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Event-related theta oscillatory substrates for facilitation and interference effects of negative emotion on children's cognition

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ABSTRACT

We investigated the brain oscillatory contribution to emotion-cognition interaction in young children. Five-year-old participants ($n = 27$) underwent EEG recording while engaged in a color identification task. Each trial began with an emotional prime. Response times indicated whether emotional primes facilitated or interfered with performance. Related effects were detected in theta-band power over parietal-occipital cortex, early in the response epoch (<500 ms). Children in the emotion facilitation group showed greater theta synchronization for negative stimuli. The opposite trend was observed in the interference group. Results suggest a role for theta oscillations in children's adaptive response to emotional content in cognitive performance.

1. Introduction

There is evidence that negative information is detected more efficiently than emotionally neutral information (Öhman et al., 2001). In some tasks, such as the emotional Stroop, a bias for processing of emotional information interferes with cognitive performance (Van Strien and Valstar, 2004). Other studies fail to demonstrate an interference effect of negative emotion (Hart et al., 2010; Thomas et al., 2007). One source of discrepancy might be individual differences in the interaction of emotion and cognition; within studies, not all participants showed the same effect of emotional information on cognitive performance (Arntz et al., 2000; Mogg et al., 1993; Pérez-Edgar and Fox, 2003).

Pérez-Edgar and Fox (2003) used event-related potentials (ERPs) to explore the neural mechanisms underlying such individual difference observed in the emotional Stroop task. During EEG recording, 11-year-old children identified the color of emotional words (e.g., cry) and neutral words (e.g., bag). Participants were classified into two groups according to reaction time following emotional and neutral words. Participants were categorized in the emotion-facilitation group if their reaction time was faster following emotional words compared to neutral words. Conversely, reaction time in the emotion-interference group was slower following emotional words. Compared to the emotion-interference group, the emotion-facilitation group exhibited an enhanced positive slow wave (600–1000 ms) amplitude in parietal electrodes. This ERP finding provides evidence of group differences in neural processing. However, to understand the neural mechanism by which emotional content can facilitate cognition for some children but interfere with performance for others, it is necessary to reveal the participant group difference in the context of processing emotional stimuli.

The present investigation made several modifications to the methods proposed by Pérez-Edgar and Fox (2003) in an attempt to expand on their findings. First, to enhance the elicitation of an affective response in young children, we adopted human facial expressions as experimental stimuli in place of emotional words (Carr et al., 1982; Spruyt et al., 2002). The present study enlisted 5-year-old children as the participants, whose cognitive performance may be more susceptible to the effects of emotional content (Campos et al., 2004). Second, the emotional stimuli were presented as subliminal primes before the cognitive target. This experimental design is thought to maintain effects of emotional information on cognitive processing while eliminating confounding effects of some stimulus attributes (e.g., physical character of the emotional stimuli) (Bernat et al., 2001; Van Honk et al., 2000). Third, we separately considered the effect of stimulus valence on performance, because of evidence that positive and negative emotion interacts with cognition via separable pathways (Li et al., 2013). Finally, instead of averaging single trials to reveal ERP components, we analyze the event-induced oscillation of brain electrical activity at the single-trial level.

Averaged ERPs reflect oscillations in brain activities that are phase-locked to the stimulus or event. Induced responses are also relevant to the cognitive act but oscillatory phase might be misaligned across

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measurements and thus canceled out during averaging (Makeig et al., 2002). Event-induced oscillation of brain electrical activity refers to modulation in ongoing brain activity induced by processing of stimuli or movement preparation. Such modulation could present as amplitude, frequency and phase of ongoing brain activity change. Amplitude changes in oscillatory activity are thought to arise from the synchronization of neural activity, for instance by synchronization of spike timing or membrane potential fluctuations of individual neurons. Increases in oscillatory power are thus referred to as event-related synchronization (ERS), while decreases are referred to as event-related desynchronization (ERD) (Pfurtscheller and da Silva, 1999).

Neural oscillatory responses can be classified according to the 'natural frequencies' of the brain (delta: 1–3 Hz, theta: 3–8 Hz, alpha: 8–13 Hz, beta: 13–30 Hz, and gamma: 30–70 Hz) (Kamel and Malik, 2014). Frequency-band specific activity has been related to various mental status and function (Başar et al., 2001). Of particular relevance to the present investigation is activity in the theta-band, (3–8 Hz), which is associated with emotional and cognitive processing. For example, emotional stimuli induce greater theta-band power than neutral stimuli (Aftanas et al., 2001; Balconi and Pozzoli, 2009; Başar, 2006), and theta activity varies during attention (Orekhova et al., 2006), retrieval (Jacobs et al., 2006), and exploratory behavior (Young and McNaughton, 2009) in proportion to cognitive effort and efficiency.

