting the relationship between bottom-up attentional capture and top-down attentional control (Stein & Stanford, 2008; Talsma et al., 2010). Indeed, the Load Theory of Attention (Lavie et al., 2004) suggests the degree of distraction caused by task-irrelevant stimuli depends on the perceptual load. A high perceptual load implies less cognitive capacity to inhibit distractor interference. In our design, the highest perceptual load is imposed by the audiovisual stimuli as they combine visual and auditory inputs. Static images and muted videos have lower demands.

Consequently, we expect that participants will be slower to find number 1 (the first target) in the threat condition compared to the neutral condition, but will produce faster search times (i.e., finish the task faster). Furthermore, we expect this effect to be more pronounced in the audiovisual condition compared to the muted video and picture-only conditions. In addition, on an exploratory basis, as it has rarely been done in previous research, we also sought to test whether there is a relationship between subjective levels of anxiety and fear and our behavioural measures. Here, we anticipated that participants who are more fearful of threatening weather would find number 1 slower and produce longer search times in the number matrix task.

Methods

Participants

The estimated required total sample size for ANOVA with fixed effects, main effects, and interactions using the following parameters f = .25, power = .95, r = 0.5 is 28. However, we wanted to collect more data than this to make sure that we have adequate power for the interaction. Thus, our goal was to oversample, and we therefore collected data in one-week increments until the required sample size was exceeded. A total of 48 students (11 male, age range = 19-24) participated. All participants reported normal or corrected-to-normal vision. Our research was approved by the Hungarian United Ethical Review Committee for Research in Psychology 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. The study was preregistered at OSF (https://osf.io/9r2vn/?view_only = a281a504d9284cfa8703c2d4a4efa156).

Questionnaire

To measure how fearful participants are of threatening weather conditions, we used the Storm Fear Questionnaire (SFQ) developed by Nelson et al. (2014) in 2014. SFQ is a self-report questionnaire consisting of 15 items that participants rate on 5-point Likert-type scales (0 = not at all true and 4 = almost always true). The scale provides a score ranging from 0 to 60, with higher scores indicating greater fear of severe weather conditions. The McDonald's omega for the present sample was 0.896, indicating that the questionnaire scores were reliable.

We also used the short form of the Spielberger State-Trait Anxiety Inventory (STAIS-5/STAIT-5) (Zsido, Teleki, et al., 2020) to measure participants' anxiety levels. The scale consists of two domains, specifically state and trait anxiety each measured with five items that participants rate on 4-point Likert-type scales (1 = not at all, 4 = very much). State anxiety indicates how the patient feels at the moment, whereas trait anxiety indicates how the patient feels in general. Higher scores indicate greater levels of anxiety. The McDonald's omega was 0.836 for STAIS-5 and 0.806 for STAIT-5 on the present sample, indicating sound reliability.

Experimental stimuli and apparatus

The visual search task consisted of sequentially looking for numbers in ascending order starting from the number 1 and clicking on them with the left mouse button in matrix-like arrays. See Figure 1 for an example of the stimulus. The number matrices used in this study were generated by a specialized

