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Functional connectivity associated with individual differences on the emotional attentional blink task

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ABSTRACT

The emotional attentional blink (EAB) task has been used in numerous studies to examine attention capture by emotional stimuli. In this task, participants are instructed to detect a rotated image embedded within a rapid-serial-visual-presentation (RSVP) of images. When an emotional photograph ("critical distractor") appears 200 msec before the target item, participants consistently show a dramatic impairment in target detection. However, the size of the EAB differs across participants. In the current study, we used resting-state fMRI to examine whether differences in functional connectivity were related to individual differences in the size of participants' EAB effects. Twenty-five participants completed a resting-state fMRI scan and an EAB task in different experimental sessions. On each trial of the EAB task, a negative, erotic, or neutral distractor appeared either 200 msec or 800 msec prior to a rotated target image. Accuracy scores were calculated for each distractor type (negative, erotic, and neutral) and lag (200 msec vs. 800 msec). Values representing the negative EAB effect and the erotic EAB effect trials were then entered as covariates in seed-based analyses. The functional connectivity between the right orbitofrontal cortex and parietal regions were positively correlated with the size of both the negative and erotic EAB effects. The erotic EAB was also associated with the functional connectivity between the right orbitofrontal cortex and left middle frontal gyrus.

1. Introduction

Emotional stimuli capture and hold attention, thus increasing the likelihood that an individual will be able to generate situation-appropriate responses (e.g., Dolcos et al., 2011; LeDoux, 2000; Pessoa et al., 2019). This robust relationship between emotional perception, attention, and motoric planning has clear evolutionary advantages and has received considerable attention from researchers. Emotion-attention interactions, in particular, have been examined using a number of different paradigms including—but not limited to—the dot-probe task (e.g., MacLeod et al., 1986; Mogg and Bradley, 1999), the emotional Stroop task (e.g., Ben-Haim et al., 2016; Williams et al., 1996), and numerous variants of visual-search tasks (e.g., Eastwood et al., 2001; Öhman et al., 2001). One paradigm that has produced particularly robust effects is the attentional blink (AB) task (Raymond et al., 1992). In its standard version, the AB requires participants to identify two targets presented as part of a rapid-serial-visual-presentation (RSVP) stream. If the second target (T2) is presented in close temporal proximity to the first target (T1), the ability to accurately identify T2 is impaired. However, if T2 is emotional in nature, the AB is reduced, suggesting that the emotional stimuli 'break through' the AB to reach conscious awareness (Anderson, 2005; Anderson and Phelps, 2001).

A more recent variant of the AB task showed that emotional stimuli are sometimes so salient that they can temporarily impair the perception of subsequent items in an RSVP stream, even if the emotional stimuli are not task-relevant. In this task, participants are asked to identify a rotated target image that is presented as part of a 17-item RSVP display of photographs (Most et al., 2005; McHugo et al., 2013). When none of the images are emotional in nature, participants are quite adept at detecting these visually anomalous targets. However, if an aversive emotional item is presented 200 msec prior to the target, accuracy is significantly impaired. This emotional attentional blink (EAB), or emotion-induced blindness, extends for 200–500 msec after the appearance of the emotional image (Most et al., 2005; Most and Junge, 2008). Subsequent research found that the EAB occurred for erotic images (Ciesielski et al., 2010; Most et al., 2007), aversively conditioned items (Smith et al., 2006), emotional faces (de Jong, Koster, van Wees and Martens, 2010; Gutiérrez-Cobo et al., 2019; Nakamura and Kawabata, 2014; Sklenar

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and Mienaltowski, 2019), surprising stimuli (Asplund et al., 2010), motivationally relevant stimuli (Campbell et al., 2018; Piech et al., 2009), and emotional words (Arnell et al., 2007; Macleod et al., 2017; Mathewson et al., 2008).

Although numerous studies have reported robust EAB effects, it is important to note that not all participants show the same degree of emotion-induced blindness. Several researchers have reported that this heterogeneity can be linked to individual differences in specific personality traits. Most et al. (2005) noted that EAB effects were more pronounced in harm-avoidant individuals. This effect is consistent with later studies with clinical populations which reported larger EABs in individuals with generalized anxiety disorder (Olatunji et al., 2011), obsessive compulsive disorder (Olatunji et al., 2011), and posttraumatic stress disorder (Olatunji et al., 2012). Researchers have also reported that the size and duration of the EAB is associated with neuroticism (Bredemeier et al., 2011). In contrast, other research has found that personality traits can *attenuate* the EAB. For example, Makowski and colleagues found that trait mindfulness—particularly the non-reacting subcomponent of this trait—was associated with a shorter EAB (Makowski et al., 2019). Together, these studies make a significant contribution to our understanding of the different factors that can influence individual differences in sensitivity to emotional distractors in the EAB task. However, an area of investigation that has received relatively little attention from researchers is the neural substrates underlying this heterogeneity.

