Developmental changes in neural correlates of cognitive reappraisal: An ERP study

using the late positive potential

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Abstract

Objective: The reduction of the amplitude of the late positive potential (LPP) following cognitive reappraisal has been used as a neural marker of emotion regulation. However, studies employing this neural marker in children are scarce and findings are not conclusive, with most studies showing a lack of LPP modulation after reappraisal in children in the age range of 5-12 years. The aim of the current study was therefore to investigate developmental changes in sensitivity of LPP modulation to cognitive reappraisal. To do so, LPP modulation due to cognitive reappraisal of negative pictures was compared between two age groups (8- to 11- versus 12- to 15-year-olds) and regression analyses were applied within the total sample to test whether sensitivity of LPP modulation shows a linear increase with age. **Method:** In 63 children the LPP was measured after negative pictures that were either combined with a negative story or with a neutral, reappraising story. **Results:** Although groups did not differ for self-reports on reappraisal, a significant reduction of LPP following cognitive reappraisal was only found in the older children, whereas such an effect was absent in the younger children. Findings were similar for boys and girls. Additional analyses showed a linear increase in sensitivity of LPP modulation with age. **Conclusions:** The results indicate that LPP modulation as measured in the current paradigm can be used as a valid index of emotion regulation in boys and girls but that caution is recommended using it in younger children.

Keywords: emotion regulation; neural marker; late positive potential (LPP); children

1 Introduction

Because of its importance for successful adaptation (Aldao, Nolen-Hoeksema, & Schweizer, 2010; Eisenberg, Fabes, Guthrie, & Reiser, 2000; Zeman, Cassano, Perry-Parrish, & Stegall, 2006), a lot of studies have focused on emotion regulation, especially on reappraisal, a strategy that is used to change the emotional impact of a situation by altering the meaning of that situation (Gross, 2015). Reappraisal is used to reduce distress associated with negative emotional events by generating benign or positive interpretations (Gross, 1998). For example, a picture of a house that is burned down could be interpreted as a very old building that had to go and was burned down to build a new one. Reappraisal results in more positive and less negative emotions and better interpersonal functioning and well-being (Gross & John, 2003) and less use of reappraisal is associated with the development of psychopathology (Belden, Pagliaccio, Murphy, Luby, & Barch, 2015; Carthy, Horesh, Apter, Edge, & Gross, 2010; Garnefski, Rieffe, Jellesma, Terwogt, & Kraaij, 2007; Van Cauwenberge, El Kaddouri, Hoppenbrouwers, & Wiersema, 2016). Reappraisal is a complex regulatory strategy that relies on other abilities such as perspective taking, working memory and monitoring the affective state (Ochsner and Gross, 2008). Reappraisal is traditionally measured by means of self-report questionnaires (Cole, Martin, & Dennis, 2004). The use of self-reports on reappraisal in children has disadvantages as their validity and reliability are affected by developmental factors such as self-awareness of emotions and cognitions, autobiographical memory, and the propensity to engage in dichotomous thinking (Zeman, Klimes-Dougan, Cassano, & Adrian, 2007). In addition, scores on such questionnaires do not necessarily reflect the ability to use reappraisal and its effectiveness to regulate emotional reactions (Cole et al., 2004; Zeman et al., 2007) but rather reflect how often the strategy is used (e.g., Gullone, Hughes, King, & Tonge, 2010). The use of questionnaires also hamper disentangling emotional reactivity and emotion regulation processes (Cole et al., 2004; Troy, Wilhelm, Shallcross, & Mauss, 2010).

To address these issues, researchers have started to study reappraisal in children with neuroimaging techniques or psychophysiological measures (Belden, Pagliaccio, Murphy, Luby, & Barch, 2015; Davis, Quiñones-Camacho, & Buss, 2016; Dennis & Hajcak, 2009; Dougherty, Blankenship, Spechler, Padmala, & Pessoa, 2015). In those studies, children are confronted with negative emotional events and are instructed to reappraise these events.

Event-related potential (ERP) research in adults has shown that the late positive potential (LLP) may be a useful neural correlate of cognitive reappraisal (e.g., Foti & Hajcak, 2008). The LPP is a positive-going sustained component appearing approximately 300 ms after stimulus onset with a maximum topography at posterior sites. Emotionally valenced stimuli consistently elicit larger LPPs compared to neutral stimuli (e.g., Hajcak, Dunning, & Foti, 2007; Hajcak, MacNamara, & Olvet, 2010) and adult studies have consistently shown a reduction of the LPP amplitude following cognitive reappraisal (Foti & Hajcak, 2008; Hajcak, Moser, & Simons, 2006; Hajcak & Nieuwenhuis, 2006; MacNamara, Fod, & Hajcak, 2009), indicating that LPP modulation may serve as a neural marker of cognitive reappraisal.

