"To make a molehill out of a mountain": An ERP-study on cognitive reappraisal of negative pictures in children with and without ADHD

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Highlights

- Late positive potential (LPP) showed less positive modulation during cognitive reappraisal in ADHD compared to typically developing children
- Children with ADHD reported less use of cognitive reappraisal
- Further research is warranted on the inter-individual variability of LPP modulation in children

Abstract

Objective: We investigated cognitive reappraisal in children with ADHD by means of the late positive potential (LPP) and self-report ratings. We expected diminished LPP modulation following reappraisal and lower self-report scores in children with ADHD.

Methods: Eighteen children with ADHD and 24 typically developing (TD)[1] children (8-12 years) performed a cognitive reappraisal task, while EEG was recorded, and filled out a questionnaire on cognitive reappraisal.

Results: Despite the lack of main reappraisal effects on LPP, the LPP was less positively modulated during reappraisal in ADHD compared to TD children. Children with ADHD rated themselves as using less reappraisal.

Conclusions: Children with ADHD reported less use of reappraisal and could be distinguished from TD children based on LPP modulation. However the lack of main effects of reappraisal on LPP in both groups hinders clear interpretation of this finding and questions the suitability of LPP modulation within the current paradigm as a neural index of reappraisal in children 8-12 years old, and warrants further research on the inter-individual variability and sensitivity of LPP modulation as a neural index of emotion regulation in children.

Significance: This is the first study investigating the LPP during cognitive reappraisal in children with ADHD.

Keywords: ADHD; cognitive reappraisal; emotion regulation; children; Late Positive Potential (LPP)

[1] TD = typically developing

1 Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a prevalent neurodevelopmental condition characterized by symptoms of inattention and/or hyperactivity/impulsivity that interfere with everyday functioning in several domains (American Psychiatric Association, 2013). In addition to these core symptoms, children with ADHD are characterized by emotional dysregulation, representing a major source of impairment, as it plays an important role in social competence and personal wellbeing (Eisenberg et al., 2000; Riley et al., 2006; Wehmeier et al., 2010). Emotional dysregulation is manifested in mood lability, aggressive behavior, negative affect, and temper outbursts (Shaw et al., 2014). These clinical manifestations might reflect either a heightened level and intensity of emotional reactions (reactivity) or impaired top-down emotion regulation (Posner et al., 2011; Shaw et al., 2014). A growing number of studies has focused on emotional dysregulation in children with ADHD. Initially, questionnaires and naturalistic approaches (e.g., observing the child's emotional response to frustrating situations) were employed. These studies are supportive of emotional dysregulation in children with ADHD (for an overview, see Shaw et al., 2014). However, the questionnaires and naturalistic approaches often measure emotional lability and emotional reactions as outcome but not emotion regulation per se. Studies focusing on the top-down component, emotion regulation, are scarce in ADHD.

To tap this top-down component, experimental paradigms have been applied in which children are instructed to perform a cognitive task in the context of distracting emotional information (e.g., positively or negatively valenced pictures presented in the background of a Stroop task or n-back task). These studies showed that children with ADHD have difficulty with inhibiting task-irrelevant emotional information, suggesting emotion regulation impairments (e.g., Köchel et al., 2014; López-Martín et al., 2013; Van Cauwenberge et al., 2015). However, these findings are not conclusive because it has been found that larger emotional interference effects may be related to a generic interference control deficit (equally decreased interference control for emotional and neutral stimuli) rather than a specific emotional deficit in children with ADHD in these paradigms (Van Cauwenberge et al., 2015). Moreover, comorbid oppositional defiant disorder (ODD) symptoms, often present in children with ADHD, were not taken into account in all of the above-cited studies. This may however be crucial for understanding emotion regulation difficulties in ADHD as ODD has been associated with emotional dysregulation (e.g., Stringaris et al., 2010) and thus the presence of ODD symptoms could influence the results. In addition, these paradigms focused on attention modulation as an emotion regulation strategy, but to our knowledge, cognitive reappraisal skills have not been assessed yet in children with ADHD. Research on cognitive reappraisal skills in ADHD is warranted as cognitive reappraisal, attributing another meaning to a situation to reduce its emotional impact, is known to be a very effective strategy and adequate use of this strategy has consistently been associated with better interpersonal functioning and well-being (Gross, 2015; Gross and John, 2003). Furthermore, emotion regulation deficits may be masked when only behavioral performance is taken into account. In studies where both behavioral and neural measures were included, emotional interference deficits could only be demonstrated in children with ADHD at the neural level but not at the behavioral level (López-Martín et al., 2015; Passarotti et al., 2010). Therefore, neural indices may be more sensitive to capture impairments in emotion regulation. Especially electro-encephalography (EEG) seems a promising method to study emotion regulation in children with ADHD as it has an excellent temporal resolution, enabling to study the temporal unfolding of emotion regulation processes (Banaschewski and Brandeis, 2007).