Task-based neuroimaging studies of the EAB have identified several brain areas that influence performance on this task. Using fMRI, Most and colleagues (Most et al., 2006) reported amygdalar responses to negative distractors, albeit only in participants who scored high on a measure of harm avoidance. In an RSVP task utilizing linguistic stimuli, Schwabe and colleagues (Schwabe, Merz, Walter, Vaitl, Wolf and Stark, 2011) also noted amygdala activity in response to negative words. However, this activity was only detected when the emotional words were the second target (T2) in the RSVP stream. When these items were displayed as the first target (T1), which more closely mirrors the EAB task, larger activity was observed in the anterior cingulate gyrus, insula, and orbitofrontal cortex. In an event-related-potential (ERP) study, Kennedy and colleagues (Kennedy et al., 2014) found that emotional distractors suppressed both the N2 and P3b ERP components that would normally occur during target detection. This suppression occurred in posterior—primarily parietal—brain areas and may indicate that emotional distractors interfere with the consolidation of target-related information into working memory (Vogel and Luck, 2002). These researchers also reported a larger posterior positivity in parietal regions during negative distractor trials. Taken together, these neuroimaging data highlight the role of the anterior cingulate gyrus, orbitofrontal cortex, and parietal lobe, in the EAB task; they also suggest that the amygdala should have little relation to EAB results because in this task the emotional distractor is T1 rather than T2. A question that remains unanswered, however, is whether baseline patterns of brain activity in these regions can explain why some individuals show large EAB effects while others do not.

The current research used resting-state fMRI to examine whether differences in patterns of "baseline" neural activity were related to individual differences in sensitivity to emotional distractors. In resting-state scans, participants' brain activity is measured using scanning parameters similar to those used during task-based studies. However, rather than performing a cognitive or attentional task, participants are instead asked to simply remain motionless in the scanner. Importantly, during this time, neurons in the brain are still active; indeed, the degree of activity of different regions tends to fluctuate over the course of the fMRI scan (see Raichle, 2015, for a review). Numerous previous studies have found that the activity of topologically disparate regions of the brain tend to fluctuate together; this correlated activity is known as functional connectivity (e.g., Biswal et al., 1995; Buckner et al., 2008; Damoiseaux; Rombouts; Barkhof; Scheltens, P., Stam; et al., 2006; Gusnard and Raichle, 2001; Raichle et al., 2001).

One method of measuring functioning connectivity is to specify a seed region and examine the correlated activity between this region and the rest of the brain. This seed-based technique was used to examine whether the brain's resting-state functional connectivity was related to individual differences in susceptibility to an emotional attentional blink. Participants' scores on different trial types in an EAB task completed 1–2 weeks prior to scanning were entered as covariates in subsequent analyses of resting-state fMRI data. This strategy allowed us to examine whether the strength of functional connectivity between brain regions varied as a function of scores on the EAB task. Our hypotheses were based on the task-based fMRI studies described above. We hypothesized that the EAB would be associated with the functional connectivity of the orbitofrontal and anterior cingulate cortices. We specifically predicted that EAB scores related to negative emotional distractors would be positively correlated with the functional connectivity between these prefrontal cortex structures and (1) dorsal parietal regions (see Kennedy et al., 2014), and (2) extrastriate regions, which frequently show enhanced activity during the perception of emotional stimuli (e.g., Surguladze et al., 2003). If our data are consistent with those of Schwabe et al. (2011), seed analyses with the amygdalae should not be related to EAB scores. Although less research has investigated the neural substrates underlying the emotional modulation of attention by erotic stimuli, based on previous research that indicated that both positive and negative arousing distractors influence attention (Anderson, 2005), we would predict similar patterns of connectivity associated with both negative and erotic EAB scores.

2. Methods

2.1. Participants

Participants consisted of 25 undergraduate students (19 female, age range = 18–24) from the University of Winnipeg. All participants provided informed, written consent before each of the two experimental sessions and underwent MRI safety screening prior to entering the MRI scanner. Exclusion criteria consisted of a history of neurological injuries including concussions, the presence of an affective disorder—as measured by the Beck Depression Inventory II (Beck et al., 1996) and the State-Trait Anxiety Inventory (Spielberger et al., 1983)—and the presence of metal in one's body.

This project received ethics approval from both the University of Winnipeg Senate Committee for Ethics in Human Research and the National Research Council Ethics Committee. As such, the manner in which this experiment was conducted was consistent with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

2.2. Procedure

All participants completed two experimental sessions, one consisting of the computer-based EAB task and one consisting of a resting-state functional MRI scan. During the resting-state scan, participants were asked to remain motionless in the scanner with their eyes closed for 7 min. All participants completed the EAB first and were scanned within the next two weeks.

2.2.1. The emotional attentional blink task

The EAB task was programmed using E-Prime 2.0 experimental software (Psychology Software Tools, Sharpsburg, PA) and consisted of 168 trials divided into three blocks of 56 trials. The order of the trials was randomized for each participant. Each trial consisted of an RSVP stream in which 17 photographs were centrally presented for 100 msec with no gap between the images. All images were 320 × 240 pixels on the screen and measured 12.4 cm × 9.3 cm when displayed on a CRT monitor attached to a Dell Optiplex computer. Fifteen of these images consisted of photographs of landscapes or cityscapes that had been judged to be emotionally neutral in previous studies (e.g., Most et al., 2007; Smith et al., 2006). One of the 17 images on each trial consisted of the target image. All target images were landscape or cityscape photographs; however, they had been rotated 90° to the right or left (see Fig. 1). Participants were asked to press the left or right arrow key ("<" or ">") to indicate the direction of the target image.

