



## Positive reinforcement modulates fronto-limbic systems subserving emotional interference in adolescents

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### ABSTRACT

Fronto-limbic systems play an important role in supporting resistance to emotional distraction to promote goal-directed behavior. Despite evidence that alterations in the functioning of these systems are implicated in developmental trajectories of psychopathology, most studies have been conducted in adults. This study examined the functioning of fronto-limbic systems subserving emotional interference in adolescents and whether differential reinforcement of correct responding can modulate these neural systems in ways that could promote resistance to emotional distraction. Fourteen healthy adolescents (ages 9–15) completed an emotional delayed working memory task during fMRI with emotional distracters (none, neutral, negative) while positive reinforcement (i.e., monetary reward) was provided for correct responses under some conditions. Adolescents showed slightly reduced behavioral performance and greater activation in amygdala and prefrontal cortical regions (ventrolateral, ventromedial, dorsolateral) on correct trials with negative distracters compared to those with no or neutral distracters. Positive reinforcement yielded an overall improvement in accuracy and reaction times and counteracted the effects of negative distracters as evidenced by significant reductions in activation in key fronto-limbic regions. The present findings extend results on emotional interference from adults to adolescents and suggest that positive reinforcement could be used to potentially promote insulation from emotional distraction. A challenge for the future will be to build upon these findings for constructing reinforcement-based attention training programs that could be used to reduce emotional attention biases in anxious youth.

### 1. Introduction

The ability to resist interference from distracting emotional information while sustaining attention on goal-directed behavior is critical for adaptive behavior. According to some theories, emotional information is prioritized and mobilizes cognitive resources [1–3], as they contain signals closely linked to survival [4,5]. Such preferential access of emotional information to our cognitive system has been interpreted as a mechanism critical for the quick and effective processing of biologically relevant information rendering us better able to respond in an adaptive manner [6]. While emotional information may bolster cognitive processing and improve performance if it is goal-relevant [7], the same information could be distracting and have detrimental effects on cognitive function [8]. Some have proposed that emotional information is integrated within cognitive control processes creating a competition for information processing resources (i.e., Dual Competition Model) [9] and that such integration is supported by complex interactions between prefrontal and subcortical regions [10]. Using cognitive tasks modified to include emotional distracters, numerous studies have provided

evidence that emotional stimuli can influence many different aspects of cognition and behavior, and that they tend to “hijack” attention more easily than non-emotional stimuli [11–14] thereby resulting in disrupted cognitive goals and less optimal task performance (e.g., slower reaction times or reduced accuracy) [15].

One task that has been used to examine the functioning of fronto-limbic systems underlying attentional control in the context of emotional distracters is the emotional delayed working memory (EDWM) [15,16]. The EDWM task is a modified version of a visual delayed match-to-sample task that includes a visual probe held in working memory during a delay period and typically involves the presentation of no distracter, a neutral distracter, or an emotional distracter (e.g., negatively valenced pictures or facial expressions). Dolcos and McCarthy [23] reported one of the first neuroimaging findings demonstrating that impaired working memory performance in the presence of emotional distraction was associated with heightened activity in ventral neural regions supporting emotional processing (e.g., amygdala, ventrolateral prefrontal cortex) and reduced delay-related neural activity in dorsal brain regions implicated in attentional

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processes and active maintenance of task-relevant information in working memory (e.g., dorsolateral prefrontal cortex, lateral parietal cortex). They interpreted such a pattern of activation as an indication that dorsal regions might be temporarily driven “offline” (hijacking effect) by ventral brain regions responsible for detecting emotional salience such as the amygdala. Such an interpretation was consistent with findings of a positive correlation between amygdala activation and subjective ratings of distraction to emotional stimuli as well as positive coupling between the amygdala and ventrolateral prefrontal cortex during processing of emotional distraction [15]. Using a slightly different EDWM task, Anticevic et al. [16] replicated Dolcos and colleagues’ negative association between amygdala activation and task performance as well as heightened ventrolateral prefrontal cortex activation to correct (vs. incorrect) trials in the context of negative distracters [16]. Overall, the above findings suggest that performance of a working memory task in the context of negative distracters is linked with disruptions in behavioral performance along with patterns of elevated activation in the amygdala, reduced activation in dorsal regions of the prefrontal cortex, and negative coupling between the amygdala and prefrontal cortical regions. Most of the research regarding functioning of fronto-limbic systems subserving resisting emotional interference has been conducted in adults and as such it is unknown whether the above findings extend to adolescents and children. Replication of findings with different age groups are important basic steps needed to firmly establish the generality of emotional interference effects and presumed brain mechanisms. Replication with adolescents in particular could have important clinical implications in light of evidence suggesting that altered functioning of fronto-limbic systems may contribute to developmental trajectories of risk for affective disorders [17–20]. Accordingly, the first goal of this study was to examine the extent to which the above-described patterns of neural activation associated with emotional interference obtained with adults are also present in adolescents.

