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Research report

Task difficulty modulates brain activation in the emotional oddball task

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ABSTRACT

Previous functional magnetic resonance imaging (fMRI) studies have reported that task-irrelevant, emotionally salient events can disrupt target discrimination, particularly when attentional demands are low, while others demonstrate alterations in the distracting effects of emotion in behavior and neural activation in the context of attention-demanding tasks. We used fMRI, in conjunction with an emotional oddball task, at different levels of target discrimination difficulty, to investigate the effects of emotional distractors on the detection of subsequent targets. In addition, we distinguished different behavioral components of target detection representing decisional, nondecisional, and response criterion processes. Results indicated that increasing target discrimination difficulty led to increased time required for both the decisional and nondecisional components of the detection response, as well as to increased target-related neural activation in frontoparietal regions. The emotional distractors were associated with activation in ventral occipital and frontal regions and dorsal frontal regions, but this activation was attenuated with increased difficulty. Emotional distraction did not alter the behavioral measures of target detection, but did lead to increased target-related frontoparietal activation for targets following emotional images as compared to those following neutral images. This latter effect varied with target discrimination difficulty, with an increased influence of the emotional distractors on subsequent target-related frontoparietal activation in the more difficult discrimination condition. This influence of emotional distraction was in addition associated specifically with the decisional component of target detection. These findings indicate that emotion-cognition interactions, in the emotional oddball task, vary depending on the difficulty of the target discrimination and the associated limitations on processing resources.
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1. Introduction

Emotional stimuli affect how we process and respond to our surroundings. However, as Phelps (2006) has noted, despite this generally accepted tenet, human cognition research often regards emotion and cognition as separate realms. Yet, both behavioral evidence and functional magnetic resonance imaging (fMRI) results demonstrate that the two are inextricably intertwined. Emotional stimuli typically activate subcortical regions such as the amygdala, ventral striatum, and thalamus, but also a network of cortical regions including lateral and medial prefrontal cortex and the anterior cingulate, as well as sensory regions (Dolcos et al., 2011a,b; Kober et al., 2008; Mather and Carstensen, 2003). Emotional stimuli, particularly those expressing anger, fear, or disgust, can be highly salient and thus appear to be processed without requiring much attentional capacity, consistent with a predominantly subcortical pattern of activation (Anderson et al., 2003; Morris et al., 1999). However, fMRI studies that have manipulated the attentional demands of the task, in conjunction with the emotional valence of the stimuli, have led to a more complex view in which processing of the emotional stimuli is constrained by the attentional demands of the task. Specifically, several studies, both event-related potential (ERP) and fMRI, have found that the distracting effects of emotional stimuli, even those expressing fear, a negative emotion with high valence, are substantially reduced in the context of an attention-demanding task (Doallo et al., 2006; Lange et al., 2003; Pessoa et al., 2002a,b), while others demonstrate that attention to threatening stimuli is prioritized (Hartikainen et al., 2012; Schmidt et al., 2015). There is also evidence that emotional distraction is processed both automatically

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and modulated by attentional demands, yet emotion and attentional load interacted only when emotional charge and processing demands were more finely assessed. For example, distracting effects of emotion were largest with low perceptual load, long presentation duration, and images with high emotional (as compared to low emotional) content (Shafer et al., 2012). This array of results highlights the importance of manipulating both emotional valence and attentional load in order to clarify differences in emotion-attention interactions as a function of task difficulty.

The emotional oddball task (Wang et al., 2005, 2006; Wang et al., 2008a,b,c) yields information regarding the interaction of emotion and attention by measuring a detection response to relatively rare (oddball) targets, in the context of more frequently occurring standards and rarely occurring distractors. When the distractors are images with an emotional valence, they can lead to a distinct pattern of neural activation, even though neither the standards nor the distractors require an overt response, and allow for the estimation of the cognitive processes engaged in response to task-irrelevant emotional stimuli. Wang et al. (2005), for example, reported that distractors that were sad images (e.g., related to grief and despair) activated ventral brain regions, including the amygdala, fusiform gyrus, and inferior frontal gyrus, relative to neutral images (phase scrambled pictures), whereas the detection of targets (circles) activated dorsal regions of frontal, parietal, and cingulate cortex.