As with many previous studies using the EAB, a "critical distractor" item appeared either 200 msec (Lag 2) or 800 msec (Lag 8) before the presentation of the target. There were three types of critical distractors. Negative emotional distractors consisted of images of gory, disgusting, and/or threatening scenes such as a snarling dog. Erotic emotional distractors consisted of nude or semi-nude individuals. Both negative and erotic images were selected from the International Affective Picture System (IAPS; Lang et al., 2008). Neutral images consisted of unexciting interior scenes (e.g., a kitchen); these were selected from the IAPS as well as from publicly available sources. Thus, each participant produced six scores—an average accuracy score for each type of critical distractor (negative, erotic, or neutral) and lag (2 or 8).

The stimuli from the current study were identical to those used in previous research (Most et al., 2007). Items in that study were rated on a 9-point scale for emotional valence (with higher scores being positive) and emotional arousal (with higher scores indicating higher levels of arousal). For emotional valence, erotic images were rated as more positive ($M = 6.8$, $SD = 1.1$) than either the neutral ($M = 5.1$, $SD = 0.4$) or the negative images ($M = 2.1$, $SD = 0.5$). Both erotic ($M = 6.8$, $SD = 1.4$) and negative ($M = 7.0$, $SD = 0.9$) images were rated as being more emotionally arousing than neutral images ($M = 2.3$, $SD = 0.9$). It is also noteworthy that the arousal ratings for the erotic and negative stimuli were almost identical.

2.2.2. fMRI data acquisition

Data were acquired using a 3T Siemens TRIO MRI scanner (Siemens, Erlanger, Germany). All participants first underwent an 8-min, high-resolution, T1-weighted gradient-echo anatomical MRI scan. The parameters for this scan were as follows: slice thickness = 1 mm, gap = 0 mm, TR = 1900 msec, TE = 2.2 msec, in-plane resolution = .94 × 0.94, matrix = 256 × 256, field of view = 24 cm.

The resting-state fMRI scan utilized standard blood oxygenation level dependent (BOLD) neuroimaging techniques. Participants underwent a 7-min fMRI scan that used a whole brain echo planar imaging (EPI) sequence. The parameters for this scan were as follows: slice thickness = 3 mm, gap = 0 mm, TR = 3000msec, TE = 30 msec, flip angle = 90°, matrix = 64 × 64, field of view = 24 cm.

2.3. Data analysis

The behavioral data for each participant were analyzed using SPSS 19 (IBM Corp., 2017). For each participant, an average score was calculated for all six trial types (Negative Lag 2, Erotic Lag 2, Neutral Lag 2, Negative Lag 8, Erotic Lag 8, and Neutral Lag 8). These averages were then entered into a 3 (Distractor: Negative, Erotic, Neutral) X 2 (Lag: 2, 8) repeated-measures analysis of variance. Planned comparisons were made between the two lags for each distractor type (e.g., Negative Lag 2 vs. Negative Lag 8) and between the three averages at Lag 2 (e.g., Negative Lag 2 vs. Neutral Lag 2). In order to account for multiple comparisons, the p-value used to deem a result as being statistically significant was 0.008 (0.05/6 comparisons).

2.3.1. Resting-state functional MRI data analysis

For the current research, seed-based functional connectivity analysis was performed using the CONN toolbox version 20.b (Whitfield-Gabrieli & Nieto-Castanon, 2012). All data were converted to Nifti files and uploaded into CONN. Structural data were centered to (0,0,0) coordinates, segmented into gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF), and normalized into the Montreal Neurological Institute (MNI) template.

The functional data were functionally realigned and unwarped before being centered to (0,0,0) coordinates. The data underwent slice time correction, were segmented into GM, WM, and CSF, normalized to the MNI template and smoothed using an 8 mm full width at half maximum Gaussian kernel. The Artifact Detection Tool (ART toolbox;

