"Turning down the heat": Is poor performance of children with ADHD on tasks tapping "hot" emotional regulation caused by deficits in "cool" executive functions?

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Abstract

Emotional dysregulation in daily life is very common in children with attention deficit hyperactivity disorder (ADHD). It is however not clear whether this reflects a specific deficit or that it may be the result of generic executive function (EF) deficits. The current study addresses this question by means of an emotional working memory (WM) task with 2 memory load conditions and four possible backgrounds (blank screen, neutral, positive or negative picture), which was administered to 38 typically developing children and 29 children with ADHD. Children responded slower on trials when negative pictures were presented at the background versus when neutral pictures were presented, indicating an emotional interference effect; however crucially, groups did not differ in this respect. Reaction times were also slower on trials with a neutral picture as background versus trials without a picture, with children with ADHD showing an enhanced interference effect. There was a main effect of WM load on performance, but it did not interact with interference or group effects. To summarize, the findings indicate a generic interference control deficit in the children with ADHD in the current sample, while they could not provide support for an emotional interference deficit.

What this paper adds: This paper adds to the existing literature on emotion regulation in children with ADHD by addressing the question whether emotional dysregulation in ADHD reflects a specific deficit or whether it may be understood as an integral part of impaired executive functioning. An emotional n-back task with different backgrounds was applied to distinguish between emotional interference and generic interference effects. The findings could not provide support for a specific emotional interference deficit. Rather, a generic interference control deficit was found, which may have important theoretical and clinical implications.

Keywords: ADHD; emotion regulation; interference control; children

1 Introduction

Attention deficit hyperactivity disorder (ADHD) is a very common neurodevelopmental disorder with a childhood onset, which often persists into adulthood (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007; Willcutt, 2012). According to the Diagnostic and Statistical Manual of Mental Disorders 5 (DSM-5), ADHD is characterized by symptoms of inattention and/or hyperactivity and impulsivity (American Psychiatric Association, 2013). Although no longer diagnostic, impaired emotion regulation is common amongst individuals with ADHD throughout the lifespan (Shaw, Stringaris, Nigg, & Leibenluft, 2014) – and believed to be an important element in functional impairment in daily life (e.g., Anastopoulos et al., 2011). Recently, there is a renewed interest in emotion regulation in ADHD. In their review, Shaw et al. (2014) defined emotional dysregulation as excessive and inappropriate emotional reactions with regard to social norms; emotional lability characterized by rapid mood shifts; and disrupted allocation of attention to emotional stimuli. They concluded that some form of emotional dysregulation is present in 25%-45% of children and 30%-70% of adults with ADHD. Evidence for these prevalence rates was found in epidemiological studies based on self- and parent-reports, and studies investigating reactive aggression as a reflection of emotional dysregulation (Shaw et al., 2014). Emotional lability, which is characterized for instance by irritability, hot temper and sudden mood shifts, is often linked with ADHD (e.g., Skirrow et al., 2014; Sobanski et al., 2010). In addition to epidemiological studies, studies using frustration-inducing tasks to provoke emotional dysregulation have demonstrated that children with ADHD are characterized by less effective emotion regulation (less use of accommodation and more use of negative responses) and more intense emotional expression than typically developing children (e.g., Maedgen & Carlson, 2000; Melnick & Hinshaw, 2000; Walcott & Landau, 2004).

The presence of emotional dysregulation in ADHD has been linked to dysregulation of underlying neuropsychological processes such as executive functions (EFs) (Barkley, 1997). In domains such as response inhibition and working memory (WM), EF deficits have been identified in ADHD (Lijffijt, Kenemans, Verbaten, & van Engeland, 2005; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). In daily life however cognitive control often has to be applied in situations when individuals have to process affectively charged stimuli in an emotionally salient environment. In this sense emotion regulation is likely to be underpinned by broader aspects of self-regulation and executive control (Rothbart & Bates, 2006). As a result, emotion regulation has been broadly defined as: ‘‘the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goals'' (Thompson, 1994, p. 27-28). EFs are therefore likely to be important for effective emotion regulation (Ochsner & Gross, 2007) as they provide goal maintenance and inhibition of irrelevant (emotional) distractors. Nevertheless, debate continues with regard to whether emotion regulation is an integral part of EF or has an influence beyond EF as well as on how functions in these two domains are interrelated in ADHD. The key question appears to be: Is emotional dysregulation in ADHD the result of generic EF deficits (so called *cool EF*) or has it a distinctive emotional component that is specifically impaired in the disorder (so called *hot EF*)? Interestingly, recent evidence suggests that there is only a partial overlap between emotion regulation problems and EF deficits in predicting ADHD, as emotion regulation independently contributed to the distinction between children with ADHD and typically developing children (Banaschewski et al., 2012; Berlin, Bohlin, Nyberg, & Janols, 2004; Sjöwall, Roth, Lindqvist, & Thorell, 2013).