Several researchers have stressed the late positive potential (LPP) as a neural correlate of emotion regulation. The LPP is a positive deflection in the EEG starting approximately

300 ms after stimulus onset and its amplitude is modulated by the emotional intensity of stimuli. In both adults and children larger amplitudes for negatively and positively valenced stimuli compared to neutral stimuli have been observed (Hajcak and Dennis, 2009; Hajcak et al., 2010; Kujawa et al., 2012a, 2012b; Solomon et al., 2012), which is argued to reflect sustained or facilitated attention to, and processing of, emotional events (Dennis, 2010; Hajcak et al., 2010). Crucially, recent work has demonstrated that the LPP decreases after reappraisal, enabling researchers to use this ERP component for studying cognitive reappraisal (e.g., Dennis, 2010; Dennis and Hajcak, 2009; Hajcak and Nieuwenhuis, 2006). In adults, the LPP amplitude consistently decreased after negative pictures combined with a neutral interpretation (reappraisal) relative to negative pictures with a negative interpretation (Foti and Hajcak, 2008; Hajcak et al., 2007; Hajcak et al., 2006; Hajcak and Nieuwenhuis, 2006; MacNamara et al., 2009). A similar LPP modulation after cognitive reappraisal has been reported in children, be it less consistent in younger children (Babkirk et al., 2014; DeCicco et al., 2014; DeCicco et al., 2012; Dennis, 2010; Dennis and Hajcak, 2009; Leventon and Bauer, 2016). Moreover, research has shown that children's reappraisal induced reductions in the LPP were associated with daily life use of more adaptive emotion regulation strategies (Babkirk et al., 2014).

In the current study we examined for the first time the LPP as a neural correlate of cognitive reappraisal in children with ADHD, applying the paradigm as introduced by Dennis and Hajcak (2009). Because previous studies indicated an age-shift around the age of 8 for LPP modulation (DeCicco et al., 2014; Dennis and Hajcak, 2009), the paradigm was applied to children between 8 and 12 years old. We expected children with ADHD to be less able to reappraise negative pictures. Modulation of the LPP after reappraisal is indicative of a reduced impact of the negative stimulus and thus reduced LPP modulation suggests less effective reappraisal (Dennis, 2010). Therefore, we expected children with ADHD, relative to their typically developing peers, to show less LPP modulation. As LPP modulation has been found to be weaker in (younger) girls (Dennis and Hajcak, 2009) and the use of cognitive reappraisal has been reported to be different between boys and girls (Gullone et al., 2010), we included gender in the analyses, however we did not have specific prediction due to the scarcity of available research. Although emotional dysregulation has been associated with both symptom domains, there seems to be a stronger association with hyperactivity/impulsivity symptoms (Maedgen and Carlson, 2000; Sobanski et al., 2010). Hence, we expected less LPP modulation to be particularly associated with severity of ADHD hyperactivity/impulsivity symptoms within the ADHD group. ODD symptoms were taken into account to explore the unique association between ADHD and emotion regulation difficulties. In addition, self-reported reappraisal was assessed and we hypothesized children with ADHD to score lower on this measure, and the score to be positively correlated with LPP modulation.

2 Method

2.1 Participants

Participants in this study were a group of children with an official clinical diagnosis of ADHD, and a gender- and age-matched group of typically developing (TD) children, all between 8 and 12 years old. TD children were without any behavioral or emotional disorder, as reported by the parents. Part of the TD children also participated in a large Flemish longitudinal cohort study, named JOnG! (for details on the aims and the design of the JOnG!-study, see Grietens et al., 2010). The remaining children were recruited through advertisement in schools and therapy centers and in the near environment of the researchers. All children with a high risk for ASD as evaluated by the Social Communication Questionnaire (Rutter et al., 2003; Dutch translation: Warreyn et al., 2004) or an estimated total IQ below 80 (evaluated by an abbreviated version of the Wechsler Intelligence Scale for Children - Third edition - NL; Grégoire, 2000; Wechsler, 1991; Dutch translation: Kort et al., 2005) were excluded. In addition, a (sub)clinical score on one of the ADHD-scales of the Disruptive Behavior Disorder Rating Scale (Pelham et al., 1992; Dutch translation: Oosterlaan et al., 2008) was used as an exclusion criterion for TD children. Children with ADHD were not included if they had a score below the cutoff for both inattention and hyperactivity/impulsivity measured by the Diagnostic Interview Schedule for Children – IV (only in the ADHD group; DISC-IV; Schaffer et al., 2000; Dutch translation: Ferdinand and van der Ende, 2002) or when they were on ADHD medication the day of the experiment. Based on these criteria, three children with ADHD and two TD children were excluded. Due to problems with the acquisition of the EEG-data or because of too many artefacts in the data, the data of two more children with ADHD and one TD child could not be included in further analyses. The final sample consisted of 24 TD children and 18 children with ADHD (descriptives of the sample can be found in Table 1). The children with ADHD had an official clinical diagnosis before entering the study. The ADHD diagnosis was verified and confirmed for all children with ADHD by means of the DISC-IV administered by an experienced clinical psychologist, and eight children with combined type, eight with inattentive type, and two with hyperactive type were identified. In addition, five of these children scored above the cutoff of ODD. Thirteen children took stimulant medication but had a wash-out of 48 hr prior to the experiment.