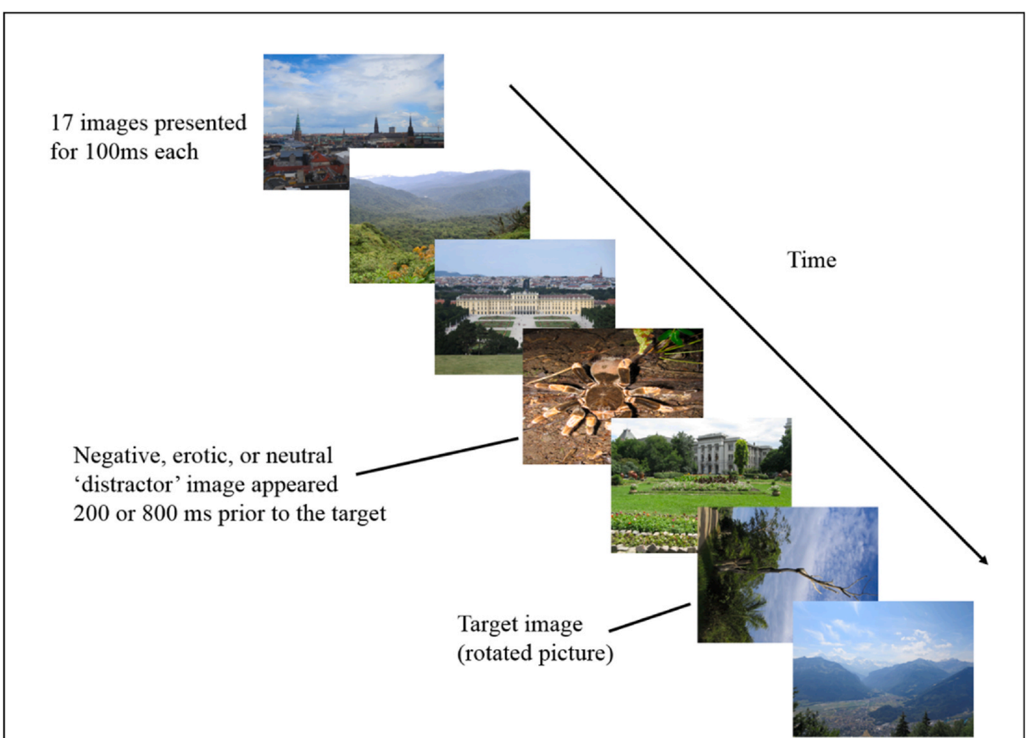

Fig. 1. A depiction of a trial on the emotional attentional blink task.

http://www.nitrc.org/projects/artifact_detect/) was used to detect outliers in these data. During de-noising, CSF, WM, and outliers detected by the ART toolbox were entered as confounding effects in a linear regression. Participant motion correction was performed using realignment parameters that had been entered into the linear regression as confounding effects (including first-order derivatives, no polynomial expansion). Linear de-trending and application of the default band-pass filter (0.008 0.09 Hz) were applied.

Seed-based functional connectivity analysis was performed with the General Linear Model, using bivariate correlation-analysis settings with no weighting applied. The five seeds used in this study–the anterior division of the cingulate gyrus (ACC), the left and right orbitofrontal cortex, and the left and right amygdalae—were selected from the CONN default atlas. These specific seeds were selected because earlier task-based fMRI studies had reported emotion-dependent activity in these specific structures (see Most et al., 2006, and Schwabe et al., 2011). Gaussian Random Field theory parametric statistics were applied with a cluster threshold of $p < 0.05$ cluster-size p-FDR corrected and an uncorrected voxel threshold of $p < 0.001$ allowing for cluster-level inferences with family-wise error control (Worseley et al., 1996).

2.3.2. Selection of covariates

Two difference scores were used to examine whether functional connectivity was associated with the EAB effect. The negative EAB effect was calculated by subtracting the accuracy in the Negative Lag 2 condition from the accuracy in the Neutral Lag 2 condition. Similarly, the erotic EAB effect was calculated by subtracting the accuracy on the Erotic Lag 2 trials from the accuracy on the Neutral Lag 2 trials. Although the difference score comparing Negative Lag 2 and Erotic Lag 2 scores would have allowed us to examine individual differences in sensitivity to different emotional distractors, the mean scores for these trial types were not significantly different (see below). Therefore, the difference scores would be small and less reliable than those used for the two analyses described above. It would also be tempting to compare performance on Lag 2 and Lag 8 trials for both negative and erotic distractors. However, although these values *could* represent an individual's ability to refocus attention after experiencing an EAB, there are other possible explanations. For instance, an individual with high accuracy on Negative Lag 2 trials *and* Negative Lag 8 trials would have a small difference score; however, this score should not be interpreted as a poor ability to refocus attention. Due to this ambiguity in interpreting the data, the [Negative Lag 8 – Negative Lag 2] and [Erotic Lag 8 – Erotic Lag 2] values were not included as covariates.

3. Results

For the purposes of clarity, we will first discuss the behavioral data from the EAB task. This will be followed by a description of the functional connectivity analyses.

3.1. Behavioral results

The percentage of accurate responses was calculated for all distractor types (neutral, negative, and erotic) and both Lags (Lag 2 and Lag 8). These data are depicted in Fig. 2. The data were then entered into a 3 (Distractor Type) X 2 (Lag) repeated-measures analysis of variance. These analysis yielded a significant main effect of both Lag, $F(1, 24) = 64.64$, $MSE = 0.530$, $p < 0.00001$, and Distractor Type, $F(2, 48) = 32.35$, $MSE = 0.156$, $p < 0.0001$. There was also a significant Distractor Type X Lag interaction, $F(2, 48) = 17.85$, $MSE = 0.093$, $p < 0.001$.

Planned comparisons were conducted to determine whether the two types of emotional distractors produced a larger EAB than the neutral distractors at Lag 2. Accuracy on trials in which the critical distractor was negative ($M = 75.33\%$, $SD = 11.78\%$) was significantly lower than on trials in which the critical distractor was neutral ($M = 91.00\%$, $SD = 5.24\%$): $t(24) = 6.09$, $p < 0.001$. Similarly, the accuracy on Lag 2 trials with erotic distractors ($M = 73.00\%$, $SD = 12.27\%$) was also significantly lower than on neutral trials: $t(24) = 7.31$, $p < 0.001$. The difference between the negative and erotic trials at Lag 2 did not differ: $t < 1$. Indeed, the correlation between negative and erotic Lag 2 trials was quite high: $r(23) = 0.501$, $p < 0.01$. The correlation between the negative EAB effect (Neutral Lag 2 – Negative Lag 2) and the Erotic EAB effect (Neutral Lag 2 – Erotic Lag 2) was similarly robust: $r(23) = 0.532$, $p < 0.01$. Together, these data indicate that on Lag 2 trials, when the time between the presentation of the critical distractor and target was 200 msec, emotional stimuli impaired target detection.

