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RESEARCH ARTICLE

Emotion-Induced Blindness Is Impervious to Working Memory Load

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Abstract

Emotionally-salient stimuli receive attentional priority. Here, we tested the extent to which top-down control can modulate this prioritization within the domain of temporal attention. To test this prioritization, we measured emotion-induced blindness, which is the effect whereby the perception of a target is impaired by the presentation of a negative distractor that precedes the target in a rapid serial visual presentation stream, relative to target perception following a neutral distractor. The degree of top-down control was investigated by manipulating participants' concurrent working memory load while performing the task. The working-memory load consisted of participants performing mathematical calculations (no load = no calculation; low load = adding two numbers; and high load = adding and subtracting four numbers). Results indicated that the magnitude of emotion-induced blindness was not affected by the working-memory load. This finding, when combined with those of previous studies, supports the notion that the prioritization of emotionally-salient stimuli in the temporal allocation of attention does not require top-down processing, while it does in the spatial allocation of attention.

Keywords Emotion · Attention · Distraction · Cognitive control · Top-down attention · Emotion-induced blindness

Our visual world typically contains too many objects for us to be able to fully process them all simultaneously. Visual attention is important for prioritising the processing of some objects to the level of awareness (Fiebelkorn & Kastner, 2020). Stimuli can receive attentional priority for a number of reasons, including because they are emotionally salient (e.g., Anderson, 2005; Anderson et al., 2011; Delchau et al., 2022; Fox et al., 2002; Frischen et al., 2008; Lipp & Derakshan, 2005; Mogg et al., 2004; Most et al., 2005, 2007; Pauli & Röder, 2008; Sutherland et al., 2017; Vuilleumier et al., 2001). Emotional salience means that a stimulus either depicts or signals threat, punishment, or reward. For example, an image of a mutilated body (threat) or a simple disc if it signals the availability of monetary reward (Anderson et al., 2011; Le Pelley et al., 2017; Most et al., 2005). Such stimuli can sometimes evoke emotions under certain conditions, but emotional salience refers to their influence on visual attention on shorter timescales without necessitating a change in the person's emotional state (Goodhew & Edwards, 2022a). While it can be important and useful to attend to emotionally-salient stimuli because of their potential relationship to threats and rewards, there are times when we need to ignore them to be able to focus on the task at hand. Excessive attentional prioritisation of emotionally-salient stimuli may also be linked to certain psychological disorders, such as anxiety (e.g., Bar-Haim et al., 2007; MacLeod et al., 2019; Mogg et al., 2008). Consequently, an interesting and important question is the degree to which top-down attentional processes are involved in this prioritisation because that will influence the degree to which this prioritisation can be attenuated.

A number of studies have investigated this general issue and in reviewing them it appears that the role of top-down attentional processes in the prioritisation of emotionally-salient stimuli may differ for the two different ways that attention can be allocated to a visual scene: specifically, spatial and temporal allocation of attention. Spatial attention refers to how attention is allocated to different spatial regions. This includes shifting the focus of attention to different locations and regulating the size of the breadth of attention (Chong & Treisman, 2005; Goodhew, 2020; Posner, 1980) and is

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typically measured by varying where visual stimuli, both targets, and non-targets, appear in space, such as in cueing paradigms (e.g., Carrasco, 2011; Frischen et al., 2007; Posner, 1980), or visual search (Treisman & Gelade, 1980; Wolfe, 2021). Temporal allocation of attention refers to how attention is allocated across time. The allocation of temporal attention is typically measured via the rapid serial visual presentation (RSVP) of stimuli in a single spatial location, and gauging to what extent stimuli in close temporal proximity are processed. For example, the attentional blink is said to be a temporal attentional phenomenon (e.g., Dux & Marois, 2009; Olivers & Meeter, 2008). Notably, temporal attention is applied to the psychological representation of stimuli, which persists beyond their physical presentation (Keysers & Perrett, 2002).