Recently, researchers have started to study emotion regulation by using EF tasks that include an emotional dimension. However, so far only a few studies have applied emotional EF tasks in ADHD, and although results in general confirm disrupted emotion regulation, findings across studies are not fully consistent. Köchel, Leutgeb, and Schienle (2014) used an emotional go/no-go task and found an impairment to inhibit responses toward angry faces in children with ADHD compared to healthy controls. In another study, a digit categorization task was used with emotional and neutral pictures in the background. Boys with ADHD were found to be slower when confronted with emotional distractors compared to neutral distractors, whereas typically developing controls showed no such effect (López-Martín, Albert, Fernández-Jaén, & Carretié, 2013). A study by Posner et al. (2011) reported a greater interference effect for error rates in adolescents with ADHD compared to typically developing controls when negative words were presented in an emotional stroop task. In addition, the adolescents with ADHD also experienced a greater cognitive distraction. In contrast, no differences in emotional interference between children with ADHD and typically developing children were observed by Passarotti, Sweeney and Pavuluri, who applied a WM task (n-back) with emotional faces (2010b), and an emotional stroop task in another study (2010a). The, to our knowledge, only study on adults reported that subjects with ADHD exhibited lower rates of accuracy in a n-back task compared to control subjects, indicating enhanced distractibility by emotionally salient stimuli (Marx et al., 2011). Finally, the study of Passarotti et al. (2010a) found ADHD-related reduced activity in the ventrolateral prefrontal cortex despite the lack of differences in behavioral performance, which may indicate the use of compensatory strategies.

In the current study, an emotional n-back task was used to study emotion regulation in children with ADHD (Ladouceur et al., 2005). Participants had to perform a non-emotional WM task while irrelevant emotional information appeared in the background. Participants with weakened abilities in regulating their responses to ignore the emotional information were expected to produce slowed reaction times or lower accuracy in high emotion conditions. In contrast with previous studies comparing neutral with positive and/or negative stimuli, we included a fourth condition in this task, resulting in four backgrounds: a black screen, a neutral picture, a negative picture and a positive picture. The inclusion of a condition without any background information made it possible to distinguish a general interference deficit (whereby any distracting information affects performance – a situation commonly seen in ADHD) from a specific problem of emotional interference (whereby especially emotionally charged stimuli affect performance). More specifically, it was predicted that if children with ADHD have difficulties specifically during emotion regulation tasks, any general effect of neutral background distractors would be exacerbated when strong, arousing emotional content is added. Their performance would deteriorate significantly more on trials with emotionally charged distractors compared to neutral distractors than on neutral trials compared to no information trials. We also incorporated two memory-load conditions —no memory load (0-back) and memory load (1-back)— to examine the distinct impact of memory load on emotion regulation abilities.