Planned comparisons were also conducted in order to determine if participants were able to refocus their attention if the time between the critical distractor and targets was longer. Statistical investigation of these differences found that accuracy on negative trials at Lag 8 ($M = 89.50\%$, $SD = 7.13\%$) was significantly better than at Lag 2: $t(24) = 5.27$, $p < 0.001$. A similar result was found for the comparison of Lag 8

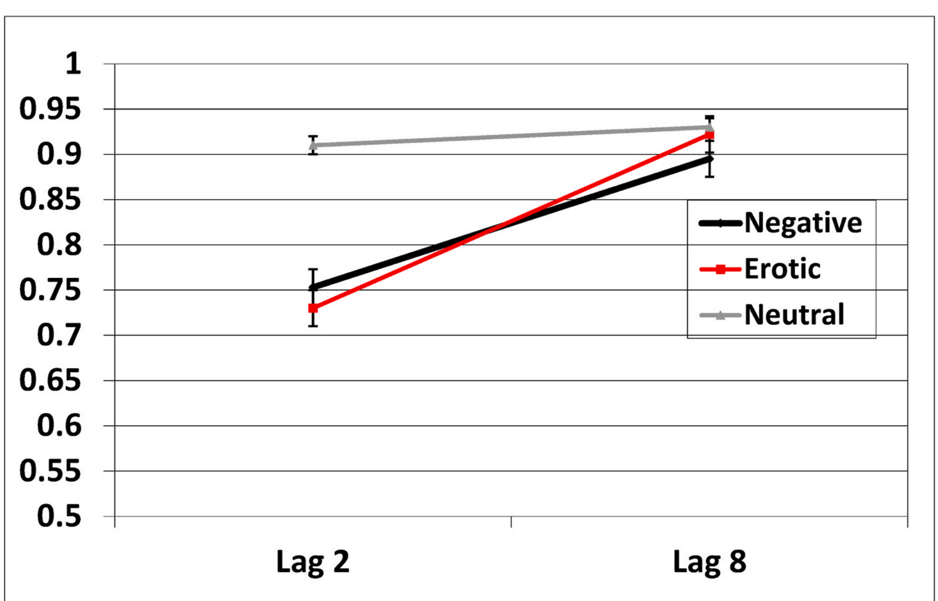

Fig. 2. Behavioral performance on the emotional attentional blink task. Error bars represent the standard error of the mean.

erotic trials ($M = 91.17\%$, $SD = 5.55\%$) and Lag 2 trials: $t(24) = 8.13$, $p < 0.001$. The difference between Lag 2 and Lag 8 neutral trials was not significant: $t(24) = 1.59$, $p = 0.124$. These analyses reinforce the point that emotional images presented in close temporal proximity to the target impair participants' target-detection accuracy.

A *post hoc* analysis of the Lag 8 data found one only significant difference. Negative stimuli presented 800 msec prior to the target impaired accuracy to a larger degree than neutral distractors: $t(24) = 2.46$, $p = 0.021$. However, this effect did not survive any controls for multiple comparisons.

3.2. Functional connectivity analyses

The first set of difference scores that were examined consisted of the difference in accuracy between Neutral Lag 2 and Negative Lag 2 trials. Each participant's value for this 'negative EAB effect' was entered as a covariate in the functional connectivity analysis. These results are shown in Fig. 3 and Table 1. Here, a larger value would represent a larger sensitivity to negative emotional distractors (i.e., a larger EAB effect). Only one significant correlation was observed for these data: the functional connectivity between the right orbitofrontal cortex and a single cluster consisting of voxels within the left planum temporale, supramarginal gyrus, angular gyrus, and posterior superior temporal gyrus.

The second set of difference scores represented the difference in accuracy between Neutral Lag 2 and Erotic Lag 2 trials (i.e., an erotic EAB effect); these data are depicted in Fig. 4 and Table 2. Again, a higher difference score would indicate a larger EAB effect. This analysis yielded significant effects for the functional connectivity of the right orbitofrontal cortex seed. One of the clusters that correlated with the right orbitofrontal seed region was similar to the cluster related to the negative EAB scores. It consisted of voxels in the left supramarginal gyrus, posterior superior temporal gyrus, and angular gyrus. A second cluster

Table 1
Seed-based analysis results showing functional connectivity differences co-varied with difference scores between the accuracy rates for the Neutral Lag 2 and Negative Lag 2 trials ($p < 0.05$ cluster-size p-FDR corrected, voxel threshold $p < 0.001$ uncorrected). The MNI coordinates, cluster size, t-, and p-values are given for the cluster. The brain regions corresponding to the voxels within the cluster are listed.

Seed	Cluster size	t	p
Orbitofrontal Cortex (R)			
Cluster 1: 56, -46, 18 (x,y,z)	188	>3.77	0.022
Planum Temporale (L)			
Posterior Supramarginal Gyrus (L)			
Angular Gyrus (L)			
Posterior Superior Temporal Gyrus (L)			
Parietal Operculum Cortex (L)			

Abbreviations: t, t-value; p, p-value; R, right; L, left.

