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Cognitive emotion regulation in children: Reappraisal of emotional faces modulates neural source activity in a frontoparietal network

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ABSTRACT

Emotion regulation has an important role in child development and psychopathology. Reappraisal as cognitive regulation technique can be used effectively by children. Moreover, an ERP component known to reflect emotional processing called late positive potential (LPP) can be modulated by children using reappraisal and this modulation is also related to children's emotional adjustment. The present study seeks to elucidate the neural generators of such LPP effects. To this end, children aged 8–14 years reappraised emotional faces, while neural activity in an LPP time window was estimated using magnetoencephalography-based source localization. Additionally, neural activity was correlated with two indexes of emotional adjustment and age. Reappraisal reduced activity in the left dorsolateral prefrontal cortex during down-regulation and enhanced activity in the right parietal cortex during up-regulation. Activity in the visual cortex decreased with increasing age, more adaptive emotion regulation and less anxiety. Results demonstrate that reappraisal changed activity within a frontoparietal network in children. Decreasing activity in the visual cortex with increasing age is suggested to reflect neural maturation. A similar decrease with adaptive emotion regulation and less anxiety implies that better emotional adjustment may be associated with an advance in neural maturation.

1. Introduction

The attainment of flexible and effective emotion regulation skills during childhood is considered a key developmental task in support of psychological adjustment (Cole and Deater-Deckert, 2009; Eisenberg et al., 2010). Much evidence documents the relevance of poor emotion regulation for a wide range of mental health problems in children and adolescents, including anxiety and major depression (e.g. Kovacs et al., 2008; Weems and Silverman, 2006). A frequently applied treatment for these disorders in children is cognitive behavioral therapy (Muñoz-Solomando et al., 2008), which seeks to reduce symptoms of emotional dysregulation via alterations of depressogenic or anxiety-provoking cognitions quite effectively (e.g. James et al., 2015; Weersing et al., 2009). Despite cognitive emotion regulation playing a key role in developmental psychopathology, to date only few studies elucidate its neural mechanisms in children.

A technique frequently used to study cognitive emotion regulation is reappraisal, which involves changing the emotional impact of a stimulus through reinterpretation (Gross and John, 2003). In experiments with adults, reappraisal is shown to modulate a variety of emotion indicators, including self-reports, facial electromyography, startle response, or electrodermal activity (Ray et al., 2010; Urry, 2009). Moreover, adult self-reports associate habitual use of reappraisal with greater psychological well-being (John and Gross, 2004) and less psychopathology (Garnefski et al., 2002). In experiments with children, successful implementation of reappraisals given by the experimenter (directed reappraisal, Dennis and Hajcak, 2009) is reported to start between the ages 5 and 7 while self-generated reappraisals reduce emotional responses to threatening pictures in children of age 10 and older (Carthy et al., 2010). Self-reports of the use of reappraisal are applicable by 9 years (Gullone et al., 2010), and adolescents' self-reports confirm an association of reappraisal with mental health (Garnefski et al., 2002). Taken together, these findings suggest that both experimental instructions and self-reports of reappraisal are suitable to

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investigate cognitive emotion regulation in children from around the age of 8.

In adults, there is a relative consensus about relevant neural structures mediating reappraisal, based on convergent findings of fMRI studies. Both up- and down-regulation via reappraisal increased neural activity in regions associated with cognitive control, such as the prefrontal cortex, while neural activity in regions associated with emotion generation, such as the amygdala and insula, was increased during up-regulation and reduced during down-regulation (Ochsner and Gross, 2005, 2008). Previous fMRI experiments in children and adolescents converge by showing increased activity in prefrontal and increased or decreased activity in emotion generating regions during reappraisal. Moreover, these studies consistently demonstrate age-related changes particularly in prefrontal structures (Lévesque et al., 2004; McRae et al., 2012; Pitskel et al., 2011), although the detailed pattern of results is quite inconsistent. So, children's neural networks underlying reappraisal overlap with those of adults, but data of children are still rare and age-related changes remain to be specified.

Reappraisal has also been investigated by event-related potential (ERP) studies, which have focused on the late positive potential (LPP). The LPP is a visual ERP component occurring around 300 ms that is typically enhanced by emotional compared to neutral stimulus content in adults (Schupp et al., 2006; Olofsson et al., 2008) and children (Hajcak and Dennis, 2009; Wessing et al., 2011) and is believed to reflect facilitated attention to and enhanced processing of emotional stimuli (Lang and Bradley, 2010). In adults, ERP studies documented that the LPP can be modulated by reappraisal, with enhanced amplitudes during up-regulation (Moser et al., 2009, 2010) and reduced amplitudes during down-regulation (Hajcak and Nieuwenhuis, 2006; Moser et al., 2009). In children, an effective reduction of the LPP amplitude by reappraisal was observed in 7–10-year-olds (Dennis and Hajcak, 2009), while in 5–7-year-olds this effect could not yet be shown reliably (DeCicco et al., 2012; Dennis and Hajcak, 2009). Beyond that, these studies revealed positive correlations of the LPP with symptoms of anxiety and negative correlations with emotion regulation capacities. The neural generators of these effects are currently unknown.