Studies using LPP modulation as an index of emotion regulation in children are scarce and findings across studies are inconsistent (Babkirk, Rios, & Dennis, 2014; DeCicco, O'Toole, & Dennis, 2014; DeCicco, Solomon, & Dennis, 2012; Dennis & Hajcak, 2009; Hua, Han, & Zhou, 2015; Leventon & Bauer, 2016). Dennis and Hajcak (2009) investigated cognitive reappraisal in children (5-10 years old). In their paradigm, which was also applied in the current study, a negative picture was first presented, after which the children heard a short story and saw the same picture again. They were instructed to match the picture with the story. Half of the pictures received a neutral interpretative story, half of the pictures a negative story. There was a significant reduction of the LPP after negative pictures coupled with a neutral story compared to pictures with a negative story in most children, except in the

youngest girls of their sample. A recent study replicated this finding in preschool children, although a different paradigm was used together with simplified interpretations (Hua, et al., 2015). Instead of randomly altering the meaning of the stories on trial basis, they applied neutral interpretation blocks and negative interpretation blocks. There were only six different interpretative stories and these were repeated in 4 words prior to the presentation of the pictures. In contrast, other studies applying paradigms similar to (first the picture, then the story and then again the picture) and different from (first the story, then the picture) the original one as introduced by Dennis and Hajcak (2009) failed to find smaller LPPs following reappraisal in children with an age ranging from 5 to 12 years across these studies (Babkirk, et al., 2014; DeCicco, et al., 2014; DeCicco, et al., 2012; Leventon & Bauer, 2016; Van Cauwenberge et al., 2016). In the study by DeCicco et al. (2014), correlations with age showed a linear increase in sensitivity of LPP modulation to cognitive reappraisal with age (DeCicco et al., 2014), suggesting that the child's age may be a significantly contributor to the variability in findings across studies. Developmental changes in emotion regulation abilities, including cognitive reappraisal may be due to ongoing brain development. Development of emotion regulation appears to be underpinned by ripening of the prefrontal cortex and optimizing connectivity between prefrontal areas and subcortical and limbic regions, such as the amygdala, resulting in more efficient top-down control (Ahmed, Bittencourt-Hewitt, & Sebastian, 2015; Ochsner & Gross, 2008). To date, developmental changes in LPP modulation have not yet been systematically studied in a wide age range, which was the aim of the current study.

Therefore, in the present cross-sectional study, a large group of children between 8 and 15 years old performed the cognitive reappraisal task as implemented by Dennis and Hajcak (2009). The original English stories were translated into Dutch.. Although the initial study of Dennis and Hajcak (2009) found some children under the age of 10 to show a smaller LPP

after cognitive reappraisal, overall findings are far from conclusive, as most other studies could not demonstrate significant reductions of the LPP following cognitive reappraisal in children younger than 12 years old (Babkirk, et al., 2014; DeCicco, et al., 2014; DeCicco, et al., 2012; Leventon & Bauer, 2016; Van Cauwenberge et al., 2016). Research on the LPP as an index of cognitive reappraisal in children older than 12 years old is lacking. Emotion regulation undergoes important developmental changes with the transition from middle childhood to adolescence (Gross, 2013) related to maturation of executive functions, echoed in the more frequent use of strategies such as cognitive reappraisal (Riediger & Klipker, 2014). Considering this, we chose to compare LPP modulation during reappraisal between a group of children younger than 12 (8-11) and a group of children older than 12 years (12-15) in the current study. We additionally applied regression analyses within the total sample to test whether the sensitivity of LPP modulation shows a linear increase with increasing age. We hypothesized a reliable modulation of the LPP by reappraisal to be present in the older children, but not or less so in the younger group. In addition, we expected sensitivity of the LPP to show a linear increase with increasing age. Studies investigating gender effects are scarce and findings are inconsistent. In the study by Dennis and Hajcak (2009), (young) girls failed to show LPP modulation, while a lack of gender effects was reported in 2 other studies (DeCicco et al., 2012; Van Cauwenberge, et al., 2016). Because of the scarcity of studies evaluating gender effects and inconsistency of findings, we decided to include gender in the analyses to further explore the effect of gender on LPP modulation. As a result of the inconsistent findings in the literature, we had no a priori hypothesis regarding gender effects. Finally, self-reports on reappraisal were assessed and correlated with reappraisal induced LPP modulation. We hypothesized that there would be a positive relationship between both indices of reappraisal.