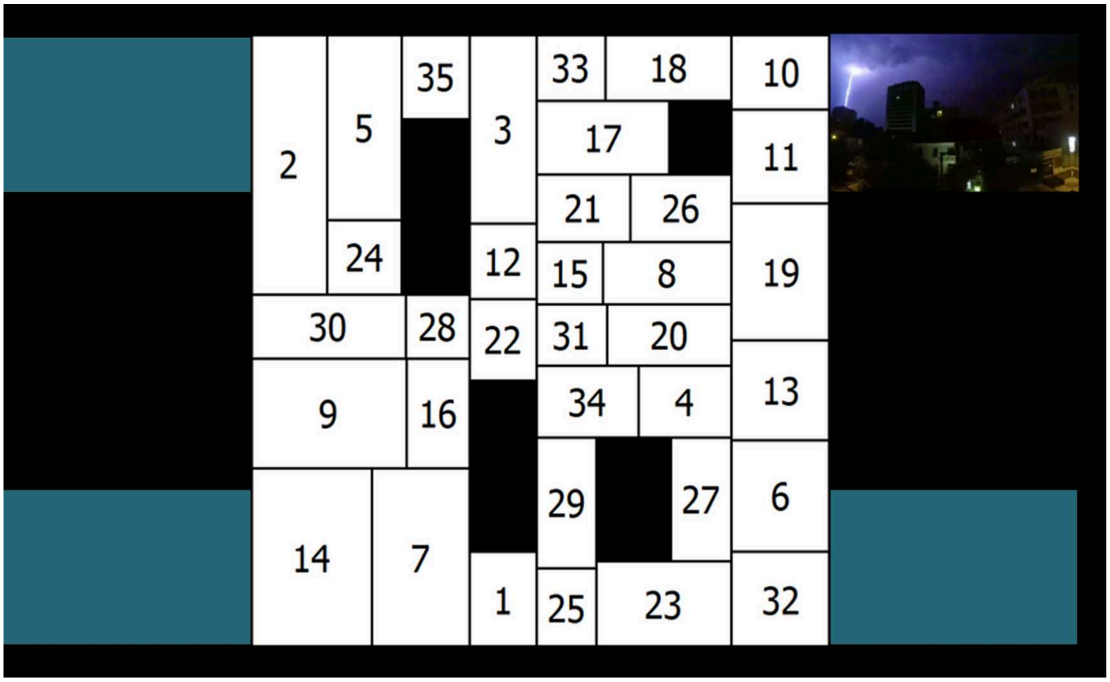

Figure 1. An illustrative example of the stimuli used in this study. Participants searched for numbers in ascending order in the matrix-like array while audiovisual, muted video or pictorial distractors were presented in one of the four possible locations. Please note that while we highlighted the possible distractor locations with blue rectangles for better visibility here, they were not used during the experiment.

programme, freely accessible at http://baratharon.web.elte.hu/nummatrix/.

In the task, similarly to previous studies using this paradigm (Keys et al., 2021; Krause et al., 2017; Zsido et al., 2022), the numbers ranged from 1 to 35, with each number appearing only once in a given matrix. The matrices were 700 × 700 pixels (17.55° x 17.55°visual angle) in size. They contained 35 white rectangles and 3–6 black rectangles, randomly distributed among the white rectangles to maintain the overall shape of the search area. The width and height of the rectangles varied from 70 to 230 pixels (1.51° to 4.98°). Both the matrices and the rectangles had a 2-pt black border. All the rectangles had a number printed in black in 32-pt Tahoma font. The number matrices were randomized across individuals and trials. For each trial, a task-irrelevant distractor appeared in one of the four possible spatial positions (the corners of the number matrix).

We chose weather stimuli as distractors because they could be matched across modalities. Thus, we opted not to use standardized emotional databases in order to ensure ecological validity and because stimulus types are not well represented in such databases, which compose mainly of static images of a single, central object, usually depicting people and there were not enough materials. To ensure that the stimuli were closely matched in terms of their visual characteristics across the different conditions the muted and audiovisual conditions used the same videos, which differed only in terms of whether or not sound was present. There was only one exception to this, the muted version of an audiovisual stimuli was rated low on threat, and we therefore selected a different, but similar muted video to replace it. For the picture condition, we either extracted still frames from these videos or selected highly similar images. Therefore, to meet our goal, we sourced the task-irrelevant visual distractor stimuli from copyright-free online platforms using Google Images and YouTube and did not want to mix the materials from the image sets with the materials sources on internet. For searches of the materials, we used keywords such as "storm," "lightning," "flood," "tornado," "rainstorm," and "severe weather." A key selection criterion was the exclusion of any stimuli showing people or animals to isolate participants' responses to weather conditions themselves. While we retained the original sources for all videos, the exact image sources could not always be documented due to the nature of image collection via search engines. All available source details and stimuli for videos are provided via the study's OSF repository.

All sourced stimuli were then validated for emotional content through a pre-rating study. By this we intended to ensured both emotional relevance and ecological validity for the purposes of the present study. The audiovisual and the muted video stimuli were the same video, only with the difference of extracting the sound of the videos. An independent group of participants (N = 46) rated all materials along four dimensions: positivity, negativity, threat level, and arousal. Materials were rated on 7-point Likert-type scales (1 = not at all to 7 = very much positive/negative/threatening/arousing). Thus, arousal in this current study refers to subjective self-reported arousal, not physiological arousal. Such subjective assessments of arousal have been shown in earlier research to be highly correlated with physiological measures of affective processing (such as heart rate, skin conductance, EEG, and EMG), thereby confirming their validity as a marker of emotional intensity (Andersen et al., 2020; Cuthbert et al., 2000; Olofsson et al., 2008). For each type of modality, we selected 14 stimuli based on valence, arousal, and threat level. We sought to include stimuli in the "threatening" category that were rated as more threatening and arousing than the midpoint (3.5) of the scale (of 1–7) for both arousal and threat dimensions . Furthermore, in order to minimize the inclusion of positively arousing stimuli, threatening stimuli had to have positivity rating as low as possible (< 2.5). Our stimulus set was consistently threatening in terms of both perceived arousal and content with these criteria. There was one exception to this, as we also included one audiovisual stimuli that had an arousal rating of 3.375 (and threat rating of 4.0) to have the same number of stimuli across all modalities, and to avoid unbalanced repetition of stimuli.

A stimulus was categorized as neutral if it received low threat (<2.5) and arousal ratings (<3.5). Stimulus individually was rated on four dimensions. These ratings were used to classify the stimuli into threatening and neutral sets, making sure that they were clearly distinct and did not overlap. To ensure that the threat and arousal ratings of threatening and neutral stimuli were, in fact, different we used paired-sample t-tests. Results showed that threat ratings were significantly higher for threatening compared to neutral stimuli in all three modalities (picture: $t(6) = 20.80$, $p < .001$; muted video: $t(6) = 16.30$, $p < .001$; audiovisual: $t(6) = 12.50$, $p < .001$). Arousal ratings were also significantly higher for threatening compared to neutral stimuli (picture: $t(6) = 10.92$, $p < .001$; muted video: $t(6) = 4.69$, $p = .003$; audiovisual: $t(6) = 5.27$, $p = .002$). All of the the materials (including those that did not meet our inclusion criteria), instructions for raters, the ratings, and a note on which materials were used in the experiment are available on the OSF site of the project: https://osf.io/xzfhc/?view_only = 47dc806efef74b12beaa1735072a611d.

