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The temporal and spatial brain dynamics of automatic emotion regulation in children

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ABSTRACT

Mechanisms for automatic emotion regulation (AER) are essential during childhood as they offset the impact of unwanted or negative emotional responses without drawing on limited attentional resources. Despite the importance of AER in improving the efficiency and flexibility of self-regulation, few research studies have investigated the underlying neurophysiological mechanisms. To fill this gap, we used magnetoencephalography (MEG) to investigate AER-related brain processes in 25 children (~10 years old) who performed a go/no–go task that included an incidental exposure to faces containing socio-emotional cues. Whole brain results revealed that the inhibition of angry faces (compared with happy faces) was associated with a stronger recruitment of several brain regions from 100 to 425 ms. These activations involved the right angular and occipital gyri from 100 to175 ms, the right orbito-frontal gyrus (OFG) from 250 to 325 ms ($p^{corr} < 0.05$), and finally, the left anterior temporal lobe (ATL) from 325 to 425 ms. Our results suggest a specific involvement of these regions in the automatic regulation of negative emotional stimuli in children. In the future, this knowledge may help understand developmental conditions where inhibition impairments are exacerbated by an emotional context.

1. Introduction

During development, children learn how to adapt, or inhibit, their behaviour in accordance with exposure to various types of emotions (Cole et al., 2004). Particularly in the context of peer interactions and social activities, children rapidly detect implicit socio-emotional cues (e.g., facial expressions) and use appropriate strategies to regulate their emotions accordingly (Gross, 2002; Cole et al., 2004). For instance, whereas smiling faces will encourage answers and approach, a negative countenance will trigger behavioural regulation (e.g., inhibition) to avoid a potentially disturbing situation. This suggests that the impact of emotion on cognition depends on the arousal and valence of the stimulus (Pessoa, 2009).

Although the development of emotion regulation strategies has important affective, cognitive and social consequences in children, behavioural and neuroimaging studies investigating this process are few and their results are discrepant. For instance, at the behavioural level, whereas Cohen Kadosh et al. (2014) reported that children (11–12 years old) encounter more attentional control difficulties in the context of fearful compared to happy faces (Cohen Kadosh et al., 2014), others have shown that emotional context alters response inhibition ability in children; however, this inhibition is equal to both happy and sad faces (Urben et al., 2012).

Knowledge about the inhibitory brain mechanisms, in children, that trigger emotion regulation, particularly those that allow adaptive functioning in the presence of socio-emotional cues (face expressions), is also limited. Thus far, a few ERP studies in children have highlighted the functional role of the N2, an inhibitory-related frontal component occurring 200–400 ms after stimulus onset, in the regulation of socio-emotional cues (Lewis et al., 2007; Todd et al., 2008; Hum et al., 2013a,b). These studies used an *emotional go/no–go task* where participants responded to 'go' stimuli and withheld responses to 'no–go' stimuli in the context of happy, angry or fearful faces. Although the results are of interest, the protocols could be improved in several ways. Firstly, these studies compared go trials (containing a motor response) with no–go trials (containing no motor response), thus integrating a motor confound into the analysis (see discussion in Vidal et al., 2012). Secondly, previous ERP studies have used explicit socio-emotional cues

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during the emotional go/no–go task which required participants to directly respond to emotion (i.e., Happy/Angry/Fearful; (Hare et al., 2008)) or gender (Lewis et al., 2007; Hum et al., 2013a,b) of the stimulus. However, although emotion regulation is usually portrayed as a deliberate and explicit process (Gross, 2014), a growing body of research has shown that emotion regulation often operates on more implicit or automatic levels (Gyurak et al., 2011; Koole and Rothermund, 2011; see Koole et al., 2015, for a review). According to these models, automatic emotion regulation (AER) processes operate almost constantly in daily life and represent a powerful aid in keeping emotional context from interfering with one's ongoing activities. Hence, investigating the impact of an incidental exposure to emotional stimuli on controlled behaviour provides a more a realistic measure of socio-behavioural interactions, where emotional cues are often incidental (Goldstein et al., 2007; Todd et al., 2008, 2012). The AER assists children in developing adaptive emotion regulation strategies by facilitating an implicit and rapid monitoring of whether an emotional response is appropriate or not (Hopp et al., 2011 and see Koole et al., 2015 for a recent review). For instance, by efficiently offsetting the impact of unwanted or negative emotional responses without drawing on limited attentional resources, the AER crucially contributes to resilience to stressful life events and to personal growth (Bonanno, 2004; Gross and Muñoz, 1995; Moore et al., 2008). Moreover, implicit emotion regulation has been associated with improved well being or social adjustment and reduced depressive symptoms (Bonanno, 2004; Hopp et al., 2011).