2 Method

2.1 Participants

The initial sample consisted of 63 typically developing (TD) children between 8 and 15 years old from the community without any behavioral or emotional disorders or neurological condition. Some of the children were participating in a large Flemish longitudinal cohort study, named 'JOnG!' (for details on the aims and the design of the 'JOnG!'-study, see Grietens, Hoppenbrouwers, Desoete, Wiersema, & Van Leeuwen, 2010). The remaining children were recruited trough advertisement and word of mouth. The study was approved by the ethical committees of both Ghent University and KU Leuven. Three children were excluded: one child scored above the cutoff of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan et al., 2008), another child had an estimated total IQ below 80 (evaluated with the short version of the Wechsler Intelligence Scale for Children - Third edition - NL [WISC-III-NL]; Grégoire, 2000; Wechsler, 1991; Dutch translation: Kort et al., 2005), and finally, the EEG-data of one child contained too many artefacts. The characteristics of the final sample of 60 children, subdivided into two age groups, are presented in Table 1. There were no differences in age between boys and girls (for younger children: t [28] < 0.01, p = 1.000; for older children: t [28] = 0.31, p = .760). Total estimated IQ did not differ as an effect of age group or gender (F[1,56] = 0.80, p = .374 and F[1,56] = 3.41, p = .070). There was a significant interaction of age group and gender (F[1,56] = 9.13, p = .004), indicating that the total estimated IQ differed significantly in the oldest age group between boys and girls. However, IQ was not correlated with LPP modulation in these children and was therefore not included as a covariate in further analyses. The score on the self-report measure for reappraisal did not differ as an effect of age group or gender (all p's > .44).

Table 1

Means and Standard Deviations for Age, Estimated IQ and Scores on the Self-report Measure of Emotion Regulation and the Gender Distribution for Younger and Older Children

| Variables	Younger children (8-11 years)		Older children (12-15 years)	
	Boys *M* (*SD*)	Girls *M* (*SD*)	Boys *M* (*SD*)	Girls *M* (*SD*)
Age (years)	9.40 (1.06)	9.40 (1.06)	13.67 (1.18)	13.53 (1.19)
Estimated IQ	103.53 (7.57)	106.33 (10.21)	112.87 (9.88)	101.27 (9.02)
ERQ-CA - REAP	21.33 (4.20)	21.07 (3.75)	20.07 (4.30)	20.80 (2.83)

Note. Estimated IQ = estimated total IQ based on the subtests similarities, picture arrangement, block design, and vocabulary of the WISC-III-NL. ERQ-CA - REAP = subscale reappraisal of the Emotion Regulation Questionnaire for Children and Adolescents.

2.2 Measures

2.2.1 Cognitive reappraisal task.

A cognitive reappraisal task similar to the one introduced by Dennis and Hajcak (2009) was used, with the same 30 negative pictures from the International Affective Picture System (Center for the Study of Emotion and Attention [CSEA-NIMH], 1999; Lang, Bradley, & Cuthbert, 2008). We wanted to stay as close as possible to the original paradigm as applied by Dennis and Hajcak (2009). In that paradigm, the stimulus was presented twice, once before and once after hearing a story. This was done in order to reduce working memory demands and to help children better attend to and understand the interpretations. Neutral stimuli were

not included (see also Dennis & Hajcak, 2009) because we did not want to unnecessarily prolong the task and the aim of the study was not to compare neural processing of negative and neutral pictures but to evaluate age differences in reappraisal of negative pictures in children. The pictures were initially presented for 2000 ms, followed by a black screen in combination with an auditory story (see Figure 1). The content of the story was either a neutral interpretation of the negative picture (reappraisal condition, e.g., an angry dog becomes a dog that just went to the dentist and has clean teeth) or a negative interpretation (negative condition, e.g., the dog is really angry and will attack someone). The auditory stories had a variable duration between 5000 and 10000 ms. After the auditory story the same picture was presented for another 2000 ms. Children were instructed to think about the picture so that it matches with the story. For each child a random selection of half of the pictures was
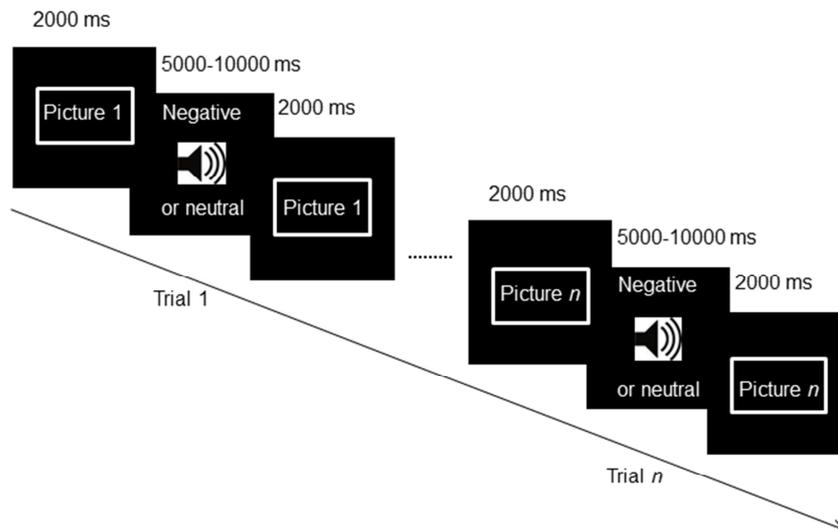
Figure 1. Illustration of the cognitive reappraisal task (see also Dennis & Hajcak, 2009). The pictures were taken from the IAPS (Lang et al., 2008). Due to copyright reasons, the actual pictures are not shown here.