Procedure

The experiment was carried out in a dimly lit, quiet room in groups of up to eight, with each participant having a separate computer booth. On arrival to the lab, participants were seated at approximately 60 cm from the monitor (21.5-inch LCD with a resolution of 1920 × 1080, 16:9 aspect ratio, a refresh rate of 60 Hz, and a colour depth of 16.7 M) and were given verbal and written instructions. Participants completed all questionnaires before they started the experiment. Then, they were given headphones and asked to adjust the volume to their liking before the experiment began. They then completed a practice trial and were given the opportunity to ask questions. Once they reported that they fully understood the task, the experiment began. We used the PsychoPy, software version 2023.2.3 3.0 for Windows (Peirce, 2007), to present the stimuli and to collect participants' responses. Behavioural responses were recorded using the computer mouse. On each trial, a task-irrelevant stimulus from one of the modalities (audiovisual, muted video, image) appeared in one of the four possible positions (one of the corners of the matrices). Each trial began with a white fixation cross displayed on a black background (for 1000 milliseconds). The number matrix was then displayed in the centre of the screen, with a stimulus at one of four possible locations (one of the corners of the matrix); the background remained black (again, see Figure 1 for an illustrative example). Participants were instructed to find the numbers in ascending order starting with number 1 and to click on them using the computer mouse. Each number matrix was presented for 30 s. The experiment was broken down into three blocks. We examined their reaction times (RTs) to find the number 1 and for the overall search time (the time spent finding numbers 1 through 10). We arranged the blocks according to stimulus modality, with each block containing an equal number of threatening (14) and neutral (14) trials (7 stimuli in each condition, displayed twice). Thus, there were 28 trials per block and 84 trials for the whole study. Trials were randomized within blocks and the order of presentation was counterbalanced across participants by randomizing the order of the blocks. All three blocks were administered in one test session, although participants could take a short break between them if they felt it was necessary. The experiment lasted approximately 60 minutes.

Statistical analyses

The analysis plan was preregistered (https://osf.io/9r2vn/?view_only = a281a504d9284cfa8703c2d4a4efa156). We performed the statistical analyses using the JAMOVI software version 2.2.5 for Windows (Jamovi (Version 2.5) [Computer Software]., 2024). The assumption of normality was not violated, the absolute value of Skewness and Kurtosis were less than 2 for all variables used (George & Mallery, 2019). We performed 2×3 mixed ANOVAs with stimulus Emotional Condition (neutral, threatening) and stimulus Modality (audiovisual, muted video, image) as within-subject factors. Our dependent variables were behavioural measures that included reaction times (RTs) in seconds for finding the number 1 and overall search times in seconds for finding numbers 1 through 10. Search times were calculated as the difference between the RT for the tenth number and the RT for finding number 1. We then used Pearson correlations to see if there was a relationship between these behavioural measures and the questionnaires (SFQ, STAIS and STAIT). Statistical results are presented in tables rather than in the text to make the description of the results easier to follow. See Supplementary Material 1 for detailed descriptive statistics for questionnaires and for detailed descriptive statistics across all conditions.

We asked participants to complete the task as accurately as they could, but our main focus during analysis was on reaction time. We removed less than 5% of the trials due to missing or incorrect responses, such as skipped numbers or missed clicks. These missing responses are best interpreted as occasional participant errors rather than technical issues. Given the very low overall error rate and its even distribution across participants and conditions, we have maintained our focus on reaction time measures. In future studies, it might be worth making the task a bit harder or changing the instructions to better explore how accuracy and speed interact.

Results

Finding number 1

First, we analyzed RTs to test our hypothesis that participants would take longer to find Number 1 in the threat condition relative to the neutral condition and that this effect would be more evident in the audiovisual versus the muted video and picture-only conditions. See Table 1 for descriptive data including mean RTs, standard deviations and 95% confidence intervals. Figure 2 shows the descriptive statistics for such comparisons; also see Table 2 for exact statistical

Table 1. Descriptive data for finding the first number and the overall search time, separately for each condition. Mean reaction times, standard deviation and 95% confidence interval values are presented in seconds.