In the present study, 5-year-old children underwent electroencephalography (EEG) recording as they engaged in a color identification task, wherein each trial was preceded by an emotional prime. We examined oscillatory ERS and ERD to better understand how emotional content facilitates cognitive performance for some children, but interferes with cognition for other children. We hypothesized that an effect of emotional content would be related to greater theta activity in the facilitation group (in which emotional content was related to faster reaction times) compared to the interference group (in which emotion content was associated with delayed responses). However, in order to test whether it is only theta band that plays a specific role in discriminating the participant groups, we investigate event-related changes in spectral power across five frequency bands (delta, theta, alpha, beta and gamma).

2. Methods

2.1. Participants

We recruited 37 right-handed children (18 female, 19 male; age range: 4.5–5.5 years) with normal vision to attend present study. Parental consent and child assent were both obtained prior to study participation. The details of experiment plan including experimental stimuli were approved by the Human Subjects Review Board of Liaoning Normal University, which aims to ensure that all procedures adhere to the ethical standards laid down in the 1964 Declaration of Helsinki. The participants were told that they could quit the experiment at any time as they liked. According to the parents and the teachers' report, these children had no history of seizure, head injury, or loss of consciousness, and were not taking medications or drugs (e.g., anticonvulsants) that could affect EEG results. The final number of participants for EEG data analysis in present study is 27. The criteria and the procedure for excluding and grouping participants were shown at the first paragraph in the result section.

2.2. Stimuli

Emotional stimuli consisted of gray-scale images of human faces. To emphasize the facial expression and reduce additional variability across stimuli, face images were cropped around the eyebrow, outer ear and neck. Emotional stimuli were divided into three valence categories: positive, negative, and neutral. Positive stimuli consisted of smiling faces and the negative depicted people crying.

Thirty-two pictures were selected for each category using procedures described by Spruyt et al. (2002). Forty undergraduate college students rated the emotional valence of 270 human faces on a seven-point scale (1 = most negative, 4 = neutral, 7 = most positive). Two-tailed *t*-tests were conducted to compare mean scores for each picture against the null hypothesis that responses reflect a neutral rating (*Mean rating* = 4). Pictures associated with means significantly higher than four ($p < 0.001$) were considered positive, and pictures associated with means significantly lower than four ($p < 0.001$) were considered negative. The neutral pictures were those with means not significantly different from four ($p > 0.05$).

To control for confounding effects of other visual features (e.g., appearance, shape), 40 undergraduate students also evaluated the extent to which they experienced the pictures as "attention grabbing" on a seven-point scale (1 = not at all, 7 = most). Item-level average ratings within the 95% confidence interval of the overall mean were selected as experimental stimuli. In the selected group of stimuli, a pair-wise comparison of ratings across the three stimuli categories (positive, neutral, negative) confirmed between-group differences (neutral vs. negative: t (39) = 26.62, $p < 0.001$; neutral vs. positive: t (39) = −25.22, $p < 0.001$; negative vs. positive: t (39) = −44.28, $p < 0.001$). In addition to emotional stimuli, the experimental material included three 5 × 6 cm images: a swatch of black grid lines, and two 24-bit color swatches (blue: R = 110, G = 0, B = 200; red: R = 180, G = 0, B = 200).

2.3. Procedure

Participants were fitted with a 128-channel Geodesic Sensor Net (EGI, Eugene, OR, USA) and seated 60 cm from a computer monitor. Visual stimuli were presented at eye level. Participants were provided with the following instructions for the task: use one of two response keys to identify the color (blue or red) of a square presented on the computer screen as quickly as possible. Response keys were counterbalanced among participants. Each participant took one break in the middle of the experiment. The entire experimental session required up to 15–30 min of participation.

The experiment was performed on a PC computer running Eprime (Psychological Software Tools Inc., Pittsburgh, PA, USA). All stimuli were presented in the center of a 17-inch cathode ray tube monitor (85-Hz refresh rate) on a white background. The testing room was dim. The experimental task consisted of one practice block (20 trials) and one experimental block (180 trials). Each category of emotional condition (i.e., negative, neutral, positive) was represented in 60 of these 180 trials. A trial began with a blank screen (randomized duration between 500 and 700 ms), followed by a fixation cross-hatch (randomized duration between 500 and 700 ms). A photo of human face was presented for 12 ms, followed by a mask (gridline swatch) for 60 ms. A target (color swatch) was then presented and remained on the screen until the participant pressed one of two response keys. Following their response, participants received feedback (a check mark or an X) for 500 ms. The photo (i.e., negative, neutral and positive faces) and the target color swatch (i.e., blue or red) were randomly paired across trials and participants.

2.4. EEG preprocessing

A 0.1–100 Hz hardware band-pass filter was applied during EEG acquisition prior to digitization. Samples were recorded at a rate of 250 Hz with a 22-bit A/D converter. The data were referenced to the vertex channel (Cz) during acquisition, and all electrode impedances were kept below 50 KΩ. Offline processing was carried out using NetStation software provided by EGI (Eugene, Oregon). Continuous EEG data was segmented relative to emotional image onset (200 ms before and 1000 ms after) and sorted into valence categories (negative, positive, or neutral face). Segmented EEG data were re-referenced to the average reference.