Experimental paradigms that investigate the degree of prioritization of emotionally-salient stimuli use emotionally-salient and neutral stimuli that are not task-relevant and compare performance between those two stimulus conditions. For example, for spatial attention, two common paradigms are the dot-probe and the irrelevant-distractor paradigms. In the dot probe, two spatially offset stimuli are presented, one neutral and the other emotionally-salient. They then disappear and are replaced by a target stimulus in the location of one of these stimuli and the extent to which responses are facilitated when the target appears in the location that was occupied by the emotionally-salient stimulus is taken as a measure of prioritization of the emotionally-salient stimulus (Frewen et al., 2008; Kappenman et al., 2014; MacLeod et al., 1986). The irrelevant-distractor paradigm consists of presenting a search array and a distractor image that is either neutral or emotionally salient. The difference in target accuracy and/or response times between the two image conditions is taken as a measure of prioritization (Forster & Lavie, 2008a, b, 2016). When it comes to assessing the influence of emotionally-salient stimuli on temporal attention, a commonly used paradigm is emotion-induced blindness (EIB). The EIB paradigm uses a RSVP sequence and is similar to the attentional blink, except that only one target is used, with a task-irrelevant distractor preceding the target. The EIB effect is that task performance (judging the orientation of the target) is worse when an emotionally-salient distractor occurs close in time before the target, compared to a neutral distractor (Goodhew & Edwards, 2022b; Most et al., 2005). It has been shown that the spatial versus temporal prioritization of task-irrelevant emotionally-salient stimuli are distinct processes. One study showed that measures of each (dot-probe versus emotion-induced blindness) do not correlate with one another, and each explains unique variance in participants' self-report negative affect in everyday life (Onie & Most, 2017).

Evidence for potential differences in top-down involvement in the spatial and temporal allocation of attention comes from studies that investigated an aspect of top-down control: the degree that this prioritization of emotionally-salient stimuli can be modulated by proactive attentional control. Multiple studies have shown that proactive control differs for spatial versus temporal aspects of attentional prioritization. Walsh and colleagues (Walsh et al., 2018, 2019, 2021) tested spatial attention by using the irrelevant-distractor paradigm and found that having an emotionally-salient central image slowed response times compared to an emotionally-neutral image but that this impairment was eliminated when the motivation of participants was increased. They did this by having participants be able to earn points if they were both correct and faster on their responses, compared to previous trials where they could not earn points (Walsh et al., 2018) and occurred when those points translated into monetary rewards and also when they did not (Walsh et al., 2021). This finding is different to that obtained for temporal attention as tested by EIB studies. Monetary rewards do not result in reduced EIB (Most et al., 2007). These findings suggest that the top-down control of the attentional-prioritization of emotionally-salient stimuli differs for spatial and temporal allocation of attention, with the former being amenable to top-down control and the latter not.

A similar difference between spatial and temporal allocation of attention is obtained for the effects of manipulating distractor frequency on the effect of emotionally-salient stimuli. Manipulating distractor frequency is thought to engage different types of attentional control, with low-frequency distractors engaging reactive control and high-frequency proactive control because it encourages the recruitment of proactive control to maintain focus on the task by reducing distractor interference (Braver, 2012; Grimshaw et al., 2018; Zhao & Most, 2019). Using the irrelevant-distractor paradigm, Grimshaw et al. (2018) showed that increasing the frequency of emotionally-salient distractors eliminated their impairment on performance, while Zhao and Most (2019) showed increasing the frequency of the emotional distractors had no impact on EIB magnitude. Once again, these results are consistent with top-down control of attentional-prioritization of emotionally-salient stimuli for the spatial allocation of attention, but not for temporal.

However, a study by Kennedy et al. (2018) showed that EIB can be at least partially modulated by proactive attentional control. They provided participants with trial-by-trial information about the nature of the distractor (e.g., "Ignore gruesome") and compared performance to when no such information was given. These instructions improved performance at Lag 2 for both negative and erotic distractors, and at Lag 4 for negative distractors. A more generic "graphic" warning for both negative and erotic distractors improved performance for both distractor types at Lag 2, but only for erotic distractors at Lag 4. Thus, while EIB was never eliminated, it could be reduced, which supports the idea of a degree of top-down control of the degree of prioritization of emotionally-salient stimuli by temporal attention (Kennedy et al., 2018). In a similar vein, Most and colleagues found that when participants were given specific information about the type of target (e.g. target is a building) it could reduce EIB in that it interacted with the harm avoidance component of the Tridimensional Personality Questionnaire (Cloninger et al., 1991), such that those low on harm avoidance had reduced EIB for the target-specific condition (Most et al., 2005). Though a later study failed to replicate this (Most et al., 2006).

Given these mixed findings for the role of top-down regulation of the prioritization of emotionally-salient stimuli by temporal attention, the aim of the current study was to investigate this issue further. We did this by using a different, and arguably powerful way to determine the role of top-down attention: determining the impact that increasing working memory load has on performance for tasks that may be mediated by those processes. Specifically, we assessed EIB magnitude under no, low, and high active working memory load conditions. Top-down regulation requires the involvement of the central executive and a working-memory load consumes the resources of that executive (DeStefano & LeFevre, 2004). Thus, if performance on a task is affected by increasing working-memory load, that is a clear indication for the role of top-down control in mediating that process. Using the dot-probe paradigm, Delchau et al. (2020) showed that the low and high working-memory-load conditions eliminated the spatial prioritization of emotionally-salient stimuli that they observed in the no-load condition. A result that is consistent with a role for top-down attentional processes in the attentional prioritization of emotionally-salient stimuli by spatial attention. By applying the same working-memory-load task and levels used by Delchau and colleagues to an EIB procedure, we will be able to determine if top-down processes play a similar role in temporal attention.