	Emotional Condition	Modality	Mean	SD	95% Confidence Interval	
					Lower	Upper
Finding Nr. 1	Neutral	Audiovisual	1.91	0.371	1.80	2.01
		Muted Video	1.89	0.496	1.75	2.03
		Image	1.70	0.241	1.63	1.77
	Threatening	Audiovisual	1.86	0.296	1.77	1.94
		Muted Video	1.93	0.362	1.83	2.03
		Image	1.86	0.360	1.76	1.96
	Emotional Condition	Modality	Mean	SD	95% Confidence Interval	
					Lower	Upper
Overall Search Time	Neutral	Audiovisual	25.2	0.941	25.0	25.5
		Muted Video	25.6	0.956	25.3	25.8
		Image	25.3	1.15	25.0	25.6
	Threatening	Audiovisual	25.7	0.744	25.5	25.9
		Muted Video	25.2	1.02	24.9	25.5
		Image	25.0	1.12	24.7	25.4

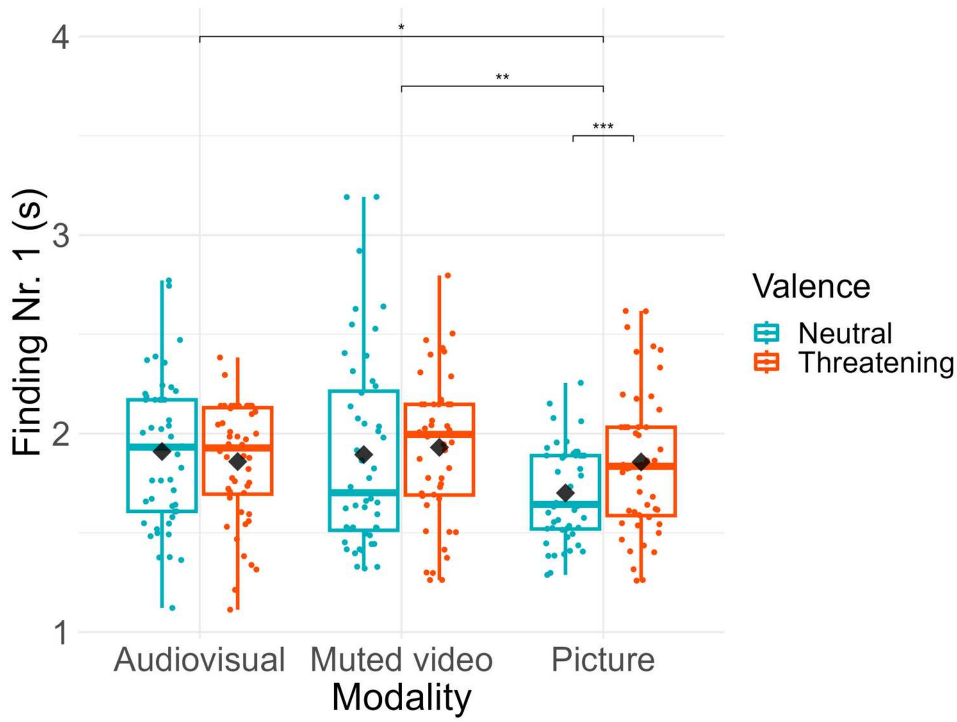

Figure 2. Reaction times for finding the first number. Findings are presented across stimulus Modality (Audiovisual, Muted video, Picture) levels using separate boxplots for Emotional Condition (Blue = Neutral and Red = threatening, respectively). Median values are presented with a line, average values are presented with black diamonds for each boxplot. Significant differences are marked with a black line. $^*p < .05$; $^{**}p < .01$; $^{***}p < .001$.

Table 2. Detailed statistical results for reaction time for finding Number 1 with main effects, interactions, follow-up ANOVAs, and pairwise comparisons (with Tukey corrected p values).

		df	F/t	p	η^2p / Cohen's d	Mean difference
Emotional Condition Modality		1,47	2.20	0.144	0.045	
		2,94	6.66	0.002	0.124	
	Audiovisual – Muted video	47	−0.724	0.751	0.104	−0.028
	Audiovisual – Picture	47	2.919	0.015	0.472	0.105
	Muted video – Picture	47	3.268	0.006	0.421	0.133
Emotional Condition ✻ Modality		2,94	3.76	0.027	0.074	
Audiovisual	Neutral vs Threatening	47.0	1.1568	0.253	0.167	0.051
Muted video	Neutral vs Threatening	47.0	−0.5092	0.613	0.074	−0.037
Picture	Neutral vs Threatening	47.0	−3.7670	< .001	0.544	−0.156

results. Results from the ANOVA indicated a significant main effect, indicating that the modality of stimulus influenced how quickly participants detected the Number 1 ($F(2,94) = 6.66$, $p = .002$, $\eta^2p = .124$). Pairwise comparisons showed that participants were significantly slower in the audiovisual condition than in the picture condition ($M_{difference} = -0.028$), and in the muted video condition compared to the picture condition ($M_{difference} = 0.133$). No significant difference was found between audiovisual and muted video conditions. There was no significant main effect of Emotional Condition. There was, however, a significant interaction between Emotional Condition and Modality ($F(2,94) = 3.76$, $p = .027$, $\eta^2p = .074$), as threat vs. neutral differences were examined within each modality. Follow-up comparisons revealed that in the picture condition, threatening stimuli led to significantly slower RTs than neutral stimuli ($M_{difference} = -0.156$). No significant threat-related effects were observed in the muted video or audiovisual conditions. These results partially support our hypothesis: threatening stimuli slowed initial attentional capture, but only when presented as static images. The absence of this effect in the dynamic conditions suggests that motion – regardless of emotional content – may dominate early attentional processing and override the impact of threat cues during target detection.