2.2 Procedure

The study was approved by the ethical committees of both Ghent University and the Catholic University of Leuven. Informed consents were obtained from the parent and the child. A

Table 1

Means and Standard Deviations for Gender Distribution, Age, Estimated IQ and Scores on the DBDRS for the Study Sample

	TD [a] children	Children with ADHD		
Variables	*M (SD)*	*M (SD)*	χ^2 *(df) / t (df)* [e]	*p*
Boys/girls	18/6	14/4	0.04 (1)	.834
Age (years)	9.8 (1.4)	9.8 (1.5)	0.13 (40)	.901
Estimated IQ	103.83 (8.09)	106.33 (11.53)	-0.83 (40)	.413
DBDRS - INATT [b]	10.79 (1.38)	14.28 (1.67)	-7.39 (40)	<.001
DBDRS - HYP/IMP [c]	10.58 (1.18)	14.44 (1.50)	-9.34 (40)	<.001
DBDRS - ODD [d]	10.79 (1.32)	12.67 (1.88)	-3.62 (28.95)	=.001

Note. [a] TD = typically developing children; [b] DBDRS - INATT = score for the inattentive subscale of the DBDRS; [c] DBDRS - HYP/IMP = score for the hyperactive/impulsive subscale of the DBDRS; [d] DBDRS - ODD = score for the subscale ODD of the DBDRS; [e] χ^2 statistic for analyses with gender distribution; *t* statistic for analyses with age, estimated IQ, and scores on questionnaires.

short computer task, outside the scope of this article, was administered before the cognitive reappraisal task. Finally, the rating task was completed by the children. The DISC-IV was administered by an experienced clinical psychologist, which took place during the computer tasks of the child or afterwards at home. The questionnaires for parent and child were filled in at home. If the questionnaires were too difficult for the child, the parents were allowed to explain the items but not to decide on the answers.

2.3 Measures

2.3.1 Cognitive reappraisal task

The cognitive reappraisal task was similar to the one as used by Dennis and Hajcak (2009), and included 30 negative pictures from the International Affective Picture System, suited for children (Center for the Study of Emotion and Attention [CSEA-NIMH], 1999; Lang et al., 2008; McManis et al., 2001). After an initial presentation of 2000 ms, the picture was followed by a black screen combined with a short (5-10 s) auditory story (see Figure 1). The story had the purpose to either provide a neutral interpretation to the picture (neutral 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). After this story the picture was shown again for 2000 ms. Half of the pictures were combined with a neutral story, half with a negative story. All pictures were randomly

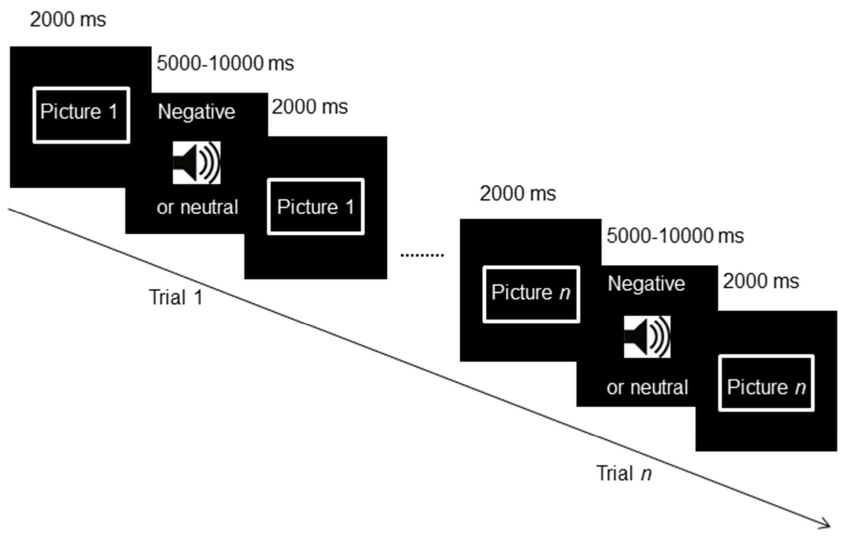

Figure 1. Illustration of the cognitive reappraisal task. The pictures were taken from the IAPS (Lang et al., 2008). Due to copyright reasons, the actual pictures are not shown here.

presented twice, with the same story, in two separate blocks. The interpretation of the first story was different for both blocks (see also Dennis and Hajcak, 2009). The children were instructed to match the picture with the story in their head.