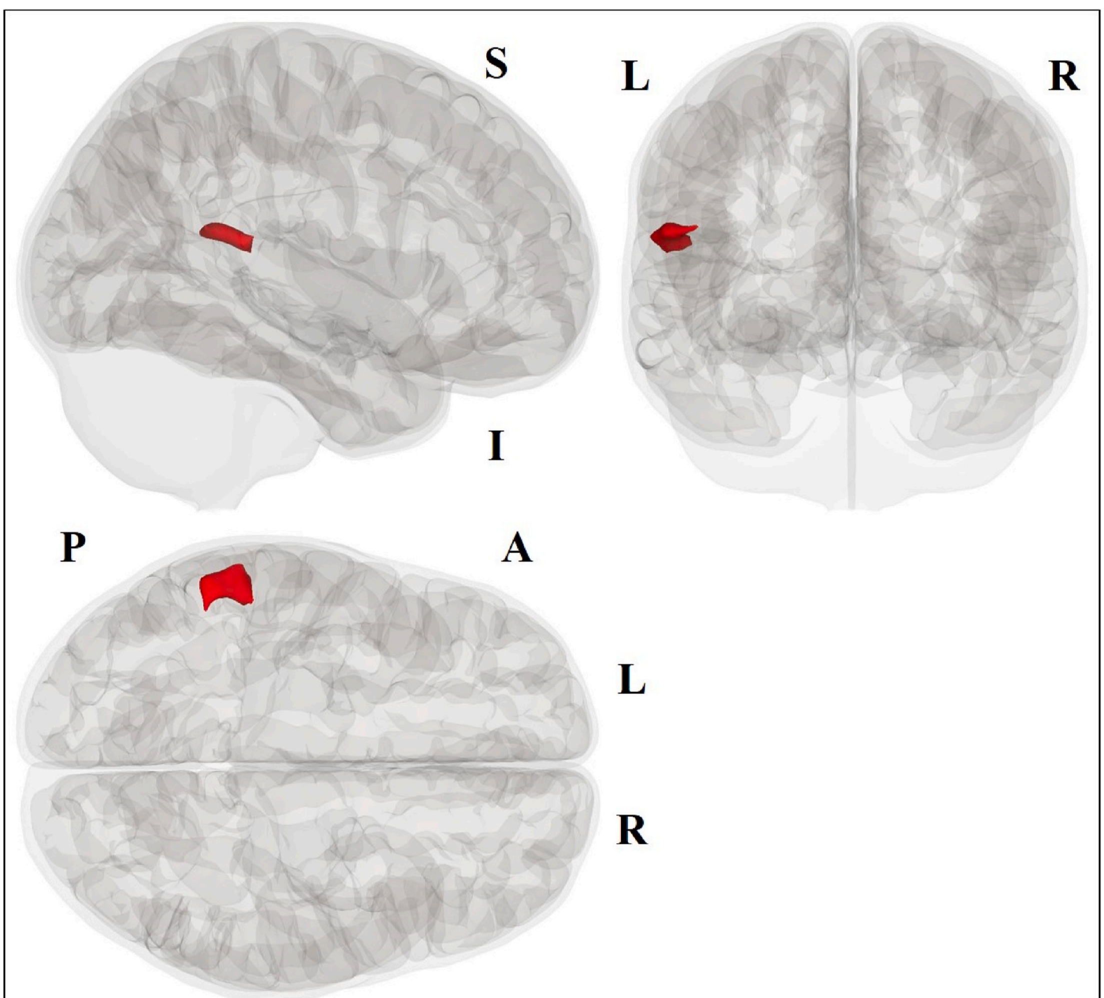

Fig. 3. Seed-based analysis results showing functional connectivity co-varied with difference scores of the accuracy rates for the Neutral Lag 2 and Negative Lag 2 trials for the right orbitofrontal cortex seed. The single cluster is displayed on a glass brain in sagittal, coronal and axial orientations with a $p < 0.05$ cluster-size p-FDR corrected, voxel threshold $p < 0.001$ uncorrected. Abbreviations: A, anterior; P, posterior; L, left; R, right; S, superior; I, inferior.