Despite the importance of the AER in improving self-regulation in children, a clear understanding of AER-related neurophysiological mechanisms is still missing. To our knowledge, only one functional magnetic resonance imaging (fMRI) study has characterized the brain regions involved in AER regulation (i.e., incidental exposure to happy or angry faces during a go/no–go task) in children (Todd et al., 2012). Results showed that inhibition-related activity in the orbito-frontal cortex (OFC) was modulated by the emotional valence of the faces. In particular, whereas Happy faces triggered more activity in the left OFC, compared to Angry faces, in younger children (4.4–6.5 years), the emotion-related modulation of the OFC shifted to greater activation for Angry faces in older children (6.5–9.0 years; Todd et al., 2012). Although Todd et al. (2012)'s fMRI study showed the specific contribution of the OFC in socio-emotional regulation processes in children, and possibly its crucial importance during development, the poor temporal resolution of fMRI precludes an understanding of the brain dynamics that regulate inhibition and emotion interaction.

The goal of the present study was to characterise precisely the spatio-temporal brain dynamics of AER in children. To do so, we used magnetoencephalography (MEG) which offers a unique opportunity to investigate both the spatial and temporal brain patterns that underlie inhibitory brain mechanisms. We determined how these brain processes were modulated by an incidental exposure to negative (angry faces) vs. positive (happy faces) emotions, thus, allowing adaptive functioning in children. As MEG provides excellent time resolution and better spatial localisation than ERPs, it represents a remarkable tool for studying such complex cognitive processes (e.g., see Hari et al., 2010 for a review). The MEG analyses compared the timing and localisation of inhibition-related brain activity which occurred with incidental exposure to positive vs. negative emotional faces. Moreover, to prevent the usual confound of movement-related activity (when go and no–go trials are contrasted), we compared no–go trials associated with stimuli in an *inhibitory* condition to no–go trials occurring within a *vigilance* condition (same no–go stimuli in a non-inhibitory context) to ensure the specificity of the inhibition task effect. We hypothesised that the emotional context, particularly the presence of angry faces, would affect inhibitory brain processes and this would be expressed by greater activation in brain areas classically linked to inhibition.

2. Material and methods

2.1. Participants

Participants were selected from a larger series of 40 children [age range: 7–13 yrs]. All children had normal vision and no history or existing diagnosis of psychiatric, neurological disorders or learning disability. One child was excluded due to high IQ (>140), three were excluded due to excessive movement in the MRI and MEG scanners and 11 were excluded due to poor performance on the task (high false alarm (FAs) rate of no–go trials, $<10\%$ difference between HITS and FAs).

Thus, the final sample of this study included 25 children (17 males: 8 females, mean $\pm$ SD: 10.23 $\pm$ 1.79yrs), 21 were right handed and 4 left–handed. All children provided informed assent and parents gave informed written consent. The study was approved by the Research Ethics Board at the Hospital for Sick Children and is in accordance with the declaration of Helsinki. All children were in the appropriate grade level in school and were recruited through fliers, advertisements and word of mouth. Prior to MEG testing, all participants received instructions and completed practice trials to ensure full understanding of the task.

2.2. Experimental MEG task and procedure

The children completed an emotional go/no–go task (see Fig. 1a) in the MEG scanner. During this task, children were instructed to respond as fast as possible to 'go' stimuli by pressing a button, and to withhold a response to 'no–go' stimuli. The go and no–go trials were identified by a coloured frame around either an Angry or a Happy face. Participants were instructed to ignore the faces and only attend to the colour of the frame (e.g., go trials were identified by a blue frame and no–go stimuli by a purple frame). Children were thus incidentally exposed to two different emotional valences of faces which allowed us to investigate how emotional context (Happy vs. Angry) affects inhibition processing.

Inhibition performance and the associated brain activity were compared to a go/no–go vigilance (control) task. In the *Inhibition* (I) condition, the majority of stimuli were go trials (75%) so the prepotent tendency to respond was established, and thus it was difficult to inhibit to no–go trials (25%). In contrast, the *Vigilance* (V) condition included 75% no–go trials, with only 25% go trials, and can thus be seen as a classic vigilance task. The two MEG tasks were presented in randomized order across participants.

The go or no–go stimuli were randomized to be either a blue or purple frame, within which emotional distracter faces were presented. There were 52 emotional faces (26 females: 26 males) that were selected from the NimStim Set of Facial Expressions (Tottenham et al., 2009). Only images that were correctly classified as Happy or Angry with $\geq 80\%$ accuracy were used.

All stimuli appeared on a projection screen located 80 cm from the children's eyes; the visual angle of the stimuli subtended approximately 4° of visual field. Trials began with a stimulus duration of 700 ms, which was adjusted between 300 and 700 ms, followed by a fixation cross in the inter-stimulus interval (ISI), which varied between 650 and 1300 ms, based on response accuracy. The paradigm was designed to maintain a steady error rate ($\geq 95\%$ accuracy for go trials, $\geq 80\%$ accuracy for no–go trials). Therefore, the stimulus duration and ISI were adjusted in real time based on global go and no–go accuracies (calculated from the start of the run) as well as recent accuracy rates (calculated from the last 5 trials of each stimulus type). ISI duration