combined with a neutral interpretation, and half with a negative interpretation. All 30 pictures were presented in the first block and after a short break, they were presented a second time, with the same story, in the second block. Because it is difficult to select more than 30 age-appropriate negative pictures from the IAPS, the same pictures were used in the second block in order to increase the number of trials for the LPP. The presentation of the pictures occurred in a random order, with the exception of the first trial of the second block, for which the valence of the story was always different from the first story of the first block (see also Dennis & Hajcak, 2009).

2.2.2 Rating of the pictures.

After the cognitive reappraisal task, children rated the 30 pictures with a computer based Self-Assessment Manikin (Bradley & Lang, 1994; Lang, 1980). These ratings were used to verify if the children found the stories negative or reappraising. A 5-point Likert scale was used for the evaluation of valence on one hand (from *negative* (1) over *neutral* (3) to *positive* (5)) and arousal on the other hand (from *not arousing* (1) to *high arousing* (5)).

2.2.3 Self-report questionnaire.

The use of reappraisal was assessed with a Dutch version of the Emotion Regulation Questionnaire for Children and Adolescents (ERQ-CA; Gullone et al., 2010). With a 5-point Likert scale from *strongly disagree* (1) to *strongly agree* (5), the children evaluated, on the subscale reappraisal, their use of this strategy. The internal consistency for both groups was sufficient for the current sample (Cronbach's α = .69 for younger children and .79 for older children).

2.3 Procedure

The research took place in the Faculty of Psychology and Educational Sciences at Ghent University. After informed consents were received from both the parent(s) and the child, a total of three computerized tasks were administered in a fixed order. The first task, which lies outside the scope of this article, was followed by the cognitive reappraisal task and the rating task. Intelligence measurements were done either before or after the computer tasks. Questionnaires were filled out at home, prior to the lab visit.

2.4 EEG-Data Acquisition and Reduction

An electrode cap with 128 Ag/AgCl electrodes (EasyCap Active, EasyCap GmbH), placed according to the 10/5 International System (Oostenveld & Praamstra, 2001), was used to collect the EEG-data, with the ground electrode at Fpz. Eye-movements were recorded at three positions near the eyes and through an additional electrode below the right eye. The EEG signal was amplified with an open pass-band from direct current to 100 Hz using a QuickAmp amplifier (Brain Products GmbH, Germany), digitized with a sample rate of 500 Hz. Offline, a low cutoff filter of 0.1 Hz, a high cutoff filter of 30 Hz and a notch filter of 50 Hz was applied with Brain Vision Analyzer software (Version 2.0.1). After segmentation (500 ms before stimulus onset to 2000 ms after), ocular artefacts were corrected (Gratton, Coles, & Donchin, 1983). Activity below 0.5 µV, a gradient above 50 µV/ms and a difference of more than 200 µV between minimum and maximum in an epoch of 200 ms were defined as artefacts. Segments containing any of these artefacts were removed resulting in 50 to 100% remaining segments for most of the children (M = 23.00, SD = 5.30 for younger children; M = 24.22, SD = 5.30 for older children). Only four children were left with 10 to 13 acceptable segments but for these children a data check revealed reliable LPPs with the expected