2.3.2 Rating of the pictures

The 30 pictures were rated by the children on valence and arousal using the computer based Self-Assessment Manikin (Bradley and Lang, 1994; Lang, 1980). A 5-point Likert scale from *negative* (1) over *neutral* (3) to *positive* (5) was used to evaluate valence and a scale from *not arousing* (1) to *high arousing* (5) asked for arousal ratings.

2.3.3 Questionnaires

The parents completed the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham et al., 1992; Dutch translation: Oosterlaan et al., 2008). In this 42-item questionnaire the behavior of the child is evaluated by means of a 4-point Likert scale ranging from 0 (*not at all*) to 3 (*very much*), resulting in scores for ADHD-inattention, ADHD-hyperactivity/impulsivity, ODD and conduct disorder.

The children filled in the Emotion Regulation Questionnaire for Children and Adolescents (ERQ-CA; Gullone et al., 2010), a self-report questionnaire on emotion regulation in daily life, translated to Dutch with approved back translation (translation: Van Cauwenberge, Dhar, and Wiersema). It has been demonstrated that the ERQ-CA is reliable and has an adequate convergent validity. The construct validity has been found to be invariant across age and gender (Gullone and Taffe, 2012). Only scores on the reappraisal scale were related to LPP modulation in the task. These scores can vary between 6 and 30. The internal consistency of this scale in the current study was sufficient for the TD and ADHD group (Cronbach's α .71 and .70 respectively).

2.4 EEG-data acquisition and reduction

EEG-data were collected with 128 active 10 mm Ag/AgCl electrodes (EasyCap Active, EasyCap GmbH), placed according to the 10/5 International System (Oostenveld and Praamstra, 2001), and digitized using Brain Vision Recorder software (Version 1.10) with a sample rate of 500 Hz. The ground electrode for the average reference was positioned within the cap at Fpz and eye-movements were recorded through electrodes enclosed in the cap near the eyes and an additional electrode below the right eye. Amplification of the signal with an open pass-band from direct current to 100 Hz was acquired with a QuickAmp amplifier (Brain Products GmbH, Germany). The data were filtered offline with a low cut-off filter of 0.1 Hz, a high cut-off filter of 30 Hz and a notch filter of 50 Hz with Brain Vision Analyzer software (Version 2.0.1). After segmentation (500 ms before to 2000 ms after stimulus onset), ocular artefacts were corrected with the Gratton and Coles algorithm (Gratton et al., 1983) and segments with a gradient above 50 μV/ms or a difference between minimum and maximum exceeding 200 μV over an epoch of 200 ms were removed. In addition, segments with artefacts resulting from activity below 0.5 μV were also removed. Average event-related potentials (ERPs) were calculated for the second presentation of the picture (i.e., after the story) for both conditions (neutral and negative interpretation) separately. The mean amplitude in the 500 ms window prior to picture onset served as baseline. The average ERPs were based on 50-100% of trials (15-30 trials) for most of the children. Nine children had for one or more conditions only 33-50% acceptable trials. However, for these children the ERPs and topographical maps were thoroughly checked and reliable LPPs were observed with the expected topography. Trial acceptance rates did not differ between negative and neutral interpretations ($F(1,37) = 3.69$, $p = .062$) or between groups ($F(1,37) = 0.24$, $p = .630$), and did not differ dependent on the child's age or gender ($F(1,37) = 0.20$, $p = .659$ and $F(1,37) = 2.18$, $p = .149$ respectively). The number of interpolated electrodes did not exceed 10% for any of the children but one (12% of the electrodes were interpolated). Based on previous literature (Babkirk et al., 2014; DeCicco et al., 2012; Dennis and Hajcak, 2009) and visual inspection of the grand averages and topographies, parietal-occipital electrode positions PO3, POz and PO4 were analyzed between 600 ms and 1500 ms after stimulus onset using the mean area amplitude.

2.5 Statistical analyses

To test for group differences in the rating of the pictures, the results of the rating task were analyzed with a 2 (condition: neutral, negative story) x 2 (group: ADHD, TD) repeated measures ANOVA on the dependent variables arousal and valence. To analyze the modulation effect of reappraisal on the LPP, a 2 (condition: neutral, negative story) x 3 (electrode: PO3, POz, PO4) x 2 (group: ADHD, TD) x 2 (gender: boys, girls) repeated measures ANOVA was conducted with LPP amplitude as dependent variable. The univariate test results were reported, corrected with Greenhouse-Geisser in case of violation of the assumption of sphericity. Finally, for the correlational analyses, a difference score was calculated between the amplitude of the LPP after a negative story and the LPP amplitude after the neutral story, both averaged across electrode positions. This difference score represents the reduction in LPP amplitude as a result of reappraisal and hence the effectiveness of reappraisal. Because of the a priori hypothesized directions of the correlations, one-sided Pearson’s correlations were reported between this difference score indicating the LPP modulation and the scores on the reappraisal scale of the ERQ-CA and the scores on the scales of the DBDRS. All the analyses were controlled for symptoms of ODD.