Method

Participants

A power analysis was conducted in G*Power (Faul et al., 2009). Assuming a medium effect size (0.5) in a *t*-test (e.g., to compare EIB magnitude in under one load condition versus another), an alpha level of 0.05 and power of 0.95, a sample size of 54 was required. Therefore, assuming approximately 10% of possible exclusions (e.g., due to poor task performance), this was increased to a recruitment target of $N = 60$. Note that even for a medium effect size in a six-condition repeated-measures ANOVA, G*Power indicates that $N = 28$ is required, which we exceeded.

A total of 60 participants (31 male, 29 female) completed the study, with an average age of 20.6 years ($SD = 3.7$ years). Participants were recruited via the Australian National University's (ANU) online Psychology Research Participation Scheme (SONA) and compensated for their time via either course credit or $15 cash payment. All participants gave voluntary, informed consent, and the study was approved by the ANU Delegated Human Research Ethics Committee.

Apparatus and Stimuli

The distractor images were selected from the International Affective Picture System (IAPS; Lang et al., 2008) based upon their valence and arousal ratings. On rating scales ranging from 1 = negative valence to 9 = positive valence, and from 1 = low arousal to 9 = high arousal, the 60 neutral images had a mean valence rating of 5.29 ($SD = 0.13$) and arousal rating of 3.56 ($SD = 0.58$) and consisted of images of household items, flora, fauna, abstract art, and people in everyday situations. The 60 negative images had a mean valence rating of 1.91 ($SD = 0.31$) and arousal rating of 6.45 ($SD = 0.55$) and consisted of images of mutilated bodies, violence, guns pointed directly at the camera, and images that would elicit disgust. See the Supplementary Material for a complete listing of the IAPS images used. The filler images consisted of 290 landscape or architectural images and the 120 separate target images consisted of the same type of images as the filler images but rotated to the left or right by 90 degrees. All images were presented on an LCD monitor at a visual angle of 11.2 degrees high, and 18.4 degrees wide. The screen background was white and the viewing distance was 600 mm.

In choosing the working memory-load task, care needs to be taken to use one that actually engages the central executive, rather than one that just engages short-term memory (Baddeley, 2002). Thus, we used one that required participants to perform mathematical calculations at three level: no load (no maths task); low load, adding two numbers together (A + B); and high load, adding and subtracting four numbers (A + B – C + D). The numbers appeared in black in the centre of the screen. This working memory load manipulation has been used previously to investigate the role of top-down attentional processes in the dot-probe task, which resulted in the finding that the attentional bias to emotionally-salient stimuli was lost in the high-load condition (Delchau et al., 2020).

Importantly, Delchau et al. (2020) also tested how long it typically took participants to solve these equations and a make response in the absence of other stimuli. The low load sums took participants on average 1,351.2 ms ($SD = 311.9$), while the high load sums took participants on average

5526.2 ms (SD = 1479.0). In both cases, accuracy was high (M = 95.3%, SD = 6.8, and 92.9% and SD = 5.3). Even allowing several hundred milliseconds for a motor response, these averages indicate that in the high load condition, in particular, it was very unlikely participants would have solved the maths equation prior to the RSVP stream given that the EIB sequence started 3,000 ms after the initial presentation of the maths equation (see below).

Procedure

Each trial consisted of the presentation of the maths equation for 2,500 ms prior to start of the EIB sequence. The EIB sequence consisted of a fixation cross (presented for 500 ms) then 17 images presented in an RSVP sequence with each image being presented for 100 ms. At the end of each trial, the participant used the left or right arrow keys to first respond to the EIB task (left arrow for target left, and right for target right) and then the working-memory task (left arrow for odd and right arrow for even). Consistent with previous research (Proud et al., 2020), a single lag was used (lag 2—that is, the target was the second image after the distractor), and the temporal position of the distractor-target combination in the sequence was randomised to reduce expectancy effects, with the restriction that the target was never the last image in the RSVP sequence. Two blocks of 120 trials (60 neutral and 60 negative distractor trials, randomly intermixed) were run.

