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Neurophysiological mechanisms in the emotional modulation of attention: The interplay between threat sensitivity and attentional control

Tracy A. Dennis *, Chao-Cheng Chen

Hunter College, The City University of New York, 695 Park Avenue, New York, NY 10065, United States

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Abstract

Processing task-irrelevant emotional information may compromise attention performance, particularly among those showing elevated threat sensitivity. If threat-sensitive individuals are able to recruit attentional control to inhibit emotional processing, however, they may show few decrements in attention performance. To examine this hypothesis, attention performance was measured in three domains—alerting, orienting, and executive attention. Task-irrelevant fearful, sad, and happy faces were presented for 50 ms before each trial of the attention task to create a mildly competitive emotional context. Electroencephalographic recordings were made from 64 scalp electrodes to generate event-related potentials (ERPs) to the faces. Participants reporting high threat sensitivity showed enhanced ERPs thought to reflect emotional processing (P200) and attentional control (P100 and N200). Enhanced N200 following fearful faces was linked to sustained and even slightly improved executive attention performance (reduced conflict interference) among high threat-sensitive individuals, but with decrements in executive attention among low threat-sensitive individuals. Results are discussed in terms of cognitive processing efficiency and the balance between threat sensitivity and attentional control in relation to executive attention performance. Results may have implications for understanding automatic and voluntary attentional biases related to anxiety.

Keywords: Cognitive control; Event-related brain potentials; Behavioral inhibition system; Emotion–attention interactions

Preferential processing of negative emotional information may compromise attention performance (Cacioppo and Berntson, 1994; Hare et al., 2005; Simpson et al., 2000). This relatively automatic 'negativity bias' is adaptive because it facilitates rapid processing of threat, but may also deplete the resources available for more voluntary control of attention performance (Bishop et al., 2004; Desimone and Duncan, 1995; Kieras et al., 2000; Miller and Cohen, 2001).

Individuals who show behavioral inhibition system (BIS) sensitivity and anxious mood are thought to show enhanced negativity biases, particularly towards threat and fear-related stimuli (Bishop et al., 2004; Carver and Scheier, 1998; Gray and McNaughton, 2000; Higgins et al., 1997; Leen-Feldner et al., 2004; Mathews and Mackintosh, 1998). Threat-sensitivity is more likely to interfere with attention when it exceeds an optimal level: for example, elevated anxiety has been shown to increase the negative impact of threat-related emotional stimuli on executive attention (Jazbec et al., 2005; Mathews and Mackintosh, 1998; Wood et al., 2001) such as conflict interference tasks (Fenske and Eastwood, 2003; Williams et al., 1996).

BIS-sensitive individuals, however, vary in the degree to which they recruit cognitive control resources to inhibit attention towards emotional information (Gray and Burgess, 2004) and in the degree to which this attentional control supports attention performance (Derryberry and Reed, 2002). For example, in a study with anxious adults, those showing high versus low dispositional attentional control showed reduced threat biases (orienting towards threatening cues; Derryberry and Reed, 2002). In other research, high BIS sensitivity has been linked to improved spatial working memory (Gray, 2001), but this likely depends on increased activation in the medial frontal cortex (Gray et al., 2005). Indeed, negative emotional states and information may actually enhance the responsiveness of prefrontal systems related to cognitive control (Gray et al., 2002; Potts et al., 2006). Such findings suggest that, although increased neural activation may reflect reduced neural efficiency (Gray et al., 2002), those showing high BIS sensitivity may

* Corresponding author. Tel.: +1 212 650 3878; fax: +1 212 650 3931.
E-mail address: tracy.dennis@hunter.cuny.edu (T.A. Dennis).

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require greater cognitive control resources to modulate emotional reactivity and facilitate cognitive performance (Gray and Braver, 2002). Another implication of a neural efficiency framework is that low BIS-sensitive individuals, who presumably show less reactivity, should not require enhanced recruitment of cognitive control in emotional contexts. Those who do show more neural activation related to cognitive control might be cognitively ''inefficient'' and thus be vulnerable to emotion interference effects that impair performance (Compton, 2003; Eysenck and Calvo, 1992; Hanoch and Vitouch, 2004). Scalp-recorded event-related potentials (ERPs) provide a powerful measure of cognitive processing efficiency because they capture very early and rapid stages of emotional and attentional processing that may be particularly difficult to measure via behavioral performance (De Pascalis et al., 2005). ERP responses to human faces have received considerable empirical attention due to their social significance and affective salience; in particular, very early ERP responses reflecting relatively automatic emotional and attentional processing have been targeted (Eimer and Holmes, 2002; Pizzagalli et al., 1999; Sato et al., 2001). As early as 80–100 ms, negative emotional faces compared to neutral faces elicit enhanced ERPs in posterior regions reflecting enhanced visual attention (Hillyard et al., 1995; Smith et al., 2003). For example, a negative posterior negative deflection around 170 ms, enhanced in the right hemisphere, may be specifically sensitive to negative emotional faces (Batty and Taylor, 2003; Bentin et al., 1996; Eger et al., 2003; Pizzagalli et al., 1999; Righart and de Gelder, 2006). Some studies, however, fail to document emotional sensitivity of the N170 (Eimer and Holmes, 2002) and have found both earlier and later latencies of the component (Pizzagalli et al., 1999; Sato et al., 2001). The posterior P200 (180–250 ms) may also reflect emotional significance processing and is enhanced for negative emotional stimuli (Carretié et al., 2001; Correll et al., 2006; Schutter et al., 2004).