3 Results

3.1 Rating of the pictures

The arousal ratings of the pictures did not differ between conditions ($F(1,40) = 2.32$, $p = .135$, $\eta^2 = .05$) or between groups ($F(1,40) = 2.07$, $p = .158$, $\eta^2 = .05$). Also the group by condition effect was not significant ($F(1,40) = 0.95$, $p = .335$, $\eta^2 = .02$) (see Table 2). The valence of the pictures was judged more negative after a negative story compared to a neutral story ($F(1,40) = 31.66$, $p < .001$, $\eta^2 = .44$). Groups did not differ in this respect ($F(1,40) = 1.37$, $p = .249$, $\eta^2 = .03$ for group; $F(1,40) = 0.18$, $p = .673$, $\eta^2 = .01$ for group by condition).

3.2 Effect of cognitive reappraisal

The LPP topography maps are depicted in Figure 2. No significant main effect of condition was found ($F(1,38) = 0.26$, $p = .616$, $\eta^2 < .01$). However, a main group and a group by condition effect were found ($F(1,38) = 4.96$, $p = .032$, $\eta^2 = .12$ and $F(1,38) = 5.28$, $p = .027$,

Table 2

Means (and Standard Deviations) for the Rating of Arousal and Valence of the Negative Pictures After a Neutral or Negative Story

	TD [a] children		Children with ADHD	
Rating variable	Neutral	Negative	Neutral	Negative
Arousal	3.01 (0.74)	3.23 (0.93)	2.71 (0.90)	2.76 (1.10)
Valence	2.81 (0.62)	2.23 (0.85)	2.55 (0.60)	2.04 (0.61)

Note. [a] TD = typically developing.

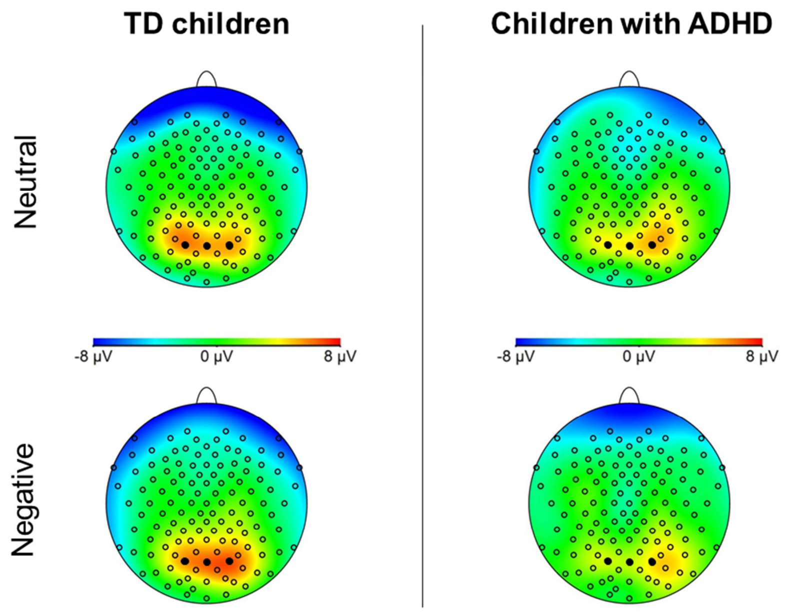

Figure 2. Scalp topography of the LPP (600-1500 ms) after neutral and negative interpretation in TD children and children with ADHD. Electrodes included in the analyses are indicated.

η^2 = .12 respectively), showing overall smaller LPPs and a difference in LPP modulation between groups, with relatively less positive modulation (negative condition – neutral condition) in children with ADHD compared to TD children (see Table 3 and Figure 3). Further testing revealed that, as expected, the effect of condition was not significant for ADHD (F(1,17) = 2.89, p = .107, η^2 = .15). The effect of condition in TD children was however also not significant (F(1,23) = 2.30, p = .143, η^2 = .09). Finally, a main electrode effect emerged (F(2,76) = 3.66, p = .030, η^2 = .09), indicating a right distributed LPP. None of the other effects were significant, including effects related to gender.

To investigate if the results would remain similar if ODD was taken into account, the analyses were repeated with ODD symptoms as a covariate. Whereas the main effects of

Table 3

Means (and Standard Deviations) for the LPP Amplitude (600-1500 ms) After a Neutral or Negative Story at PO3, POz and PO4

Electrode	TD [a] children		Children with ADHD	
	Neutral	Negative	Neutral	Negative
PO3	6.23 (4.71)	5.68 (5.67)	5.19 (5.60)	3.60 (6.17)
POz	4.91 (5.57)	6.70 (4.80)	3.70 (4.77)	1.76 (5.55)
PO4	6.00 (6.04)	7.67 (5.43)	5.97 (5.04)	4.29 (6.68)

Note. [a] TD = typically developing.