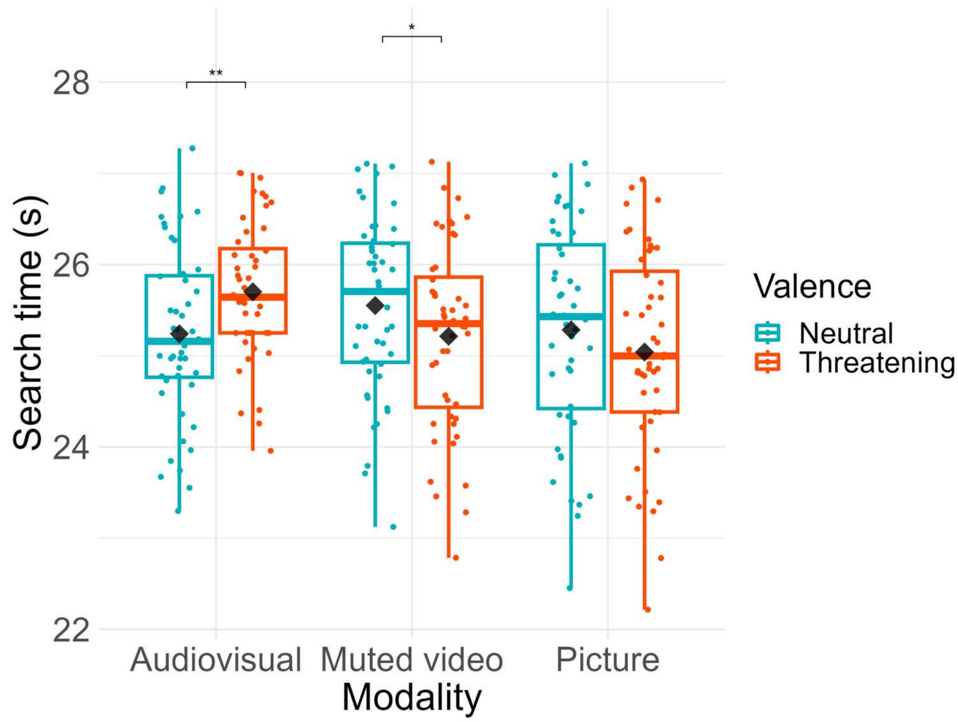

Figure 3. Overall search time for finding the numbers 1 through 10. Findings are presented across stimulus Modality (Audiovisual, Muted video, Picture) levels using separate boxplots for Emotional Condition (Blue = Neutral and Red = threatening, respectively). Median values are presented with a line, average values are presented with black diamonds for each boxplot. Significant differences are marked with a black line. *$p < .05$; **$p < .01$; ***$p < .001$.

Overall search time

We next examined overall search times to test our prediction that the threat condition compared to the neutral condition will produce better performance, and that this effect would be more pronounced in the audiovisual condition compared to the muted video and picture-only conditions. See Table 1 for descriptive data including mean RTs, standard deviations and 95% confidence intervals. Figure 3 presents the descriptive statistics for these comparisons; statistical results are presented in Table 3. The stimuli's Emotional Condition and Modality main effects were nonsignificant, however the interaction between the two factors was significant ($F(2,94) = 9.984$, $p < .001$, $\eta^2 p = .175$). Pairwise comparisons showed that threatening compared to neutral audiovisual distractors resulted in worse performance ($M_{difference} = -0.460$), whereas threatening compared to neutral muted video distractors resulted in better performance ($M_{difference} = 0.243$). No significant difference was observed in picture condition. These results partially support our hypothesis, but not in the expected direction. We expected that threatening distractors would lead to better overall search performance, given that they are arousing stimuli, particularly in the audiovisual condition. However, the opposite pattern observed: threatening stimuli improved performance in the muted video condition but impaired performance in the audiovisual condition. In

Table 3. Detailed statistical results for overall search time with main effects, interactions, follow-up ANOVAs, and pairwise comparisons (with Tukey corrected p values).

		df	F/t	p	$\eta^2 p$ / Cohen's d	Mean difference
Emotional Condition		1,47	0.183	0.671	0.004	
Modality		2,94	2.625	0.078	0.053	
Emotional Condition ✻ Modality		2,94	9.984	< .001	0.175	
Audiovisual	Neutral vs Threatening	47.0	−3.193	0.003	0.461	−0.460
Muted video	Neutral vs Threatening	47.0	2.603	0.012	0.376	0.337
Picture	Neutral vs Threatening	47.0	1.496	0.141	0.216	0.243