The aim of the present study was to investigate neural mechanisms underlying cognitive emotion regulation in children using magnetoencephalography (MEG) based source localization. MEG offers a high time resolution and a fairly good localization of LPP-related cortical activity, which allows filling the gap between existing fMRI and ERP findings. Moreover, this non-invasive and easily tolerated method is perfectly suited for the investigation of children. As children were shown to effectively use reappraisal and give self-reports on emotion regulation with about 8 years, this determined the lower age limit. To further allow for an examination of age-related changes – as an approximation to development – within one experimental set-up the upper age limit was set to 14 years.

An experimental design for the regulation of emotions recently used in adults (Wessing et al., 2013) was adapted to children. Children saw pictures of faces with angry or neutral expressions, while MEG was recorded. Prior to picture presentation, children were instructed to use reappraisal, which involved imagination of the depicted persons in different social situations. To up-regulate threat (threat-up), children imagined they were confronted with an angry, scolding neighbor. To down-regulate threat (threat-down), children imagined to evaluate the performance of an actor. In a control condition, children attentively viewed the pictures (view). Following picture presentation, children performed a threat rating of each presented face and completed questionnaires on emotion regulation and anxiety.

Based on the precursor study with adult participants (Wessing et al., 2013), the LPP was examined in an interval between 280 and 680 ms and it was hypothesized that (1) an emotion effect should evoke enhanced neural activity in response to angry versus neutral faces in visual sensory and prefrontal cortex (PFC) regions, (2) reappraisal should increase activity in the PFC, and (3) down-regulation should reduce and up-regulation should enhance the emotion effect. In addition to experimental manipulations, correlation analyses were conducted to analyze changes of neural activity with age and two indexes of emotional adjustment. Based on previous findings (Dennis and Hajcak, 2009; DeCicco et al., 2012) it was hypothesized that LPP-related neural activity should show (4) negative correlations with emotion regulation and (5) positive correlations with trait anxiety.

Table 1
Distribution of age and gender.

Gender	Age			
	8–9	10–11	12–14	Total
Male	8	11	10	29 (51.8%)
Female	9	9	9	27 (48.2%)
Total	17 (30.4%)	20 (35.7%)	19 (33.9%)	56 (100%)

2. Methods

2.1. Participants

Fifty-six children (28 female) aged 8–14 years (M = 132.43 months; SD = 21.82) participated in this study, with gender almost evenly distributed across ages ($\chi^2(2) = 0.24$; $p = .94$; see Table 1). All children had normal or corrected-to-normal vision, did not suffer from any child psychiatric disease (structured clinical interview: *Kinder-DIPS*; Unnewehr et al., 2009), and had normal to high intelligence (IQ: M = 113.71; SD = 16.33; up to 8; 5 years: CFT-1, 5th ed., Cattell et al., 1997; above 8; 5 years: CFT-20-R, Weiß, 2008). Participants were recruited via classroom information sessions. Each child obtained a cinema voucher for participation and parents received a compensation for their travel expenses. Children and parents were informed about the procedure in written and oral form, and both gave written informed consent. The study design was approved by the ethics committee of the Medical Faculty, University of Muenster, in accordance with the Declaration of Helsinki.

2.2. Self-report of emotion regulation

Children completed the Questionnaire for the Measurement of Emotion Regulation in Children and Adolescents (FEEL-KJ; Grob and Smolenski, 2005), which captures the use of adaptive and maladaptive emotion regulation strategies for anxiety, anger, and sadness. This German-language questionnaire consists of 90 items and is designed for the ages 10–20 years. An experimenter ensured the understanding of all items and response schemes also by younger children. T-scores were built for the use of adaptive and maladaptive strategies based on the T-norms for 10;0 to 15;11 years. A difference score was calculated by subtracting the T-scores for adaptive and maladaptive strategies, resulting in a single score with positive values for a predominant use of adaptive and negative values for a predominant use of maladaptive strategies.

2.3. Self-report of trait anxiety

Children's trait anxiety was measured using the T-Anxiety scale of the State-Trait Anxiety Inventory for Children (STAIC; Spielberger, 1973). This 20-item questionnaire was designed for elementary school children. The response to each item is scored with 1–3 points, with more points signaling increasing anxiety. Since there are no T-norms available for the German version