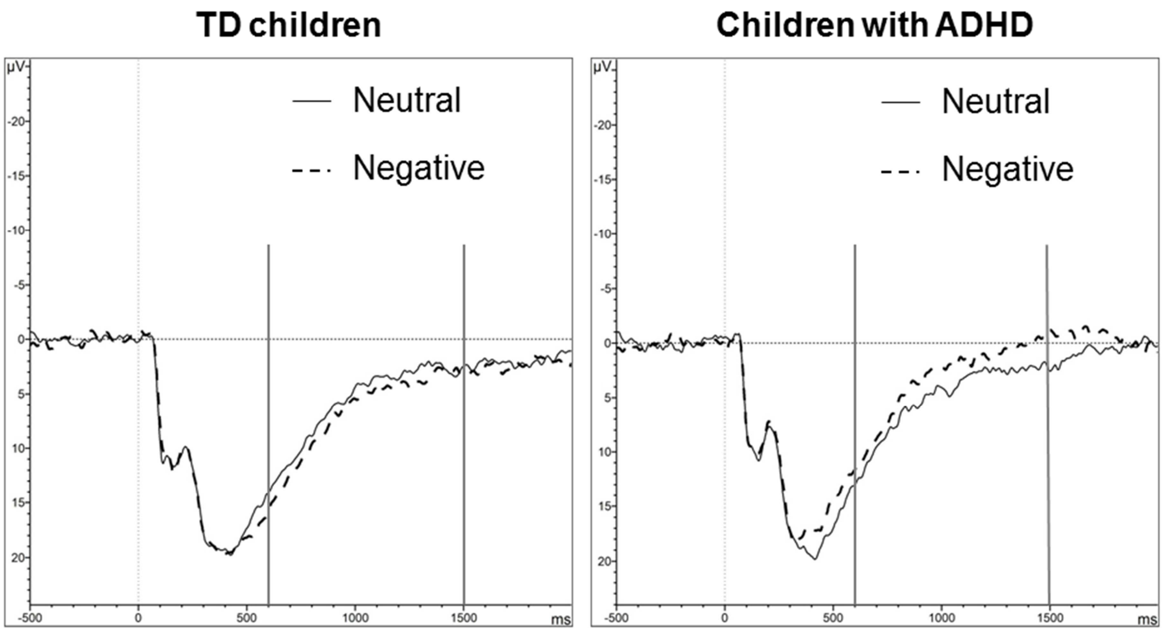

Figure 3. Stimulus-locked ERPs elicited by unpleasant pictures after neutral or negative interpretation pooled over electrode sites PO3, POz and PO4 in TD children and children with ADHD.

group and electrode disappeared ($F(1,37) = 3.26$, $p = .079$, $\eta^2 = .08$ and $F(2,74) = 1.68$, $p = .194$, $\eta^2 = .04$ respectively), crucially, the effect of group by condition remained significant ($F(1,37) = 5.00$, $p = .032$, $\eta^2 = .12$).

The ERPs (Figure 3) suggest that a group difference may be apparent already earlier in time, at the P3 level. However an additional analysis in the time window of 300-600 ms could not confirm this as no significant group effects were found (all *p*'s > .40).

3.3 Correlations with self-reported reappraisal and ADHD symptoms

Children with ADHD rated themselves on the ERQ-CA as using less reappraisal in daily life (ADHD: 17.73 [*SD* = 4.37]; TD: 21.22 [*SD* = 4.03]; $F(1,36) = 6.35$, $p = .016$, $\eta^2 = .15$), even after controlling for ODD ($F(1,35) = 5.98$, $p = .020$, $\eta^2 = .15$). A significant small positive correlation (Cohen, 1988) was found between this reappraisal score and LPP modulation ($r = .28$, $p = .042$, one-tailed), suggesting that more self-reported reappraisal was associated with a larger reappraisal induced modulation effect on the LPP. However, this was for a large part driven by outliers (see Figure 4 for a scatterplot); an additional Spearman's rank correlation analysis, which is more robust for outlier effects, showed no significant association ($\rho = .16$, $p = .166$, one-tailed). In addition, in the ADHD group, no significant correlations were found between LPP modulation and hyperactivity/impulsivity symptoms ($r = -.27$, $p = .136$, one-tailed) or inattentive symptoms ($r = -.05$, $p = .425$, one-tailed). The correlations remained non-significant after controlling for symptoms of ODD (partial correlations); for hyperactivity/impulsivity: $r = -.32$, $p = .218$; for inattention: $r = -.05$, $p = .856$.

