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Emotional reactivity and its impact on neural circuitry for attention–emotion interaction in childhood and adolescence

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ABSTRACT

Attention modulation when confronted with emotional stimuli is considered a critical aspect of executive function, yet rarely studied during childhood and adolescence, a developmental period marked with changes in these processes. We employed a novel, and child-friendly fMRI task that used emotional faces to investigate the neural underpinnings of the attention–emotion interaction in a child and adolescent sample (n = 23, age M = 13.46, SD = 2.86, range = 8.05–16.93 years). Results implied modulation of activation in the orbitofrontal cortex (OFC) due to emotional distractor valence, which marginally correlated with participant age. Additionally, parent-reported emotional reactivity predicted the trajectory of BOLD signal increase for fearful emotional face distractors such that participants low in emotional reactivity had a steeper latency to peak activation. Results imply that the use of the OFC to modulate attention in the face of social/emotional stimuli may mature with age and may be tightly coupled with adaptive emotional functioning. Findings are discussed in the context of risk for the development of psychiatric disorders, where increased emotional reactivity is particularly apparent.

1. Introduction

Executive function, described as the capacity to control and coordinate thoughts and behaviors (Elliott, 2003), is hypothesized to develop throughout late childhood and adolescence. As adolescents become increasingly independent from family members and transition into responsibility for their own daily social functioning (e.g. driving, choosing friends), adaptive executive function can aid in successful decision making rather than negative outcomes, such as school failure, drug and alcohol abuse, and juvenile delinquency (Steinberg, 2007). Executive function skills rely heavily on frontal lobe development (Goldman-Rakic, 1987; Casey et al., 1997; Rubia et al., 2003), which has been noted to peak in structural maturation during adolescence (Giedd et al., 1999). Multiple studies have also examined the development of executive functioning and its associated functional neural mechanisms during adolescence (Eigsti et al., 2006; Luna, 2009). Based upon this burgeoning literature, Steinberg (2004) has proposed an interaction between two brain networks in his research on adolescent social decision making. One of these is the cognitive-control network localized to lateral prefrontal and parietal cortex, but also includes parts of the anterior cingulate cortex. This network subserves executive functions such as planning, attention shifting, inhibitory control, and self-regulation.

Interacting with the cognitive control network in social decision making processes is the socioemotional network. This network is more sensitive to social stimuli and

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localized to limbic and paralimbic areas of the brain, including the amygdala and medial/orbitofrontal cortex (Steinberg, 2004). Previous studies have highlighted the interface between these brain networks by examining the impact of social/emotional information on executive functioning during adolescence. Most of this work comes from the study of inhibitory control. Hare and colleagues, for example, found that, when compared to adults and children, adolescents displayed heightened amygdala activity during a go/no-go task using emotional faces as target stimuli (Hare et al., 2008). Further, connective coupling between the amygdala and ventral prefrontal cortex was correlated with greater amygdala habituation to fearful faces. The authors describe these findings as a possible explanation for poor decision making in adolescence. Greater initial reactivity in subcortical regions, combined with immature prefrontal connectivity, considered to be inherent in the guiding of adaptive action, might contribute to inappropriate decisions in momentary emotional context.

Another executive function that becomes particularly important during this period is attention modulation, which also plays a role in effective decision making. In daily social functioning, children and adolescents must maintain attention to relevant environmental stimuli (e.g., homework) even when faced with competing emotional distractors (e.g., friends, phones, music). In one behavioral study of adolescents, scores on an emotion–attention interference task were negatively correlated with parent-reported executive function skills. The addition of executive function individual difference scores (effortful control, specifically) also predicted adolescent problem behavior, which hints at the role of attention modulation in decision making (Ellis et al., 2004). This study points to the critical role of executive functioning in the development of adolescent behavior, however, less is known about the neural mechanisms underlying attention modulation during adolescence and how it might be altered by social context. The current study focuses upon the impact of the emotion-attention interaction, both from the perspective of competing affective stimuli in the environment and individual differences in emotional functioning.

Studies in adult populations point to the anterior cingulate cortex (ACC), which is forms a part of Steinberg's (2004) cognitive-control network and the amygdala and orbitofrontal cortex (OFC), pieces of the socioemotional network, as regions of a neural circuit for emotion-attention interaction. The ACC seems to be particularly involved in shifting attention between emotional and non-emotional stimuli. In one study, greater activation of the ACC was shown when participants attended to the emotional state elicited by an affectively arousing scene than when simply attending to physical aspects of the image (Lane et al., 1997). Yamasaki et al. (2002) also found that the ACC was the only brain region with equivalent responses to attentionally and emotionally manipulated stimuli, emotional scenes in this case. In contrast, amygdala activation seems to be reduced when attention is directed away from an emotional stimulus or higher order cognitive processing is required. Hariri et al. (2000) found that amygdala activation when labeling the emotional content of a face was reduced when compared to a simple matching task of emotional faces that required less cognitive resources. Additionally, Pessoa et al. (2002) found that amygdala activation decreased as attentional demand shifted away from an emotional face stimulus. However, Vuilleumier et al. (2001) provide evidence that amygdala activation to fearful faces is not changed by task motivated attention modulation in contrast to the fusiform gyrus. Finally, the OFC may be the part of the circuit most modulated by *valence* of emotional stimulus under attentional demand. One study (Pessoa et al., 2002) found that OFC activity was modulated by the emotional expression of a face stimulus, which interacted with an attentional demand condition. Thus, the OFC may be most responsible for determining the social significance of the emotional stimulus competing for attentional resources.

Few studies have examined the interaction of emotional and attentional neural networks in a child and adolescent population. Monk et al. (2003) presented adolescent participants with emotional facial expressions of diverse valence but varied attention to the affective content of the face by asking participants to focus on emotional (subjective emotional feeling) vs. non-emotional (nose width) aspects of the face. The authors found that when comparing adolescents and adults, adolescents showed decreased activation of the OFC when attending to subjective emotional feeling, but increased activation in the ACC, OFC, and amygdala when attention was not directed at processing a fearful face. The authors suggest that these results signify adults' ability to employ relevant brain regions based on attentional demands that may be a developing skill during adolescence. The results of this study suggest that maturation from adolescence to adulthood may involve increased ability to galvanize relevant neural circuits toward goal-directed attention when affectively laden events compete for attention, however this study did not examine maturation from childhood to adolescence, nor did it examine the impact of individual differences in emotional reactivity on these processes. Two additional studies have used a similar paradigm to examine the role of clinical anxiety (McClure et al., 2007) and the related temperamental construct of behavioral inhibition (Perez-Edgar et al., 2007) on emotion–attention interaction, each finding heightened amygdala response in the impaired group when attending to their own subjective fearful feeling. These studies, however, were focused only on the amygdala rather than the emotion-attention circuit as a whole and compared two distinct groups rather than taking a dimensional approach to individual differences.

The goals of the current study were twofold. First, we intended to examine the developing neural circuitry involved in emotion–attention interaction when emotional stimuli were entirely irrelevant to the attentional task, and therefore, only "distractors" in nature. To do this, we developed a novel and child-friendly, socially-oriented, emotion–attention interaction task in which participants were required to count the number of infrequently occurring shape stimuli while also faced with competing, emotionally arousing, but task irrelevant emotional face stimuli in the visual environment. The goal was to create a "social" situation during fMRI scanning with the task of ignoring irrelevant social distractors (i.e. emotional faces)