2 Method

2.1 Participants

Approximately half of the children included in this study participated in a larger cohort study of the Flemish government, named ‘JOnG!’ (http://www.steunpuntwvg.be/jong). The current study is only one part of this larger study, carried out by the universities of Ghent and Leuven and approved by the ethical committees of both universities. More information about the design of the larger cohort study can be found in Grietens, Hoppenbrouwers, Desoete, Wiersema, and Van Leeuwen (2010). Children whose parents indicated that they had a clinical diagnosis of ADHD were included in the current study, as well as typically developing (TD) children without any emotional, behavioral or developmental disorder. Children in both groups were between the age of 8 and 15 years old. Additional participants were recruited through word of mouth and advertisement via the experimenters, resulting in a total of 83 children, 44 TD children and 39 children with ADHD. ADHD diagnosis was verified by means of the disruptive behavior disorders module of the Diagnostic Interview Schedule for Children - IV (Schaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000; Dutch translation: Ferdinand & van der Ende, 1998). This interview, based on the criteria of the DSM-IV-TR, was administered to the parents of children with a clinical ADHD diagnosis. Thirty-three of the 39 children met the criteria for ADHD of whom 15 had ADHD combined type, 14 ADHD inattentive type, and 4 hyperactive-impulsive type. The remaining 6 children were excluded from the study, because they did not meet the diagnostic criteria for ADHD. In addition, 11 children were identified as having comorbid oppositional defiant disorder (ODD). The parents of one child also reported a developmental coordination disorder and the parents of six children reported a learning disorder. Children with ADHD, who were taking medication (23 used methylphenidate, no other medication was used), were medication free at least 24 hours prior to the experiment. All the children were required to have a total IQ of 80 or more and were not allowed to score above the cut off of the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003; Dutch translation: Warreyn, Raymaekers, & Roeyers, 2004), a screener for symptoms of autism spectrum disorders as defined by DSM-IV-TR. Intelligence was evaluated by an abbreviated version of the Wechsler Intelligence Scale for Children - Third edition - NL, including the subtests similarities, picture arrangement, block design, and vocabulary (Grégoire, 2000; Wechsler, 1991; Dutch translation: Kort et al., 2005). In addition, children in the TD group had to score within the normal range of the Disruptive Behavior Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan et al., 2008) for DSM-IV-TR-symptoms of ADHD. Due to these criteria, 9 children were excluded (5 TD children and 3 with ADHD). One more TD child was excluded from the analyses because he did not follow the instructions and performed the wrong memory load task in one block. The characteristics of the 38 remaining TD children (25 boys) and the 29 children with ADHD (20 boys) can be found in Table 1.

Table 1

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

	TD		ADHD			
Variables	*M*	*SD*	*M*	*SD*	χ^2 *(df) / t (df)* [a]	*p*
Boys/girls	25/13		20/9		.07 (1)	.78
Age (years)	11.18	2.60	11.03	2.67	.23 (65)	.82
Estimated IQ	106.84	13.76	103.14	12.08	1.15 (65)	.25
DBDRS - INATT	10.92	1.24	14.28	1.69	-9.39 (65)	<.001
DBDRS - HYP/IMP	10.45	.95	13.96	2.55	-6.96 (32.58)	<.001
SCQ - TOT	4.39	3.43	6.89	3.84	-2.97 (65)	.004

Note. TD = typically developing children; DBDRS - INATT = standard score for the inattentive subscale of the Disruptive Behavior Disorder Rating Scale; DBDRS - HYP/IMP = standard score for the hyperactive/impulsive subscale of the Disruptive Behavior Disorder Rating Scale; SCQ - TOT = total score for the Social Communication Questionnaire.

[a] χ^2 statistic for analyses with gender distribution; *t* statistic for analyses with age, estimated IQ, and scores on questionnaires.

2.2 Measures

2.2.1 Emotional n-back task (E-n-back).

The E-n-back task used in the current study is based on the task used by Ladouceur et al. (2005) who in turn adopted it from Casey, Thomas, Welsh, Livnat, and Eccard (2000). It is a modified WM task (n-back task) in which a pseudorandom sequence of letters is presented and the participants are asked to respond to a pre-specified letter. WM load can be adapted by increasing the number of letters a child has to remember to match the target letter. We applied two memory load conditions: a 0-back condition and a 1-back condition. The 0-back condition requires no WM. The child has to react when a specific letter appears on the screen. In the 1-back condition, a response is inquired when the same letter is presented in two successive trials.

Four different backgrounds were used in the E-n-back task: a black screen (no picture), a neutral picture (e.g., a spoon, a chair), a positive picture (e.g., chocolate, smiling children) and a negative picture (e.g. a snake, a plane crash). The pictures were selected from the International Affective Picture System (IAPS; Center for the Study of Emotion and Attention [CSEA-NIMH], 1999; Lang, Bradley, & Cuthbert, 2008) and were ensured to be suitable for the use in children (McManis, Bradley, Berg, Cuthbert, & Lang, 2001). A set of 30 neutral, 30 positive and 30 negative pictures was used. Each memory load condition (0-back, 1-back) was combined with each background (black screen, neutral picture, positive picture, negative picture) resulting in eight blocks of 16 trials each.