In the present experiment we sought to determine whether the brain activation associated with sad images, in the emotional oddball task (Wang et al., 2005), varied as a function of attentional load (Doallo et al., 2006; Shafer et al., 2012), in terms of target discrimination difficulty, in order to determine if activation to emotional images is constrained by task demands, therefore presumably under the control of top-down regulation, or demonstrates no difference between target discrimination difficulty conditions, suggesting that sad emotional stimuli are given priority regardless of attentional demands. We also seek to extend previous research demonstrating the effect of target discrimination difficulty on high valence emotional stimuli, for example, fear, by determining if these findings hold true for low valence emotional stimuli, specifically sadness. In addition, the emotional oddball task is sensitive to individual differences in emotion regulation ability, as it is thought to require cognitive control in order to maintain performance in response to attentional targets despite the presence of emotional distractors, and the pattern of activation reflecting emotion-cognition interactions has been reported to vary for individuals with major depressive disorder (Wang et al., 2008c), mild traumatic brain injury, orbitofrontal cortex lesion patients, and patients with anxiety disorders (Bishop et al., 2004; Bishop, 2008; Maki-Marttunen et al., 2015, 2017). Thus, in this experiment we examined the relation between target-related activation and different aspects of target detection performance.

Many previous studies on distraction from emotional stimuli comprise tasks in which the task-relevant and emotional items are presented concurrently (Doallo et al., 2006; Lange et al., 2003; Pessoa et al., 2002a,b; Shafer et al., 2012) (but cf. Dolcos et al., 2008). The first goal of this experiment was to examine the influence of target discrimination difficulty on distraction from emotional stimuli. Specifically, for fMRI data, we examined the variation in task-irrelevant distractors of varying emotional valence (sad and neutral images), as a function of target discrimination difficulty. Also, within this goal, we examined the effects of emotional distractors on responses to subsequently occurring task-relevant items (targets), as a function of target discrimination difficulty, in activation and behavioral performance. A useful feature of the emotional oddball task is that distractors and targets are separated in time, which allows estimation of the influence of the distractors on the detection of subsequently appearing targets. Studies utilizing fMRI, electrophysiological, and behavioral measures where emotional stimuli preceded target presentation, have shown that task-irrelevant unpleasant emotional images interfere with subsequent target discrimination (Hartikainen et al., 2000, 2007). This paradigm extends previous findings to determine whether emotion-cognition interactions vary with target discrimination difficulty when emotional distraction may have an extended effect on subsequent cognitive processing, as well as whether target discrimination difficulty modulates the processing of emotional distractors, independently of the target.

A second goal of this experiment was to investigate the effects of target discrimination difficulty and emotional distraction on different components of target detection performance. We analyzed the behavioral data with a diffusion model of reaction time (RT) that distinguished the decisional and nondecisional components of the target detection response (Ratcliff et al., 2016; Voss et al., 2013; Wagenmakers et al., 2007). Previous investigations of emotional distraction effects, as in the majority of behavioral research, have measured task performance in terms of mean RT and accuracy (e.g., Doallo et al., 2006; Shafer et al., 2012). The diffusion model of RT uses estimates of the underlying RT distribution to distinguish several of the information processing components contributing to mean RT and accuracy, including the rate of information accumulation towards a decision (drift rate), visual encoding and motor response time (nondecision time), and response cautiousness (boundary separation). Whereas these RT model parameters have been found to correlate with structural properties of the brain (white matter integrity; Madden et al., 2009; Yang et al., 2015), to our knowledge the relation between task-related brain activation and RT diffusion model parameters has not been reported previously.

Previous studies have found that increasing attentional load decreases the influence of emotional stimuli (Doallo et al., 2006; Kurth et al., 2016; Lange et al., 2003; Pessoa et al., 2002a,b), presumably because increasing attentional load decreases the processing resources available for task-irrelevant items. We thus hypothesized that, for healthy adults, increasing the difficulty of the target discrimination would decrease the neural activation associated with sad emotional distractors in the present emotional oddball task. To maximize the opportunity to detect an effect of target discrimination difficulty, in this experiment, we used a sample of older adult participants, under the assumption that, in view of age-related decline in fluid cognition and some (though not all) attentional abilities (Kramer and Madden, 2008; McAvinue et al., 2012; Monge and Madden, 2016), the effects of perceptual difficulty would be more clearly evident. Maylor and Lavie (1998), for example, reported that increasing perceptual load had a greater effect on the processing of task-irrelevant stimuli for older adults relative to younger adults. Increasing the perceptual load decreased the influence of irrelevant distractors on older adults' target identification responses, consistent with a reduction in the attentional capacity available for distractor processing.

In this version of the emotional oddball task, the standards were always squares and the distractors were always negative (sad) or neutral images. Target discrimination difficulty was varied across two blocked conditions: an *easy* condition, in which the target was a circle, and a *hard* condition, in which the target was a squoval (square-oval hybrid). Three hypotheses were of central interest. First, for the emotional valence effect of task-irrelevant distractors, we hypothesized that distractor-related neural activation would reflect resource limitations imposed by discrimination difficulty: Increased task-related attentional demands for processing targets in the hard condition would leave fewer resources available for allocation to the processing of task-irrelevant (distractor) images in visual and emotional regions, thus *reducing* their associated activation. Second, for target-related activation, we hypothesized that

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