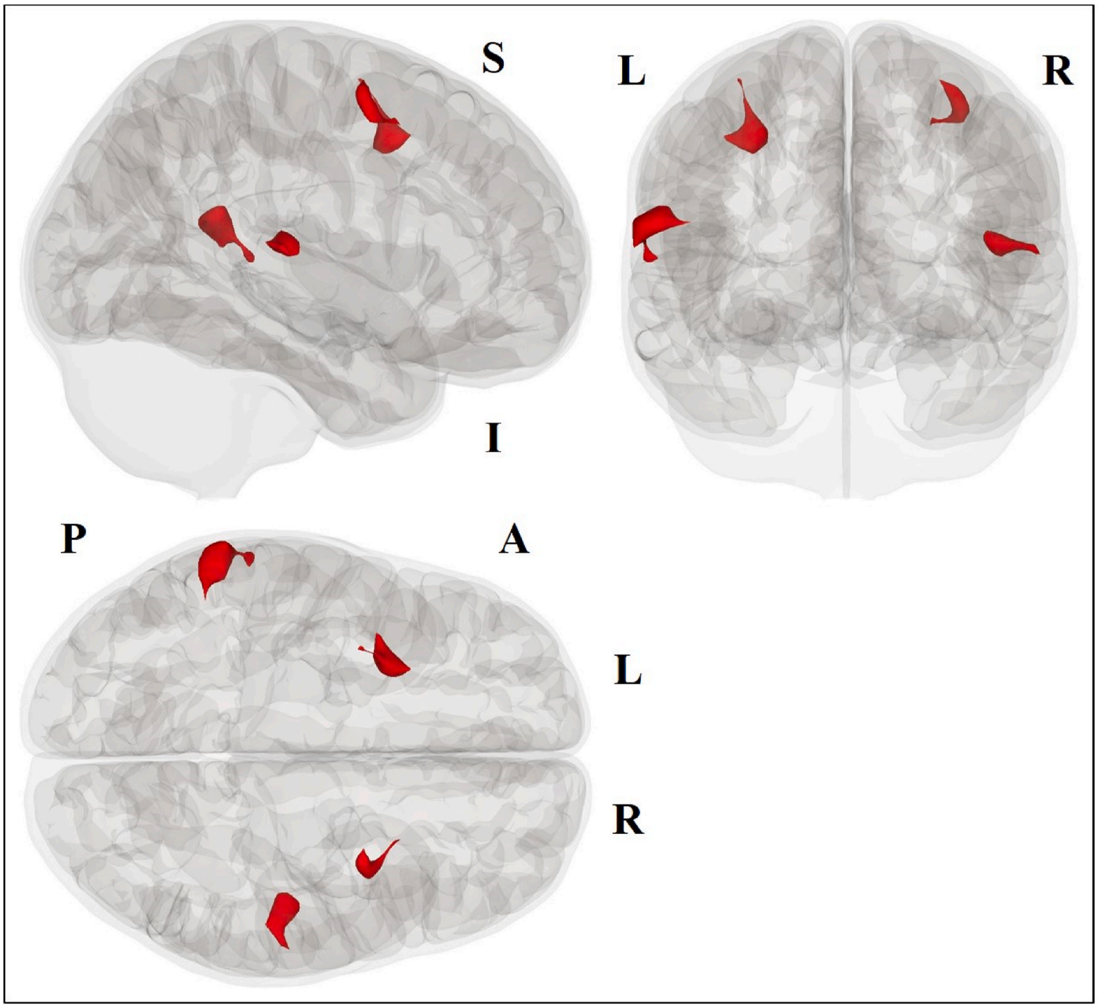

Fig. 4. Seed-based analysis results showing functional connectivity co-varied with difference scores of the accuracy rates for the Neutral Lag 2 and Erotic Lag 2 trials for the right orbitofrontal cortex seed. The four clusters are displayed on a glass brain in sagittal, coronal and axial orientations with a $p < 0.05$ cluster-size p-FDR corrected, voxel threshold $p < 0.001$ uncorrected. Abbreviations: A, anterior; P, posterior; L, left; R, right; S, superior; I, inferior.

was also similar to the negative EAB results, albeit in the right hemisphere. This cluster consisted of voxels in the right planum temporale, Heschl's gyrus, and the parietal operculum. The two additional significant clusters associated with the right orbitofrontal seed region were located in the left and right middle frontal gyri.

No significant effects were observed for the left orbitofrontal, anterior cingulate, or amygdala seeds.

4. Discussion

The primary aim of the current research was to examine whether individual differences on the EAB task were related to individual differences in the brain's resting-state functional connectivity. However, before discussing the implications of the current results, it is important to note that functional connectivity is a statistical relationship. It does not necessarily demonstrate that a particular cognitive or perceptual function has been performed. For example, if the orbitofrontal cortex and superior parietal cortex showed strong functional connectivity, it is *possible* that the orbitofrontal cortex tended to influence attention; however, this conclusion should not be drawn without supporting behavioral evidence (Poldrack, 2006). Therefore, in order to avoid this reverse-inference fallacy, we will focus on general patterns in the data and their potential implications for our understanding of the emotional modulation of attention.

It is noteworthy that all of the significant results involved the right orbitofrontal cortex. The orbitofrontal cortex is associated with a large number of emotional functions, particularly related to reward responses (Rolls, 2004, 2019). Neuroimaging studies have also highlighted the importance of the right orbitofrontal cortex in processing vivid motoric imagery (Mizuguchi et al., 2019). Given that both negative and erotic distractors would appear motorically vivid relative to the neutral distractors in the RSVP stream, it is possible that individuals with a greater sensitivity to such images would have a larger EAB effect as well as stronger functional connectivity between the right orbitofrontal cortex and brain areas related to attention. Another potential explanation for the observed orbitofrontal effects is related to the difficulty associated with perceiving the stimuli in the EAB task. Olano and colleagues (Olano et al., 2020) manipulated the intelligibility of negative and neutral words by mixing audio files with white noise. They found that the right orbitofrontal cortex was one of several structures active during the perception of negative words that were mixed with white noise. This result suggests that the right orbitofrontal cortex is involved in detecting emotional stimuli in suboptimal conditions; the RSVP stream used in the EAB task would also certainly qualify as suboptimal in the visual domain.

An additional trend that occurred for both negative and erotic conditions was that increased functional connectivity between the right orbitofrontal cortex and left parietal cortical regions was associated with larger EAB scores. This result is consistent with a task-based fMRI study by Schwabe et al. (2011) in which emotional distractors elicited activity

Table 2
Seed-based analysis results showing functional connectivity differences co-varied with difference scores between the accuracy rates for the Neutral Lag 2 and Erotic Lag 2 trials ($p < 0.05$ cluster-size p-FDR corrected, voxel threshold $p < 0.001$ uncorrected). For each cluster, the MNI coordinates, cluster size, t-, and p-values are given. The brain regions corresponding to the voxels within each cluster are listed.