topography. Trial acceptance rates did not differ between negative and neutral interpretations ($F(1,56) = 0.02$, $p = .902$) or as a result of the child's age ($F(1,56) = 0.90$, $p = .348$). ERPs were time locked at the second presentation of the picture (after the story) and averaged per condition (reappraisal versus negative), with a 500 ms pre-stimulus baseline. Based on previous literature and visual inspection of grand averages and topography in the current study, we included three parietal-occipital and three occipital electrode positions, at the midline and left and right from the midline (PO3, POz, PO4, O1, Oz, O2). This parietal–occipital scalp distribution of the LPP is illustrated in Figure 2, which depicts the scalp
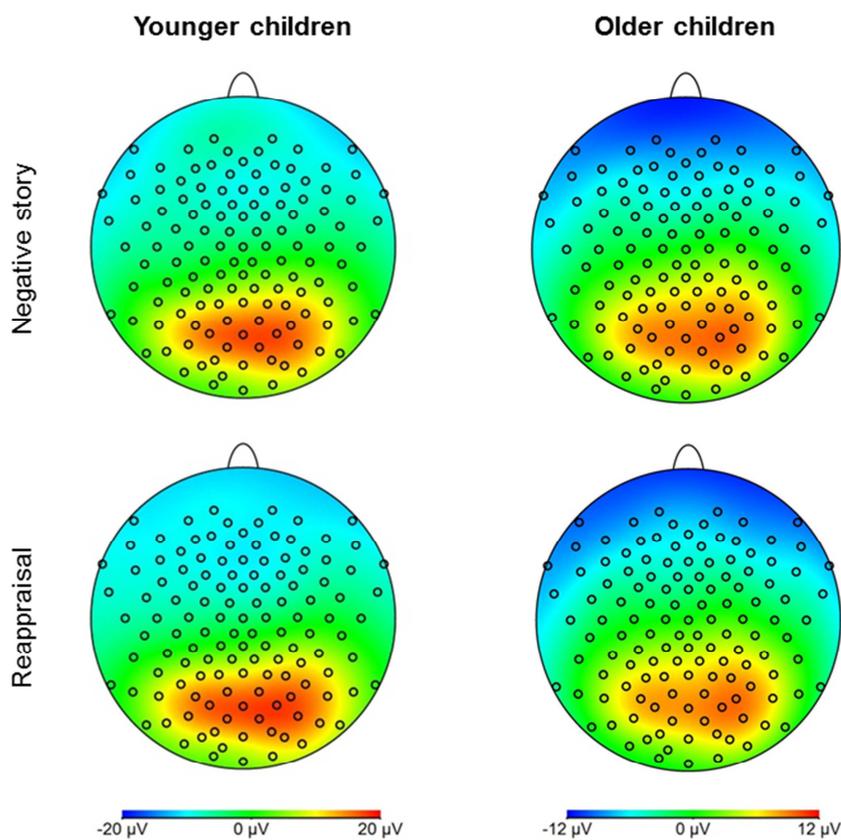
Figure 2. Scalp topography of the LPP after a negative story and reappraisal in the early time window (300-600 ms) for both age groups.

topography of the LPP between 300-600ms for younger and older children after hearing a neutral or negative story. Three time windows were used: an early window from 300 to 600 ms, a middle window from 600 to 1000 ms, and a late window from 1000 to 1500 ms after stimulus onset (Babkirk et al., 2014; DeCicco et al., 2012; Dennis & Hajcak, 2009).

2.5 Statistical Analyses

The arousal and valence ratings of the pictures were analyzed with a repeated measures ANOVA (rANOVA) with condition (reappraisal, negative) as within-subjects variable and gender (boys, girls) and age group (8-11 years, 12-15 years) as between-subjects variables. For the reappraisal task, rANOVAs were conducted separately for the different time windows as recommended by DeCicco et al. (2014). A condition (reappraisal, negative) by sagittal position (parietal-occipital, occipital) by lateral position (left, center, right) by gender by age group design was used. Univariate test results were Greenhouse-Geisser corrected in case of violation of the assumption of sphericity. In order to keep the number of reported statistical comparisons limited, in view of the scope of the current study, only relevant effects involving condition, age group or gender are discussed. Across groups, regression analyses to test the linear effect of age were applied on the LPP modulation score. This score was calculated by subtracting the LPP amplitude following reappraisal from the LPP amplitude following a negative story. Correlations with the self-reported reappraisal were also calculated with this modulation score.

3 Results

3.1 Rating of the Pictures

Overall, children rated the pictures combined with a reappraisal story less arousing than the pictures combined with a negative story (F[1,56] = 12.32, p = .001, η^2 = .18). The ratings were not different according to age group or gender (F[1,56] = 0.25, p = .618, η^2 < .01 for condition by age group and F[1,56] = 0.59, p = .445, η^2 = .01 for condition by gender) (see Table 2). Furthermore, the pictures in the reappraisal condition were rated as less negative than the pictures in the negative condition (F[1,56] = 22.99, p < .001, η^2 = .29), with a stronger effect for younger children (F[1,56] = 4.25, p = .044, η^2 = .07 for condition by age group). There were no differences between boys and girls in the rating of the valence (F[1,56] = 0.01, p = .927, η^2 < .01 for condition by gender).