In light of the role of emotional interference in affective disorders, an equally important yet unexplored area of research concerns identifying variables or procedures that can be used to prevent interference and associated declines in goal-directed behavior. Some evidence suggests emotional distraction can be mitigated by top-down interventions from attentional control regions, engaged to regulate emotional responses and cope with emotional distraction [15,21–27]. Given evidence that attentional biases to emotional stimuli are an important clinical characteristic of affective disorders [28–31] and that such biases have been interpreted in terms of deficits in attentional control [28,32,33], there is thus a need to find ways to promote attentional control of emotion. A number of animal and human neuroimaging studies have shown that positive reinforcement (i.e., receipt of a reward following a specific response) boosts behavioral performance on cognitive control tasks such as working memory [34–38] and that such improvement in performance is associated with increased neural activation in dorsal and lateral prefrontal cortical regions [38–42]. In particular, according to the dual mechanisms of control framework [43], the use of positive reinforcement would increase proactive control – that is, preparatory control that is aimed at preventing conflict and optimizing task performance through sustained activation of task-relevant information. Such findings suggest that positive reinforcement for correct responding on the EDWM task could boost behavioral performance by counteracting the effects of emotional interference. There are a number of potential routes through which positive reinforcement may exert influence. These include reduced activation in subcortical limbic regions (ventral frontal), increased activation in attentional control regions (dorsal prefrontal), or both. Accordingly, the second goal of this study was to test the extent to which providing positive reinforcement (i.e., monetary rewards for correct responses) would improve task performance and modulate prefrontal cortical and subcortical regions involved in emotional interference. Specifically, we hypothesized that positive reinforcement would be associated with

reduced activation in ventral neural regions (i.e., amygdala, ventrolateral prefrontal cortex), and increased activation in dorsal and lateral regions of the prefrontal cortex.

## 2. Material and methods

### 2.1. Participants

Sixteen right-handed adolescents without any medical or psychiatric disorders participated. Two were excluded due to data loss (i.e., excessive motion) yielding a sample of 14 adolescents (age  $M = 13.4$  years,  $SD = 1.8$ ; 8 males). All participants had normal vision, as assessed using a Snellen chart, were right handed, as assessed using the Edinburgh Handedness Inventory [44], and were free of current *DSM-IV* Axis I psychiatric diagnoses, as assessed using the Stony Brook Symptom Inventory [45]. Exclusion criteria included: history of head trauma, neurological disorder, use of drug and alcohol, presence of metal objects in their body, and pregnancy. The study was approved by the Institutional Review Board for the Protection of Human Subjects at the University of Pittsburgh. To participate, children and their parents were required to sign assent and consent forms, respectively.

### 2.2. Neuroimaging task design

Participants performed an adapted version of the emotional delayed working memory (EDWM) task [16] (Fig. 1). The task included 80 trials of a version of a delayed match-to-sample task [46] with two geometric shapes and two potential distracter types presented during the delay or the maintenance period of the task: emotionally negative images and visually complex neutral images. Prior to the start of the experiment, each participant was presented with instructions explaining the task and completed a practice session. They were instructed to try to remember two shapes presented on the screen and to keep their eyes looking at the center of the screen and to not respond once the shapes disappeared. They were also told that a single shape would then be presented for a brief time and to press a button with their index finger (yes) if this shape matched one of the shapes previously presented and to press a button with their middle finger (no) if this shape did not match any of the shapes. They were also informed that at some point during the task, graphic images would be presented. In order to examine the influence of positive reinforcement on performance of the EDWM task, each block was repeated but it included instructions at the beginning of the block indicating to the participants that they would receive a monetary reward (\$1) for each correct response. As illustrated in Fig. 1, trials began with the presentation of the memoranda (3 s) followed by a fixation cross (1 s), a delay period (fixation cross (10 s) or distracter (3 s) and fixation cross (7 s)), the probe (2.5 s), inter-trial stimulus (in blocks without positive reinforcement: fixation cross (6.5 s); in blocks with positive reinforcement: feedback (0.5 s): “Correct: win \$1” written in green following correct responses or “Wrong: no money” written in red following incorrect responses or “No response” written in white following omissions and fixation cross (7 s)). A PC running E-prime software (Psychology Software Tools (PST), Pittsburgh, PA) controlled stimulus display. A color high-resolution LCD projector projected visual stimuli onto a rear screen at the head of the scanner bore, viewable via a mirror attached to the head coil. Responses were recorded using a PST glove.

The 80 trials of the EDWM task were divided according to distracter type: 30 negative distracter trials, 30 neutral distracter trials, and 20 no distracter trials, which were blank trials with a fixation cross used to estimate distracter-free maintenance activity. The trials were grouped into 8 blocks of 10 trials each. The first two blocks included trials with no distracters (block 1 without positive reinforcement and block 2 with positive reinforcement). The following 6 blocks included 30 neutral and 30 negative trials presented in a fixed random order within each block. Three blocks were presented without positive reinforcement (blocks 3,

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