Seed	Cluster size	t	p
Orbitofrontal Cortex (R)			
Cluster 1: 64, -46, 16 (x,y,z)	237	>3.77	0.012
Posterior Supramarginal Gyrus (L)			
Posterior Superior Temporal Gyrus (L)			
Angular Gyrus (L)			
Planum Temporale (L)			
Cluster 2: 30, 10, 42 (x,y,z)	193	>3.77	0.017
Middle Frontal Gyrus (L)			
Cluster 3: 48, -22, 10	157	>3.77	0.027
Planum Temporale (R)			
Heschl's Gyrus (R)			
Parietal Operculum Cortex (R)			
Central Opercular Cortex (R)			
Cluster 4: 34, 2, 60 (x,y,z)	136	>3.77	0.036
Middle Frontal Gyrus (R)			
Superior Frontal Gyrus (R)			

Abbreviations: t, t-value; p, p-value; R, right; L, left.

in the orbitofrontal cortex, anterior cingulate cortex, and insula. It is possible that stronger functional connectivity between these prefrontal regions and parietal lobe structures makes some individuals more sensitive to salient stimuli. The mechanism underlying this sensitivity may be arousal (e.g., Anderson, 2005; Anderson and Phelps, 2001), attentional modulation (e.g., Schwabe et al., 2011), disambiguating difficult-to-perceive stimuli (Olano et al., 2020), working-memory modulation (Zhou et al., 2020), or, more likely, a combination of multiple functions.

It is worth noting that the parietal clusters also included voxels in the left posterior temporal cortex, with a larger number of significant voxels being found for the erotic than the negative EAB analyses. Although this cortical region is often associated with linguistic functions (e.g., see Binder, 2017, for a review), both structural and functional MRI studies have also indicated a potential role in the analysis of social information (Arioli et al., 2018; Gao et al., 2018; Kestemont et al., 2015; Yin et al., 2018). To assess whether the significant results reported here are indeed related to social cognition, future research could investigate whether EAB scores are related to different social-cognitive functions, specifically theory of mind and emotional-contagion tasks.

It was also intriguing that sensitivity to erotic, but not negative, distractors was positively correlated with functional connectivity between the right orbitofrontal cortex and both the left and right middle frontal gyrus. One possible explanation is that while both negative and erotic distractors would capture attention, some of the participants may have preferred the erotic distractors (nudity) to the negative distractors. These individuals may have engaged top-down attention—which involves dorsolateral prefrontal regions including the middle frontal gyrus (see Dixon et al., 2017, for a review)—to encode the erotic images, thus leading to poorer performance on the EAB task. Such an explanation would explain why the functional connectivity between the right orbitofrontal cortex and left middle frontal gyrus was only significantly correlated with erotic EAB scores.

A final result of interest involved the amygdala, a structure associated with the perception of fear-related stimuli (see Zald, 2003, for a review). The functional connectivity of this structure was *not* related to accuracy on the EAB task. There are (at least) two possible explanations for this null effect. First, consistent with the task-based study of Schwabe et al. (2011), the amygdala plays a relatively minor role in AB tasks in which the emotional stimulus is T1 rather than T2. Alternatively, it is possible that the amygdala influenced the EAB effect in all participants; as a result, there were no detectable individual differences in the resting-state activity of this emotion-related structure. Given that there were differences in the magnitude of the EAB effects across participants, the first explanation appears more likely, at least in the current study.

4.1. *Limitations*

Although the current study examined the EAB from a novel perspective, there are a number of limitations that should be noted. One issue is that this study was based on resting-state fMRI data rather than being a measurement of neural activity during the performance of an actual task. Therefore, caution must be exercised when attempting to link the patterns of functional connectivity to attentional processes. A second limitation is the relatively small sample size (25 participants). However, a similar sample size was used in a recent examination of the functional connectivity associated with emotional awareness (Smith et al., 2017) and therefore appears to be acceptable for initial investigations of a topic such as the EAB. Future studies using a larger sample size may wish to include multiple behavioural tasks in order to tease out the relationship(s) between functional connectivity and different emotion-attention interactions. It is also important to note that functional connectivity is a statistical relationship between brain areas and does not necessarily represent the efficiency of white-matter pathways between neural structures. Future studies using structural neuroimaging techniques such as diffusion tensor imaging would be necessary to address this issue. Finally, the negative emotional stimuli in the current study included both gory images and threatening images (e.g., someone with a knife). Future studies would benefit from using a more specific group of negative emotional images.

4.2. *Conclusions*

The current study demonstrated that individual differences in performance on an emotional attentional blink task were related to differences in the brain's resting-state functional connectivity. Additionally, sensitivity to both negative and erotic distractors were positively correlated with the functional connectivity between the right orbitofrontal cortex and parietal areas. However, sensitivity to erotic distractors also correlated with the functional connectivity between the orbitofrontal cortex and middle frontal gyrus. These results suggest that the neural substrates of arousal-dependent EAB effects are more nuanced than what was previously thought. Together, these results demonstrate the need for additional task-based neuroimaging studies in order to more thoroughly elucidate the neural substrates of emotion-induced blindness.

Competing financial interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data sharing statement

The data are available for use by other researchers. Please contact the corresponding author.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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