Table 2

Means (and Standard Deviations) for the Rating of Arousal and Valence of the Pictures

	Negative story		Reappraisal	
	Boys	Girls	Boys	Girls
Younger children (8-11 years)				
Arousal	3.21 (1.03)	3.45 (0.84)	3.06 (0.82)	3.07 (0.78)
Valence	2.38 (0.94)	1.76 (0.62)	2.93 (0.61)	2.37 (0.68)
Older children (12-15 years)				
Arousal	3.18 (0.59)	3.56 (0.45)	2.97 (0.68)	3.35 (0.48)
Valence	2.15 (0.57)	2.39 (0.91)	2.43 (0.53)	2.57 (0.69)

3.2 Cognitive Reappraisal

3.2.1 Early window.

The main effect of condition on the LPP was not significant ($F[1,56] = 1.08$, $p = .303$, $\eta^2 = .02$). Independent of condition, LPP amplitudes were larger in boys and in younger children ($F[1,56] = 8.74$, $p = .005$, $\eta^2 = .14$ and $F[1,56] = 22.08$, $p < .001$, $\eta^2 = .28$ respectively). More importantly, age group interacted significantly with condition ($F[1,56] = 4.79$, $p = .033$, $\eta^2 = .08$). Follow up analyses separately for the two groups showed a main effect of condition on LPP modulation in the older children ($F[1,29] = 9.19$, $p = .005$, $\eta^2 = .24$), whereas this was absent in the younger children ($F[1,29] = 0.48$, $p = .493$, $\eta^2 = .02$). As can be seen in the ERPs
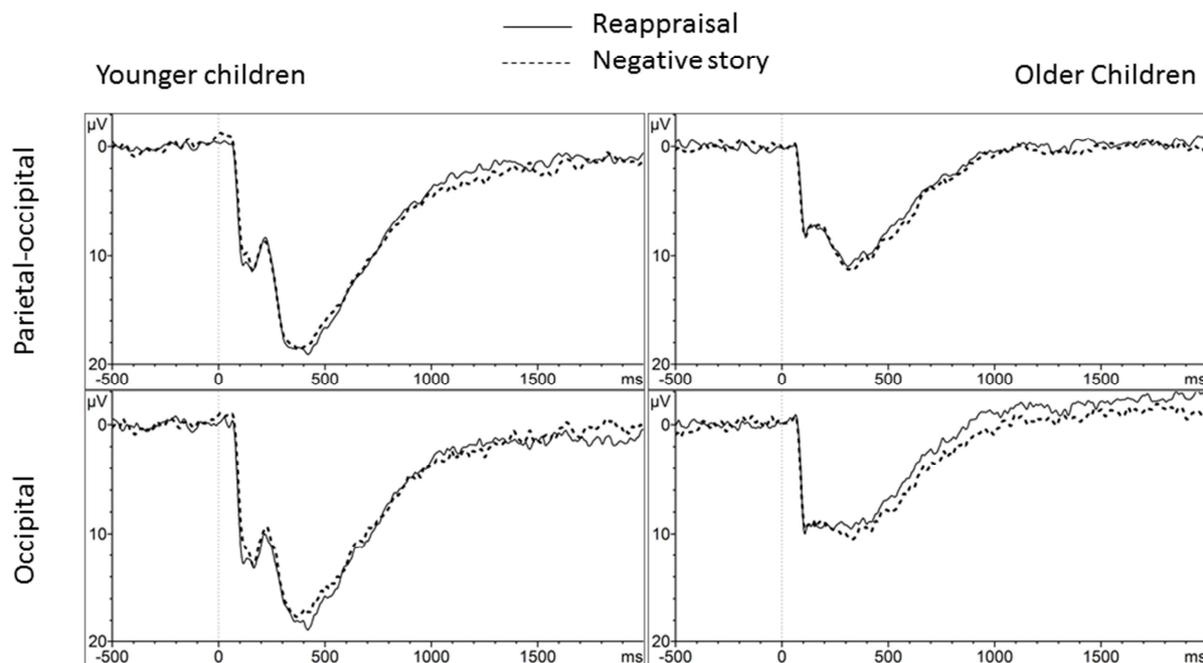
Figure 3. Stimulus-locked ERPs for both age groups elicited by unpleasant pictures after a negative story or reappraisal, pooled on the one hand over parietal-occipital electrode sites (POz, PO3 and PO4) and on the other hand occipital electrode sites (Oz, O1 and O2).

(Figure 3), the LPP was reduced following reappraisal in older children, whereas this was not the case in the younger group; they even seem to show an opposite pattern (although not significantly) with larger LPPs after reappraisal. Further examination of this pattern revealed that the opposite direction of LPP modulation can be mainly attributed to the youngestchildren (8- and 9-year-olds) and that there is a significant linear increase of LPP modulation with increasing age ($\beta = .34$, $p = .008$; see Figure 4).