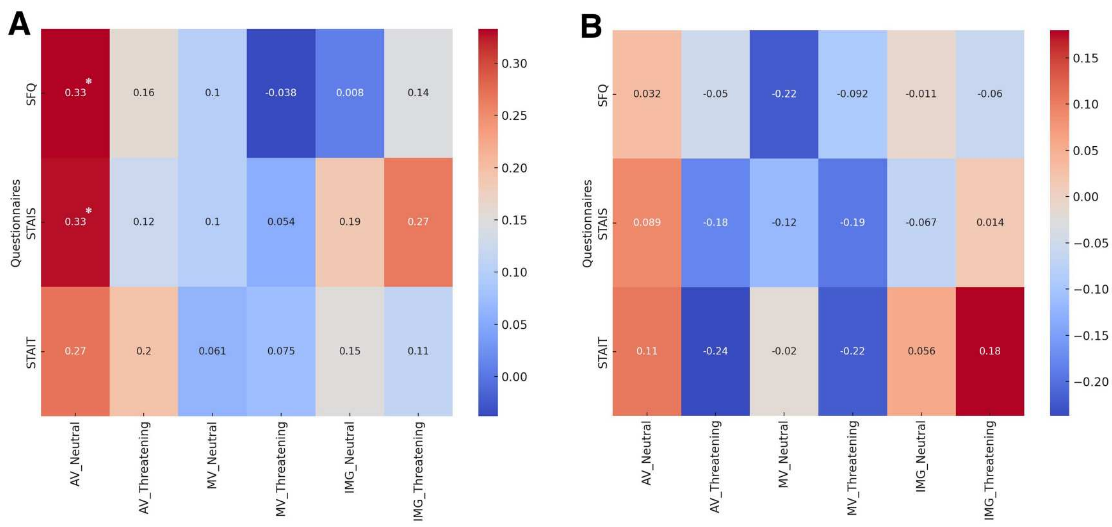

Figure 4. Correlation heatmaps showing the correlation coefficients and significance levels between RTs for finding the first numbers (A), overall search times (B) and questionnaire scores. SFQ = Fear of storms and severe weather, STAIS = State anxiety, STAIT = Trait anxiety AV: Audiovisual MV: Muted Video IMG: Image. * p < .05

contrast, RTs in static images presented no different effects between the threat and neutral condition, pointing to the lack of emotional impact may not be strong enough to affect the performance of sustained search. These results, in general, bring into light that threat's influence on attentional performance is not determined by emotional content alone but also by the sensory complexity of the distractor.

Questionnaires

Finally, we examined whether scores on the Storm Fear Questionnaire will be correlated to RTs for finding Number 1. Figure 4 shows a correlation heatmap with relevant statistical results. The correlation analysis revealed positive weak correlations between neutral audiovisual stimuli for finding Number 1 and storm fear level as well as state anxiety. However, no significant correlations were observed between the questionnaires and the reaction times in overall search time.

Discussion

In this study, we aimed to investigate how task-irrelevant threatening stimuli affect participants' attention while performing a complex cognitive task. The novelty of our study is that, in contrast to previous studies, we used more distracting moving stimuli (i.e., audiovisual and muted video) in addition to (static) pictures. We used the number finding task to measure RTs to find the first number and the elapsed time between finding the first and tenth numbers. This allowed us to examine salience and executive control of attention, the two key components of attentional biases for threat (Dolcos et al., 2020; Mogg & Bradley, 2018). In general, our results only partially support previous findings with static stimuli on the threat effect. That is, in the picture condition while we did find evidence of initial attentional capture it was not followed by improved performance. Further, while we found faster overall search performance for threatening stimuli in the muted video condition, the lack of a significant threat effect on RT of the first target in the dynamic modalities implies that emotional capture may be suppressed under higher perceptual load. Consequently, there is currently insufficient evidence to support threat-driven attentional capture in dynamic stimuli; however, they do bring up important questions regarding the interplay between load and arousal across stimulus modalities.

Our results showed an attentional capture bias for moving distractors compared to pictorial distractors, regardless of threat value, whereas we found a threat effect for pictorial distractors, in line with previous studies (and our hypothesis). This result is in line with previous studies (Burra et al., 2019; Zsido et al., 2022; Zsido et al., 2023; Zsido, Matuz, et al.,