A practice block consisting of 12 trials was used before the start of the main experiment. The practice trials in the practice block started off using long image durations (3,000 ms) but gradually decreased the duration time until the 100 ms was used for the second half of the sequences in the block. Feedback was also given in the practice block (but not in the main experiment) and participants had to respond correctly on eight or more trials to progress to the experimental blocks (practice repeated as required).

Results

Raw data are available in OSF: https://osf.io/ynk3g/. Frequentist statistical analyses were performed in Statistical Package for the Social Sciences (SPSS Version 27) and Bayesian analyses in Just Another Statistical Package (JASP Team, 2020).

Accuracy on the Low Load arithmetic task was 90.22% (SD = 9.17), and accuracy on the high-load arithmetic task was 80.85% (SD = 12.36).

Target identification accuracy scores were submitted to a 3 (working memory load: no load, low load, and high load) × 2 (distractor valence: negative vs neutral) repeated-measures ANOVA. This revealed a significant main effect of distractor valence, $F(1, 59) = 44.56$, $p < .001$, $\eta_p^2 = .430$, such that accuracy was greater following neutral (M = 76.28%, SD = 8.21) compared with negative (M = 72.43%, SD = 8.56) distractor images. This demonstrates the presence of EIB.

There was also a significant main effect of working memory load, $F(2, 118) = 22.28$, $p < .001$, $\eta_p^2 = .274$. Repeated-measures t-tests revealed that accuracy was significantly greater in the Low Load condition (M = 78.00%, SD = 8.38) than the no-load condition (M = 72.99%, SD = 9.56), $t(59) = -4.96$, $p < .001$, Cohen's $d = -0.64$, or the high load condition (M = 72.08%, SD = 9.44), $t(59) = 7.14$, $p <= .001$, Cohen's $d = 0.92$. The no load and high load conditions did not differ significantly from one another, $t(59) = 0.89$, $p = .376$, Cohen's $d = 0.12$. This demonstrates an effect of the working memory load manipulation. The non-monotonic effect of load on performance is consistent with previous research (Ahmed & de Fockert, 2012; Delchau et al., 2020).

The interaction between working memory load and distractor valence was non-significant, $F(2, 118) = 0.93$, $p = .397$, $\eta_p^2 = .016$. To check the veracity of this null result, a Bayesian Repeated Measures ANOVA was performed, with default priors and comparison to null model. For the main effect of valence, the $BF_{10} = 54{,}257.43$, and for the main effect of working memory load, the $BF_{10} = 1{,}047{,}000{,}000$. For context, BF_{10} values 10–30 are considered strong, 30–100 very strong, and 100 + indicative of decisive support in favour of the alternative hypothesis (Jarosz & Wiley, 2014). Therefore, these values clearly indicate evidence in favour of the main effects. Importantly, the interaction term Bayes factor was divided by the Bayes factor for the additive main effects, and thus isolates whether there is variance due to the interaction of the factors over and above their main effects. For the interaction term, the $BF_{10} = 0.10$, indicative of evidence in favour of the null hypothesis. This indicates that the magnitude of EIB (i.e., difference in accuracy following negative versus neutral distractor) was invariant to Working Memory Load. The accuracy data are shown in Fig. 1.

Next, we conducted two additional analyses to check the robustness of these results. First, we excluded participants whose accuracy on arithmetic tasks for either the low load or high load condition fell below 75%, to determine whether the effect of working memory load may be selective to those performing the task well. Second, we excluded participants with lower EIB magnitudes, to determine whether they were constraining the interaction. When participants whose arithmetic accuracy fell below 75% were excluded, the sample consisted of $N = 43$. For these participants, there was still a significant main effect of distractor valence ($p < .001$, $\eta_p^2 = .431$, $BF_{10} = 2{,}880.01$) and a significant main effect of working memory load ($p < .001$, $\eta_p^2 = .283$, $BF_{10} = 1{,}718{,}000$), and no interaction ($p = 0.835$, $\eta_p^2 = 0.004$, $BF_{10} = 0.08$). Similarly, if

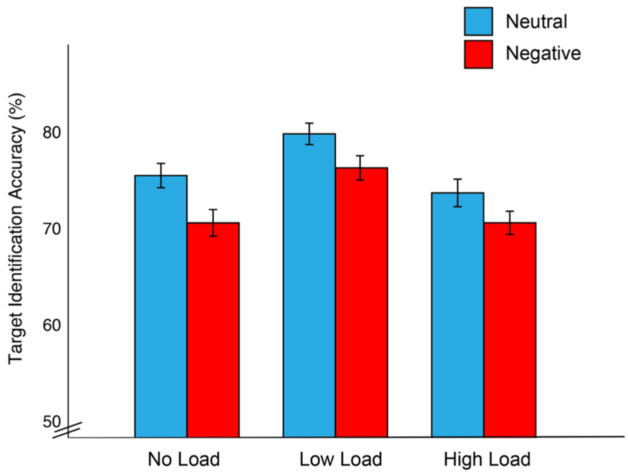

Fig. 1 Target identification accuracy following neutral versus negative distractors under each load. Note: error bars depict standard error of the mean

