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Neural activation underlying cognitive control in the context of neutral and affectively charged pictures in children

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ABSTRACT

The neural correlates of cognitive control for typically developing 9-year-old children were examined using dense-array ERPs and estimates of cortical activation (LORETA) during a go/no-go task with two conditions: a neutral picture condition and an affectively charged picture condition. Activation was estimated for the entire cortex after which data were exported for four regions of interests (ROIs): ventrolateral prefrontal cortex (VLPFC), dorsal anterior cingulate cortex (dACC), dorsolateral prefrontal cortex (DLPFC), and orbitofrontal/ventromedial prefrontal cortex (OFC/VMPFC). Results revealed faster reaction times, greater N2 activation, and greater prefrontal activation for the affectively charged picture condition than the neutral picture condition. The findings are discussed in reference to the impact of affective stimuli on recruitment of specific brain regions involved in cognitive control.

1. Introduction

Our ability to monitor and control our actions adaptively from moment-to-moment depending on current goals falls under the rubric of cognitive control. The development of cognitive control, especially in the context of negative emotion, is crucial for typical socioemotional functioning. Research on the neural correlates of cognitive control has primarily been conducted on adult samples (e.g., Blasi, Goldberg, Weinberger, & Mattay, 2006; Garavan, Ross, Murphy, Roche, & Stein, 2002; Rubia, Smith, Brammer, & Taylor, 2003), and far less is known about these neural correlates in children. Furthermore, since control mechanisms may vary depending on the context of the event, we examined children's cognitive control abilities in a relatively neutral context and an affectively charged context.

A number of cortical regions have been associated with cognitive control, including the dorsal anterior cingulate cortex (dACC; e.g., Garavan et al., 2002), the dorsolateral prefrontal cortex (DLPFC; e.g., Blasi et al., 2006), the ventrolateral prefrontal cortex (VLPFC; e.g., Aron, Robbins, & Poldrack, 2004), and the orbitofrontal/ventromedial prefrontal cortex (OFC/VMPFC; e.g., Durston et al., 2006). Furthermore, activation of the same regions associated with cognitive control, i.e., dACC, DLPFC, VLPFC, OFC/VMPFC, have also been found to vary depending on the context of the task, i.e., emotional or unemotional contexts. For example, Cremers et al. (2010) found that presentation of angry, sad, and fearful emotional faces, compared to neutral faces, revealed negative correlations between ACC-amygdala connectivity and neuroticism scores; Monk et al. (2003) found greater ACC, orbitofrontal cortex, and VLPFC activation to fearful faces than neutral faces during an attention task; and, Ochsner et al. (2004) found ACC, VLPFC, and DLPFC activation during emotional up-regulation and down-regulation. Thus, it may be that this prefrontal control system (ACC, VLPFC, DLPFC, OFC/VMPFC) recruited in relatively unemotional contexts is also recruited in emotional contexts.

However, few studies have investigated how cognitive control varies in the context of emotion for children. Two recent papers by Lamm and colleagues revealed that prefrontal cortical activation during a cognitive control task (go/no-go task) increased in the context of negative emotion, specifically when children (aged 8–14) were frustrated/anxious about potentially not winning a desired toy (Lamm, Granic, Zelazo, & Lewis, 2011; Lamm & Lewis, 2010). The authors interpreted these results to reflect the need for additional neural resources to successfully control responding in the context of negative emotion. We were interested in building on these results using a substantially different go/no-go task with affectively charged pictures. Specifically, we examined how behavioral performance and prefrontal activation differed in the context of affectively charged pictures compared to relatively neutral pictures, for a sample of 9-year-old children. We measured no-go N2 activation—an ERP component associated with cognitive control (for example, Dimoska, Johnstone, Barry, & Clarke, 2003;

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Falkenstein, Hoormann, & Hohnsbein, 1999; Jonkman, Lansbergen, & Stauder, 2003)—using dense-array EEG and a method of estimating cortical activation (LORETA; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). Activation was estimated for the entire cortex and subsequently activation values were exported for four ROIs: VLPFC, dACC, DLPFC, and OFC/VMPFC. Based on the Lamm et al. (2011), Lamm and Lewis (2010) results, we predicted that during the affectively charged condition compared to the neutral condition children would require additional prefrontal resources to effectively control their actions.

2. Method

2.1. Participants

Seventeen typically developing 9-year-old children (Mean = 9.57 years, SD = 0.28, range = 9.18–10.00 years, 7 males) were included in the current study. Participants were primarily right handed (only 1 was left handed) Caucasian (48%) or African American (32%) healthy children. None of the children had any medical or psychiatric conditions. Participants were recruited through an independent mailing company that provided addresses of families with young children located in the Washington, DC region. Seven additional children participated but were excluded from analyses due to insufficient artifact free trials.

2.2. Procedure

Upon arrival to the laboratory, the study was described and parental consent and child assent were obtained. Children were then seated in a chair 38 inches from the computer screen. Next, the electrode sensor net was applied and the go/no-go task (Zoo Game) was administered. Upon completion of the paradigm, families were paid $20.00 for their time. This study received IRB approval from the University of Maryland.