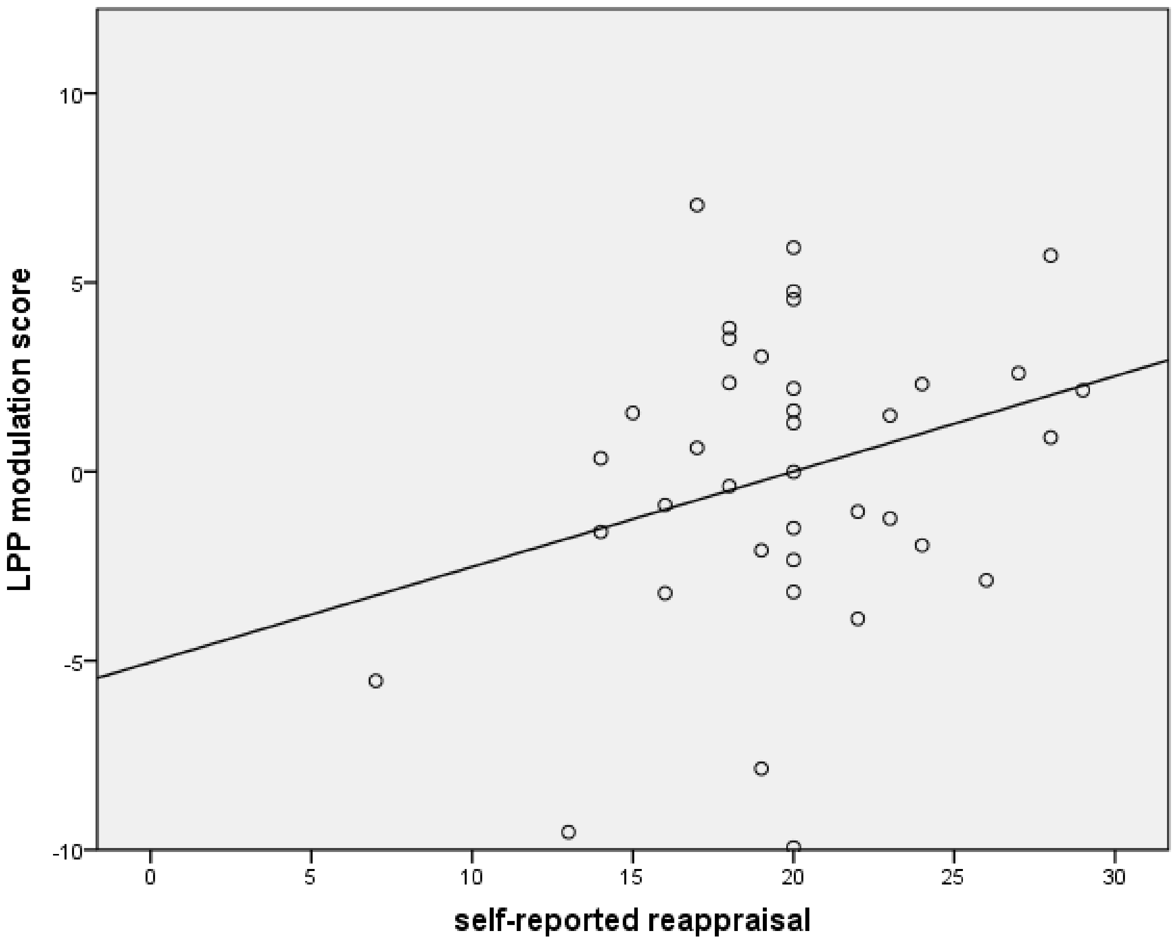

Figure 4. Correlation between the self-reported use of reappraisal in daily life and the LPP modulation score (the LPP after a negative story minus the LPP after a neutral story, pooled over electrode sites PO3, POz and PO4).

4 Discussion

This is the first study investigating the modulation of the LPP after cognitive reappraisal in a sample of children with ADHD compared to TD children. We expected children with ADHD to show less LPP modulation after cognitive reappraisal, which would be in accord with the notion of impaired emotion regulation. We furthermore hypothesized this to be associated with ADHD symptom severity, especially with symptoms of hyperactivity/impulsivity (Maedgen and Carlson, 2000; Sobanski et al., 2010). Lower self-report scores for the use of reappraisal were also hypothesized, while LPP modulation was expected to be positively correlated with self-reports of cognitive reappraisal. A significant interaction effect group x condition on LPP was found, indicating a group difference in LPP modulation. This effect was found independent of gender and ODD symptomatology. In the ADHD group, LPP modulation was not significantly associated with symptom severity. Children with ADHD reported significantly less use of reappraisal. Across groups, LPP modulation seemed to be positively correlated with the administered self-report measure of cognitive reappraisal (assessing the use of reappraisal in daily life); however this effect was not reliable, as it was driven by outliers.

Self-report results showed that children with ADHD reported less use of reappraisal in daily life. This finding is in line with a study by Schmitt et al. (2012), who also demonstrated that children with ADHD reported less use of reappraisal compared to children without ADHD and accords with the literature categorizing cognitive reappraisal as an adaptive emotion regulation strategy that is linked to adaptive functioning and less psychopathology (Aldao et al., 2010; Belden et al., 2015; Carthy et al., 2010; Eisenberg et al., 2000; Garnefski et al., 2007; Zeman et al., 2006).