3.2.2 Middle window.

Again, the main condition effect on the LPP was not significant ($F[1,56] = 1.15$, $p = .288$, $\eta^2 = .02$). A marginally significant condition by sagittal position by age group effect ($F[1,56] = 3.17$, $p = .080$, $\eta^2 = .05$) and a marginally significant condition by sagittal position by lateral
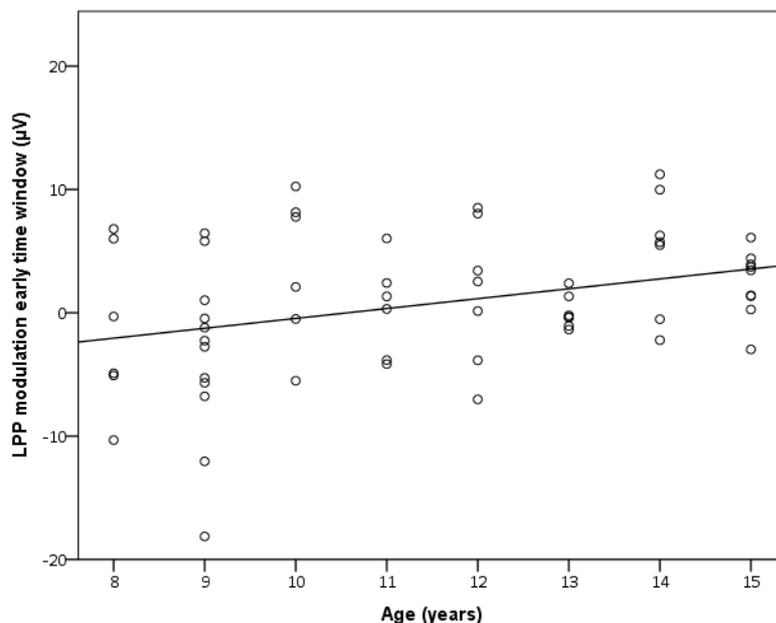

Figure 4. Linear relationship between age and the LPP modulation (pooled over both parietal-occipital and occipital electrodes) in the early time window.

position by age group effect *(F*[2,112] = 2.69, *p* = .072, η^2 = .05) were found. Further testing demonstrated no significant main effect for condition (or any interaction effect with condition) in the younger children (all *p*'s > .10). In the older children, the effect of condition and condition by sagittal position were marginally significant (*F*[1,29] = 3.96, *p* = .056, η^2 = .12 and *F*[1,29] = 3.93, *p* = .057, η^2 = .12 respectively). LPP modulation was significant at occipital (*F*[1,29] = 6.10, *p* = .020, η^2 = .17) but not at parietal-occipital sites (*F*[1,29] = 0.71, *p* = .408, η^2 = .02). Again overall larger LPPs were observed in the 8- to 11-year-olds (*F*[1,56] = 27.78, *p* < .001, η^2 = .33) and in boys (*F*[1,56] = 7.38, *p* = .009, η^2 = .12).

3.2.3 Late window.

The main effect of condition on the LPP was not significant (*F*[1,56] = 2.24, *p* = .140, η^2 = .04). The interaction between condition, sagittal position, lateral position, and age group was marginally significant (*F*[1.80,100.72] = 2.46, *p* = .097, η^2 = .04), however, further testing of this 4-way interaction did not reveal any (main or interaction) effect of condition in either age group. Again, boys and younger children showed larger LPPs in general (*F*[1,56] = 10.09, *p* = .002, η^2 = .15 and *F*[1,56] = 4.48, *p* = .039, η^2 = .07 respectively).

3.3 Self-Reported Reappraisal

Age groups did not differ in their evaluation of reappraisal on the self-report questionnaire (*t*[57] = .79, *p* = .433), as presented in Table 1. As groups differed in LPP modulation in the early time window, correlations between this measure (pooled over both parietal-occipital and occipital positions) and self-reported reappraisal scores were calculated. No significant correlations were found, neither across groups nor per group (all *p*'s > .19), also when age was partialled out (all *p*'s > .28). Correlations between LPP modulation in the middle time

window (pooled over occipital positions) and self-reported reappraisal scores were also not significant (all p's > .22).

4 Discussion

The current cross-sectional study is to our knowledge the first study to investigate developmental changes in neural correlates of cognitive reappraisal (LPP) in a wide age range of children. The results confirmed our hypothesis that the reappraisal induced modulation of the LPP is dependent on age, being present only in older children. The older children showed a significant reduction in LPP amplitude in the early time window (and a marginally significant decrease in the middle time window), whereas younger children did not show LPP modulation following cognitive reappraisal. Results further showed a linear increase in LPP modulation with increasing age. Boys and girls were found to be equally capable of downregulating their neural responses to negative stimuli following reappraisal.