When emotional stimuli are irrelevant to performing a target task, ERP responses related to the cognitive control of attention may also emerge. Positive deflections in posterior cortical areas around 100 ms, or P100, are thought to reflect automatic suppression of unattended stimuli and the recruitment of cognitive and attentional control over conflicting or emotional information (Hillyard et al., 1995; Mangun and Hillyard, 1995; Näätänen and Picton, 1987; Tendolkar et al., 2005). Later in the processing stream (200–350 ms), a range of ERP responses generated from areas of the medial frontal cortex, such as the anterior cingulate cortex, have been linked to cognitive and attentional control processes (Gehring and Willoughby, 2002; Luu et al., 2000; Parasuraman, 1998; Potts et al., 2006; Yeung et al., 2005). For example, the N200 is enhanced during tasks requiring monitoring of ''crosstalk'', or conflicting information and response options, and is thought to signal the extent to which attentional control is required (Nieuwenhuis et al., 2003; van Veen and Carter, 2002). N200 and other early frontally generated negative ERP responses may reflect a ''gating'' mechanism in the medial frontal cortex through which motivationally significant information gains access to cognitive control systems.

In summary, the combination of enhanced threat sensitivity and high cognitive control may represent a ''balance'' that facilitates attention performance when negative emotional information competes for attention (Derryberry and Reed, 2002; Gray, 2004; Matthews and Mackintosh, 1998); for those showing low threat sensitivity, however, greater recruitment of cognitive control might represent an ''imbalance'' marking inefficient cognitive processing. ERPs provide a highly appropriate measurement approach because they capture very early interactions between affect and cognitive control, in particular in relation to salient emotional stimuli like human emotional faces.

To examine these questions, electroencephalographic (EEG) recordings were made while participants completed the Attention Network Test (ANT; Fan et al., 2002). This task was modified to include briefly presented (50 ms) task-irrelevant emotional faces before each trial (Dennis and Chen, 2007; Dennis et al., in press), thus providing a mildly competitive emotional context, which may facilitate detection of individual differences in attentional biases (Matthews and Mackintosh, 1998). There were three emotional face types varying in threat-relevance and valence: fearful (most threat-related), sad (negative but less threat related), and happy (positive and not threat related). One face type was presented per block of trials in order to create three distinct emotional contexts. Emotional faces were chosen as distracter stimuli because they are salient and motivationally significant. Faces are processed extremely rapidly while competing for attentional resources; thus, early-occurring ERPs (0–300 ms) related to emotional processing of faces and cognitive control were targeted.

The ANT provides reliable estimates of three distinct attention functions: alerting, orienting, and executive attention (Fan et al., 2002; Fossella et al., 2002). These three systems vary in the degree to which they are driven by relatively automatic or voluntary attentional mechanisms (Derryberry and Reed, 2002; Posner and Petersen, 1990): alerting and orienting are supported by the more automatic posterior attention system and executive attention by the more voluntary anterior attention system, including the anterior cingulate cortex. Therefore, ERP responses to task-irrelevant emotional stimuli linked to the anterior attention system (such as the frontally generated N200) may have more of an impact on executive attention performance than ERPs linked to more automatic emotional and attentional processing operations.

There were two hypotheses: (1) after viewing task-irrelevant emotional faces, threat-sensitive individuals will show enhanced ERPs related to emotional processing (N170 and P200) and recruitment of attentional control (P100 and N200), particularly following fearful faces; (2) enhanced ERP responses related to more deliberate attentional control (N200) will reduce the negative impact of threat-related fearful faces on executive attention performance in the high threat-sensitive group, but in the low threat-sensitive group may reflect inefficient cognitive processing and predict reduced attention performance.