Although groups differed for LPP modulation as indicated by a significant group x condition effect on LPP modulation, the main condition effect of on LPP was not significant, neither over groups, nor within groups separately. This hinders interpretation of this finding in terms of impaired cognitive reappraisal in children with ADHD and raises questions about the suitability of LPP modulation within the current paradigm as a neural index of reappraisal in children 8-12 years old. Strong supportive evidence for the usefulness of the LPP for studying emotion regulation comes mainly from adult studies, in which it consistently has been shown that using variants of the current task or giving adults the instruction to reappraise unpleasant pictures provides evidence for the effect of reappraisal on the modulation of the LPP (e.g., Foti and Hajcak, 2008; Hajcak and Nieuwenhuis, 2006; MacNamara, et al., 2009). Results in child studies are far from conclusive. Although Dennis and Hajcak (2009), who applied the same paradigm, did find evidence for LPP modulation in TD children, later studies also failed to find a reliable significant effect of reappraisal on the LPP in children (Babkirk et al., 2014; DeCicco et al., 2014; DeCicco et al., 2012; Leventon and Bauer, 2016). These studies were all very similar to the current study, with a highly similar task (pictures, number of trials, etc.) and comparable sample sizes. A possible explanation for the lack of main reappraisal effects on the LPP is the large interindividual variability, not only in the ADHD group but also in TD children, which has also been observed in previous research (Babkirk et al., 2014). The interindividual differences in LPP modulation could relate to several factors, including the age of the children, resulting in variability in the sensitivity of the LPP modulation to capture emotion regulation (Babkirk et al., 2014). Research has shown a lack of reappraisal induced LPP modulation in younger children (DeCicco et al., 2014; Dennis and Hajcak, 2009), suggestive of a lower sensitivity in younger ages. Although an exploratory correlational analysis did not reveal an effect of age on LPP modulation in the current study, studies are needed that systematically investigate the age related sensitivity of the LPP as index of emotion regulation and more broadly address the interindividual variability of LPP modulation and the suitability of this measure as an index of emotion regulation in children.

Based on previous studies, we expected to find an association between the LPP modulation and symptoms of hyperactivity/impulsivity (e.g., Maedgen and Carlson, 2000; Sobanski et al., 2010). However, no significant associations were found, neither with inattention nor with hyperactive-impulsive symptoms. The lack of significant correlations may relate to the sample size in the current study. Larger samples sizes may be needed to provide a better insight into this matter.

In addition to a significant group x condition effect, analyses showed a main group effect for LPP, indicating that children with ADHD showed show overall smaller LPP amplitudes than TD children, corroborating the common finding of smaller P3 like components to non-emotional stimuli in ADHD, suggesting inappropriate attention allocation or aberrant working memory updating for both emotional and non-emotional stimuli (Raz and Dan, 2015; Wiersema et al., 2006), although this effect seems to be attributable to comorbid ODD symptoms, as this effect disappeared after controlling for ODD.

It should be noted that we could not demonstrate an effect of reappraisal on the rating of arousal that took place after completion of the task, while reappraisal did affect valence ratings. It may be that arousal effects were only brief and therefore not found in the ratings of the children. Another possibility is that scoring arousal level was too difficult for the children. Only one other child study included these ratings and could also not evidence differences in arousal after reappraised or negatively interpreted pictures (Leventon and Bauer, 2016). Future research should elaborate on this. It is also important to note that groups did not differ on these effects of reappraisal on the ratings of valence and arousal, suggesting similar emotion regulation abilities in children with ADHD and TD children. However, the comparison between the findings based on behavioral and neural indices should be interpreted with caution. The rating of the valence and arousal of the pictures did not take place during the task and a lot of cognitive processes besides reappraisal such as memory, association processes, social desirable answering, etc. might have contributed to the answer of the child. In addition, it is possible that children with ADHD used another strategy instead of reappraisal during the ERP-task, which resulted in the same rating scores as TD children.

The current study has some limitations. First, the sample size is limited and although it is similar to the ones in previous studies (DeCicco et al., 2014; Dennis and Hajcak, 2009), ADHD is a heterogeneous disorder and hence the findings may not generalize to all children with ADHD. Second, to keep working memory demands low, the picture was also shown previous to the interpretations and thus the reappraisal cannot be seen as fully antecedent-focused (see also Dennis and Hajcak, 2009). Third, there were not enough children with both ADHD and ODD included in the study in order to systematically investigate the effects of comorbid ODD by analyses on subgroups, however, including ODD as a covariate in the analyses did not change the results, indicating that the findings cannot be explained by comorbid ODD symptomatology.

To conclude, this was the first study investigating LPP modulation as a neural correlate of cognitive reappraisal in children with ADHD. LPP modulation successfully distinguished groups, irrespective of gender and comorbid ODD symptomatology. Children with ADHD also reported less use of reappraisal in daily life. The lack of main effects of reappraisal on LPP modulation within the separate groups however complicates interpretation of the LPP effects and warrants further research on the interindividual variability and sensitivity of the LPP as a neural marker of emotion regulation in children.

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