Affective and Neutral Go/No-go task: *The Zoo Game* (McDermott, White, Degnan, Henderson, & Fox, in preparation). The task employed in this study was called the Zoo Game and consisted of 75% go trials and 25% no-go trials. This ratio of go to no-go trials ensures a prepotent desire to respond (i.e., requiring enhanced response control in the no-go trials). This ratio of trials occurs within two blocks, a block of non-affectively charged pictures (280 trials) and a block of affectively charged pictures (140 trials). The block presenting affectively charged pictures was limited to 140 trials to limit the duration of children's distress. In order to limit potential affective carry-over effects the affectively charged picture block was always presented second. No-go trials, for both blocks, consisted of monkey pictures, while go trials consisted of other animal pictures. In the neutral condition, go trial stimuli consisted of non-affectively charged pictures (e.g., non-threatening looking panda bear or kangaroo). In the affectively charged condition, go trial stimuli consisted of affectively charged pictures (e.g., large dog aggressively showing teeth, large spider). Prior to completing the two blocks, children completed 12 practice trials to ensure proficiency. Children were asked to help a zoo keeper recapture escaped animals with the help of a chimpanzee referred to as the 'monkey'. To recapture the animals, children were told to respond via button-press (as fast and accurate as possible) as soon as they saw an animal on the screen unless it was the 'monkey'. Animal stimuli were presented on the screen for 500 ms, followed by a black screen for 900 ms or until the child responded (see Fig. 1). The inter-trial interval was jittered between 200 and 300 ms. Images were presented on a 17-in monitor using E-prime Software (Psychology Software Tools, Inc., Pittsburgh, PA; Schneider, Eschman, & Zuccolotto, 2002).

2.3. EEG data collection and analysis

EEG was recorded using a 64-channel Geodesic Sensor Net and sampled at 250 Hz, using EGI software (Net Station; Electrical Geodesic, Inc., Eugene, OR [data were also processed using Net Station]). Once the impedance values for all EEG channels were reduced to below 50 kΩ, data acquisition was started. During recording, all channels were referenced to Cz and after acquisition, data were re-referenced using an average reference.

Data were filtered using a FIR bandpass filter with a lowpass frequency of 50 Hz and a highpass frequency of .3 Hz. To best approximate the data, eye blink artifact thresholds were set to 140 μV. Furthermore, signal activation change exceeding 120 μV across the entire trial were marked as bad and removed after visual inspection.

2.3.1. Scalp analysis

Waveforms for correct go and no-go trails were segmented into epochs from 200 ms before to 600 ms after stimulus onset and baseline corrected for the 200 ms preceding stimulus onset. Mediofrontal N2 activation was maximal between 250 and 390 ms; thus, peak activation was exported for this time. To eliminate trials characterized by attentional lapses or chronic non-responding, no-go trials that did not have a correct go trial preceding and following them were removed from analyses. Due to this strict criterion the mean number of trials comprising correct no-go ERPs was 25.06 (ranging from 10 to 56; mean neutral = 34.18, mean affectively charged = 15.94). Mean number of trials comprising go ERPs was 134.03 (ranging from 56 to 251; mean neutral = 182.71, mean affectively charged = 85.35). Because the number of trials comprising an ERP can effect ERP activation, trial count was entered as a covariate to all ERP analyses (scalp and source). Furthermore, since a prior *t*-tests revealed no gender differences for scalp or source space analyses, Gender was not added as a covariate.

2.3.2. Source-space analysis

A distributed inverse model that incorporates the change in activation from one electrode to another (in this case 65 electrodes) was used to calculate the source-space activation. This type of algorithm estimates activation voxel-by-voxel and sample-by-sample and does not require any dipoles to be "fit", thereby limiting the influence of user bias. The specific algorithm used in the current study was LORETA (Low Resolution Brain Electromagnetic Tomography) which applies a constraint to the minimum-norm solution in order to minimizes the discrepancy between values of adjacent voxels (to achieve the most realistic model) within the GeoSource interface (Electrical Geodesic, Inc., Eugene, OR; for a review of these constraints and other minimum norm solutions, see Michel et al., 2004). A regularization constant (indicating how much noise is modeled) of 10^{-4} was applied. This amount of regularization revealed current flow patterns that matched (via visual inspection) the grand-averaged scalp topography (collapsing across conditions to prevent biasing solutions) better than other levels.

After the data were modeled (LORETA) for the entire cortex (2447 voxels), morphology-based regions of interests (ROIs) were generated using the Montreal Neurological Institute (MNI) average adult MRI (pediatric head models no available yet). We were interested in four ROIs: the VLPFC ROI (comprised of 44 voxels; lateral part of BA 11 and 47), the dACC ROI (comprised of 50 voxels; dorsal part of BA 24 and 32), the DLPFC ROI (comprised of 126 voxels; BA 9 and dorsal part of BA 46), and the OFC/VMPFC ROI (comprised of 147 voxels; ventromedial parts of BAs 11, 10, 14, and 13; see Fig. 2). Source waveform amplitudes (nA) for all voxels within an ROI were extracted for 200 ms before stimulus onset to 600 ms after stimulus onset and baseline corrected using the 200 ms before stimulus onset. To ensure that each participant's maximal activation was analyzed, we chose the voxel and moment in time