we only considered cases whose EIB magnitude (averaged across load conditions) was greater than the median EIB magnitude in the sample, this analysis of $N = 31$ participants where the mean EIB magnitude was 7.35%, exhibited a significant main effect of distractor valence ($p < .001$, $\eta_p^2 = .885$, $BF_{10} = 45{,}470{,}000{,}000$), and of working memory load ($p = .002$, $\eta_p^2 = .211$ [with Greenhouse Geisser correction applied for sphericity], $BF_{10} = 80.14$), and no interaction ($p = .467$, $\eta_p^2 = .025$, $BF_{10} = 0.15$). Altogether, this confirms that EIB magnitude was invariant to a working memory load that had a clear impact on overall performance.

Finally, we also examined the correlation between EIB magnitude and accuracy in the WM task in the full sample. The correlation between EIB magnitude (averaged across load conditions) and low load maths accuracy was non-significant, r (58) = .14, $p = .283$, [95% CI: − .11, .39], as was the correlation between EIB magnitude (averaged across load conditions) and high load maths accuracy, r (58) = .05, $p = .723$, [− .21, .31]. Furthermore, EIB magnitude specifically in the low load condition was not significantly correlated with maths accuracy in the low load condition, r (58) = − .05. $p = .731$, [− .31, .21], and EIB magnitude specifically in the high load condition was not significantly correlated with maths accuracy in the High Load Condition, r (58) = .21, $p = .113$, [− .04, .46]. Altogether, this indicates that EIB magnitude was unrelated to performance on the working memory task. In contrast, the relationship between low load and high load maths accuracy was significant, r (58) = .56, $p < .001$, [.38, .74]. This indicates that there was sufficient range and reliability in the accuracy scores to support correlations, making the absence of relationships between maths accuracy and EIB more meaningfully interpretable.

Discussion

The current results show that neither low nor high working memory load altered the magnitude of EIB relative to the no-load condition. These results contrast with the finding of a previous study in which this identical task and load eliminated a spatial-attentional bias toward emotionally-salient stimuli (Delchau et al., 2020). Taken together, these results are consistent with the notion that the prioritization of emotionally-salient stimuli by temporal attention does not require the involvement of top-down resources, while it does for spatial attention.

The findings of these working-memory studies are consistent with the studies that investigated proactive control. Those studies found that proactive control could entirely remove the spatial prioritization of emotionally-salient stimuli (Grimshaw et al., 2018; Walsh et al., 2018, 2021), while it either had no effect on temporal attention (Most et al., 2007; Zhao & Most, 2019) or, at most, only a minimal (Kennedy et al., 2018) or an inconsistent effect (i.e., an effect that was not replicated; Most et al., 2005, 2006).

Working memory is multifaceted (Baddeley, 1992, 2012). As a consequence, there are a variety of different types of working memory loads that can be used. Here, we chose one that required active information processing rather than just passive storage, and that has been shown to abolish the effects of emotionally-salient stimuli on spatial attention (Delchau et al., 2020). While this working memory load did not abolish EIB in the present study, this does not rule out the possibility that other types of working memory load may be able to do this.

We did not measure participants' working memory capacity in the present study. We do not think that this is problematic given that participants drawn from the same student population have been affected by this load (Delchau et al., 2020). However, there is evidence that working memory loads can interact with working memory capacity in determining their effects on performance (e.g., Ahmed & de Fockert, 2012). Therefore, future research could examine how individuals' working memory capacity interacts with the effect of the working memory load used here.

In conclusion, a working memory load that produced demonstrable impact on performance, and had in previous research abolished a spatial-attentional bias (Delchau et al., 2020), produced no discernible impact on the magnitude of EIB. This highlights the divergence between spatial and temporal attention when considering the attentional prioritization of emotionally-salient stimuli.

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Additional Information

Competing Interests The authors declare no competing interests.

Data Availability Raw data is available in OSF (see link in the main text).

Code Availability Upon request.

Ethics Approval This research was conducted with approval by the ANU DERC (2018/633) and we certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent to Participate All participants provided written informed consent.

Consent for Publication All authors have approved this version of the manuscript and participants signed informed consent regarding publishing their data.

Open Practices Statement The study was not preregistered.

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