2020) in that they showed that threatening distractor pictures capture attention more easily than neutral ones, leading to a performance deficit in the primary attentional task. Again, however, only static pictures were used as distractors in these studies. Previous studies have shown that the modality of the stimuli can have an impact on cognitive function, suggesting that different sensory channels activate different brain mechanisms and memory functions, which in turn affect performance and detection differently (Protzner et al., 2009). In line with our expectations, participants spent more time finding the Number 1 in the presence of an audiovisual stimulus compared to a picture. This suggests that the presence of auditory information in videos may increase the level of distraction or cognitive processing required to complete the task. This finding may be supported by previous results (Hughes et al., 2013) showing that auditory distraction resulting from direct interference between sound and task processing is largely resistant to top-down cognitive control. Furthermore, pervious study found that moving negative distractors result in longer search time, suggesting that motion itself provides extra salience to the stimuli that enhances the attentional capture (Carretié et al., 2009). Audiovisual distractors cause significantly slower responses compared to no distractors or uni-sensory distractors, particularly under high working memory or perceptual load (He et al., 2022; Yuan et al., 2023), consistently with both the cognitive load (De Fockert et al., 2001; Lavie, 2010) biased competition theories (Desimone & Duncan, 1995). The significant interaction effect between emotional condition and modality provides further insight into how these factors interact to influence cognitive performance. Participants showed significantly slower responses in the threatening relative to the neutral condition in the picture modality alone. Mean RTs in threat compared to neutral stimuli did not differ in the muted video condition, also we did not observe any significant threat effect in the audiovisual condition. This suggests that the effect of emotional threat on attentional slowing is specific to static visual presentations in our task. This means that static threatening pictures can be just as distracting as moving stimuli. While the ability to quickly recognize an unexpected threat is clearly an evolutionary advantage for human survival, it is especially crucial when a person is experiencing a high cognitive load because attention tends to lapse more easily at this time (Head & Helton, 2014). More importantly, there was no difference in the attentional capture effect for threatening and neutral moving stimuli. Based on the load theory of attention (Fairnie et al., 2016; Lavie et al., 2004) this could mean that movement produces a stronger attentional effect that overrides the threat effect. Indeed, this is also consistent with the Guided Search Theory (Wolfe, 2021), i.e., the dynamic features of the stimuli, especially motion, likely provided strong bottom-up signals that overrode emotional threat signals when determining attentional guidance. Research has demonstrated that emotional processing requires attentional resources and can be reduced under high perceptual load conditions (Pessoa et al., 2002). In our study, the presence of movement in video stimuli likely created a high perceptual load that consumed available attentional resources, thereby preventing participants from processing the emotional content of the threatening stimuli. Thus, movement appears to produce a stronger attentional demand that overrides the typical threat-related attentional bias, consistent with load theory's predictions about resource allocation under varying perceptual demands.

In terms of overall search time we found that performance was impaired for threatening compared to neutral audiovisual stimuli, whereas performance was better for muted videos and pictures in the threat condition. For picture distractors, this is in line with previous research (Blanchette, 2006; Fox et al., 2007; Öhman et al., 2001; Subra et al., 2018). The higher reactivity towards threatening stimuli is supported by evolutionary pressures. Threats are highlighted by attentional processes as potential dangers in the environment (Brosch et al., 2008; Öhman & Mineka, 2001), which increases visual performance (Hamamouche et al., 2017; Phelps et al., 2006). Our results are also consistent with the arousal stimulation effect, in that threatening stimuli improved performance compared to neutral stimuli due to increased arousal (Zsido, 2024; Zsido, Bernath, et al., 2020; Zsido, Matuz, et al., 2020). The audiovisual stimuli reversed this effect and worsened performance. This could be due to the fact that the threatening audiovisual distractor stimuli were too arousing, potentially leading to excessive distraction from the task at hand, which is again consistent with previous studies (Zsido et al., 2022; Zsido et al., 2022) suggesting that threats influence behaviour based on their level of arousal. The inverted U-shaped relationship between arousal and performance can also be used to interpret our findings (Andersen et al., 2020; Yerkes & Dodson, 1908; Zsido et al., 2025). According to this model, extremely low or excessively high arousal levels can be disruptive, but moderate levels can help with attentional control and improve performance. While performance was impaired by the audiovisual threatening stimuli (which may have induced excessive arousal), this may explain the observed faster search times linked to muted videos (which may have triggered moderate arousal). While physiological arousal was not directly assessed in our study, the trend aligns with the notion that the effect of threat on attention depends on the relationship between the threat's salience and arousal. That is, the demand of distractors on working memory resources increases with their level of arousal and the ability to filter out the distracting information decreases (Lee et al., 2014; Mather et al., 2016; Mather & Sutherland, 2011). Threat facilitates attention in situations of overall low cognitive load but disrupts performance in situations of high cognitive load (O'Toole et al., 2011). Indeed, we found that the fastest responses were made to pictures in the threat condition, whereas the slowest responses were made in the audiovisual threat condition. However, in the audiovisual condition, the addition of sound may have elevated arousal to a disruptive level, increasing cognitive load and impairing performance. While we did not manipulate arousal levels directly, nor measure them physiologically, our pre-rated stimuli did vary in arousal, and we used minimum arousal thresholds during selection. Nonetheless, because arousal was not controlled as an independent variable, interpretations along this line remain speculative and should be examined further in future research through direct manipulation or measurement of arousal responses.