The results are supportive of developmental changes in neural correlates of cognitive reappraisal as indexed by the LPP and indicate that sensitivity of LPP modulation to cognitive reappraisal is highly dependent on the child's age. This finding is not fully in accord with results of Dennis and Hajcak (2009) who did find reappraisal induced reductions in LPP amplitude within children younger than 12 years old, except for the youngest girls in their sample. The only other study that reported LPP modulation following reappraisal in younger children is that by Hua et al. (2015). However, they used a different paradigm and simplified stories (4 words). In contrast, the findings are in line with the majority of studies that included children younger than 12 years old and also failed to find LPP modulation effects (Babkirk et al., 2014; DeCicco et al., 2014; DeCicco et al., 2012; Leventon & Bauer, 2016; Van Cauwenberge et al., 2016), and with a study in 7- to 9-year-olds, that also reported a linear

relationship between age and reappraisal related LPP modulation (DeCicco et al., 2014). Boys

and girls showed similar patterns of LPP modulation. Hence, it seems safe to conclude that

LPP modulation as measured within the current paradigm can be used as a valid index of

emotion regulation in boys and girls but that caution is recommended using it in younger

children, as the LPP modulation seems to become a more reliable index of cognitive

reappraisal with increasing age in children. There may be different reasons for why the index

shows increased reliability with age. To effectively reappraise children must be able to keep

information in their working memory, to retrieve information from their memory and to

monitor the affective change due to the reappraisal (Ochsner and Gross, 2008). Development

of emotion regulation is strongly dependent on maturation of executive functions, such as

attentional control, inhibitory control, working memory, and cognitive flexibility (Rueda &

Paz-Alonso, 2013), which all may contribute to the age differences in LPP modulation by

reappraisal.

Groups did not differ for self-reported reappraisal and self-reported reappraisal scores were

not correlated with LPP modulation. This may relate to the fact that both measures differ in

important aspects. First, the questionnaire retrospectively assesses the use of reappraisal

strategies in daily life over a longer time period, while LPP measurement is based on one

single test session in the lab. Second, it is difficult to disentangle emotional reactivity and

emotion regulation based on questionnaire scores, and the scores may reflect the use of

reappraisal strategies rather than the ability to use them effectively (Cole et al., 2004; Troy et

al., 2010). The difference between both measures also becomes evident in the fact that the

younger and older children did not evaluate their use of reappraisal dissimilar but in contrast

were distinct with respect to the LPP modulation. Hence, it could be that although both age

groups report to use cognitive reappraisal strategies, they do differ in the ability to apply such

a strategy effectively as measured within the current paradigm.

Irrespective of condition, in line with previous research (Kujawa, Klein, & Hajcak, 2012; Kujawa, Klein, & Proudfit, 2013), younger children demonstrated larger LPP amplitudes than older children. This developmental decrease in the amplitude of the LPP could possibly be caused by similar processes as the ones contributing to the reduction in amplitude of the P3, reflecting more efficient neural processing (Kujawa et al., 2013). In addition, boys showed overall larger LPPs, suggestive of enhanced processing of negatively valenced stimuli, which is a novel finding to be replicated as the only other two studies taking gender into account did not report this (Hajcak & Dennis, 2009; Solomon, DeCicco, & Dennis, 2012). Importantly however, LPP modulation was not distinct between boys and girls, indicating equal capability to reappraise negatively valenced stimuli.

Some limitations of the current study need to be mentioned. Similarly as in the paradigm used by Dennis and Hajcak (2009), the picture was presented first, before the reappraising (and negative) story, in order to reduce working memory demands. As a result, cognitive reappraisal as measured in this paradigm does not fully correspond to antecedent-focused reappraisal as defined in the process model of Gross (2015). Pictures were presented also before children heard the story, to help them better attend and understand the interpretations. As antecedent-focused reappraisal is defined by Gross as reappraisal taking place before occurrence of emotional response tendencies, and we asked the children to reappraise after the emotional picture was presented, reappraisal as measured in the current study does not truly reflect Gross' definition of antecedent-focused reappraisal. Another point worth mentioning is that ideally one would compare between a neutral and negative interpretation of the same picture, however the interpretation of the picture when presented the first time has a lasting effect, which would interfere with the interpretation when the picture is presented the second time (MacNamara, Ochsner, & Hajcak, 2011). Therefore, separate pictures were used for the neutral and negative conditions. From the 30 pictures that were used, for each child separately

15 pictures were randomly selected to be presented with a neutral story and 15 with a negative story (see Dennis and Hajcak, 2009). Furthermore, the set of pictures depicted both humans and non-humans. Adult literature has described sex differences in processing of human vs non-humans (Kato & Takeda, 2016). The limited number of trials impeded evaluation of gender-related effects of social versus non-social pictures, which could be the focus of future research. Another limitation concerns the generalizability of the findings to children with an age not included in the present study and emotion regulation strategies other than cognitive reappraisal. Age effects may be different for other emotion regulation strategies, such as attentional deployment or response-focused strategies (e.g., suppression; Gross, 2015). Furthermore, the current study is a cross-sectional study and studies applying a longitudinal design are warranted.

To conclude, the findings of the current study show that LPP modulation can serve as a neural correlate of cognitive reappraisal in boys and girls, but that its sensitivity to reappraisal is age dependent. From 12 years onwards, LPP modulation as measured within the current paradigm seems a valid neural marker of cognitive reappraisal, however caution is recommended using it in younger children.

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