The distinction between the two RT measures used in this study, i.e., time to find Number 1 and overall search time, is suggestive of different stages in attentional processing. RT for finding Number 1 is used as a measure of initial attentional capture or orienting – it is more sensitive to immediate distraction exerted by onset stimuli with some level of salience or emotional valence (Fox et al., 2001). This initial attentional orienting process is largely influenced by bottom-up processes. In contrast, overall search RT presumably captures sustained visual attention, executive control, and possibly the effects of arousal or cognitive resource availability during the performance of the task (Petersen & Posner, 2012; Posner & Petersen, 1990). As participants search for numbers in a serial order, they should maintain their target number and keep updating the working memory as well as trying to suppress interference (Kane et al., 2001; Kovacs & Conway, 2016; Unsworth & Robison, 2017). This process mostly relies on top-down mechanisms. This distinction is crucial since emotional stimuli may interfere with early attention and simultaneously boost sustained processing by promoting arousal. (Ciesielski et al., 2010; Zsido et al., 2022). Our results follow that pattern – the threat slowed down initial search in the picture condition (attentional capture) but helped complete the whole task in the muted-video condition.

Contrary to our hypothesis, no significant relationship was found between the SFQ scores and reaction times in the threat condition. Interestingly, we found weak positive correlations between the level of fear of storms and state anxiety on participants' performance for finding Number 1 in audiovisual neutral condition. This may be consistent with the finding of a previous study suggesting that state anxiety interacts with emotional cues, negatively affecting performance following neutral cues but not fear (Berggren et al., 2017). In the present study, participants' anxiety levels were moderate within normal limits and no participants had a phobia of storms and severe weather. Previous studies only found differential effects in clinical populations (Koster et al., 2006; Mogg et al., 1992). Similarly, previous research found no correlation between fear or anxiety score and search performance on a healthy population (Zsido, Bernath, et al., 2020). As the participants seemed to express relatively low levels of anxiety and fear, it is possible that this may influence our results.

In summary, we conducted an experiment on a visual search task using different modalities of stimuli in threatening and neutral conditions. A novelty of our experiment was the inclusion of audiovisual stimuli and muted videos in addition to the pictures used in previous studies. Our results are consistent with those of previous studies in that finding the first number takes longer for threatening stimuli. However, in terms of overall search time, participants were delayed, which is contrary to our hypothesis. Although these differences were considered to be related to the level of arousal, no systematic manipulation was applied; thus, all accounts referring to arousal remain tentative. In further research, these assumptions must be verified with direct physiological or subjective measures.

Conclusions

The present research has its relevance; however, some limitations should be noted. One of these limitations is that, although we identified arousal as a factor influencing performance differences across stimulus modalities and threat levels, we did not manipulate arousal levels systemically. While our use of rated stimuli with arousal scores provides an indirect estimate, this approach cannot capture trial-by-trial fluctuations in individual arousal levels. Therefore, our interpretations remain speculative. In other words, some stimuli in the threat condition may have had higher level of arousal than others, meaning our threat category potentially included both moderately and highly arousing stimuli. Thus, our interpretations of our findings related to arousal should be treated with caution. We did not incorporate direct physiological measures of arousal either. Although we base our reasoning on established theoretical models and prior studies linking arousal to attentional control and performance (e.g., Mather & Sutherland, 2011; Zsido, Teleki, et al., 2020), future work should aim to include objective physiological indicators of arousal in order to better isolate its contribution. Therefore, future research may benefit from controlling or systemically manipulating and measuring arousal levels to distinguish the effects that threat and arousal have on visual search tasks. Another limitation of the study is that our focus from the start was on reaction times, so accuracy was not part of the original plan. That being said, we did check the data during cleaning, and there were very few errors – most participants did not make any mistakes, and when they did, it was just one or two. Because of that, we did not really have enough error data to analyze. Future studies could incorporate accuracy as a planned outcome by increasing task difficulty or balancing speed and accuracy demands more evenly in the task instructions.

Furthermore, factors such as individual differences in anxiety or sensitivity to threat were not considered and those may have influenced the outcome. In addition, as the questionnaire-based data relies on self-report, there may have been a lack of objective perspective in the way participants viewed themselves. Future studies may include anxiety measures such as skin conductance or heart rate variability. Finally, another possible limitation is that finding the Number 1 may have been too easy, leading to a possible ceiling effect. A more difficult task may be required to better capture the impact of threat, particularly when using moving stimuli, to observe a more distinct threat effect.

Author contributions

– Conceptualization: B.Y., A.N.Z., and B.L.K. Data curation: B.Y. and B.L.K. Formal analysis: B.Y. Funding acquisition: A.N.Z. and B.L.K. Investigation: B.Y. Methodology: A.N.Z. and B.L.K. Project administration: B.Y. and B.L.K. Resources: B.Y. and B.L.K. Software: B.Y. and B.L.K. Supervision: A.N.Z. and B.L.K. Validation: A.N.Z. and B.L.K. Visualization: B.Y. and B.L.K. Writing – original draft: B.Y., A.N.Z., and B.L.K. Writing – review & editing: B.Y., A.N.Z., and B.L.K.

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Ethical approval

Ethics approval was obtained from the Hungarian United Ethical Review Committee for Research in Psychology.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Data availability statement

The stimuli used and the datasets generated and analyzed during the current study are available in the Open Science Framework repository (https://osf.io/xzfhc/).

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