2.2.2 Rating of the pictures

The set of 90 pictures was evaluated by the children using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994; Lang, 1980) for both valence and arousal in two separate conditions on a 5-point Likert scale from *negative* (1) over *neutral* (3) to *positive* (5) and from *not arousing* (1) to *high arousing* (5).

2.3 Procedure

The children completed two computer tasks (the WM task and the rating task) and a short version of an intelligence test. A third computer task, independent of the other tasks, lies beyond the scope of this manuscript. The computer tasks were administered in a fixed order with the WM task first, prior to the intelligence test. The parents were interviewed by an experienced psychologist when the child performed the computer tests.

The E-n-back task and the rating task were programmed in Inquisit (2006). The tasks had written instructions on the screen but these instructions were also explained verbally to the children to ascertain their comprehension of the task. The E-n-back task started with two practice blocks, one for each memory load condition. During these practice blocks a black screen was presented as background. Children were told that they would see a sequence of letters in the middle of the screen and that they had to press the space bar as soon as they saw the letter M (0-back) or as soon as the letter they saw was identical as the previous one (1-back). After the practice blocks it was explained that they would have to perform these tasks alternately and that pictures would be presented in the background, which they should ignore. Before each block, the instruction to respond to a specified letter or to two identical alternate letters was displayed on the screen. Each trial started with the presentation of a letter on one of the four backgrounds (black screen or picture). After 500 ms only the background remained visible for another 2500 ms or until the child pressed the space bar. The sequence of letters was pseudo randomized whereas the pictures were randomized within each block and the order of blocks was randomized for each participant (see also Ladouceur et al., 2005). The order of conditions (arousal and valence) in the rating task was randomized as were the 90 pictures within each condition.

2.4 Statistical Analyses

The valence and arousal ratings were analyzed with a 3 (Picture type: neutral picture, positive picture, negative picture) x 2 (Group: ADHD and TD children) ANOVA on valence and arousal with picture type as within-subject variable and group as between-subject variable. The *F*-values of the multivariate tests are reported because of violation of the assumption of sphericity. In order to address our specific hypotheses of a generic interference deficit versus a specific emotion regulation deficit we used two separate repeated measures ANOVAs: a 2 (Memory Load: 0-back and 1-back) x 3 (Distractor Type: neutral picture, positive picture, negative picture) x 2 (Group: ADHD and TD children) ANOVA and a 2 (Memory Load: 0-back and 1-back) x 2 (Distractor Type: black screen and neutral picture) x 2 (Group: ADHD and TD children) ANOVA. Memory load and distractor type were the within-subject variables and group the between-subject variable. Both reaction times (RTs) and accuracy scores were analyzed. To control for age, additional analyses were performed with age as a covariate. Also, analyses were repeated excluding children with ADHD and comorbid ODD. The F-values of the multivariate tests are reported because the assumption of sphericity was not always met. Significant effects were further evaluated using ANOVAs or post-hoc comparisons with Bonferroni correction. Finally, in the ADHD group spearman correlations between ADHD symptomatology and the interference effects were calculated.

3 Results

3.1 Rating of the emotional stimuli

Table 2 presents the means and standard deviations of the ratings for valence and arousal for both groups and each type of picture. The repeated measures ANOVA for valence revealed a main effect of picture type ($F(2,64) = 200.37$, $p < .001$). The effects of group ($F(1,65) = .011$, $p = .92$) and picture type by group ($F(2,64) = .023$, $p = .48$) were not significant. The positive pictures were rated more positively than the neutral ($p < .001$) and negative pictures ($p < .001$). The negative pictures were rated more negatively than the neutral ones ($p < .001$). There was a significant main effect of picture type for the ratings of arousal as well ($F(2,64) = 142.23$, $p < .001$). Post hoc tests indicated significantly different ratings for the arousal of neutral versus positive pictures ($p < .001$), neutral versus negative pictures ($p < .001$) and positive versus negative pictures ($p = .022$). The neutral pictures were assessed as being the least arousing, the negative pictures the most arousing, and the positive pictures in between. The effect of group and the interaction effect of picture type and group were again not significant ($F(1,65) = 3.39$, $p = .070$ and $F(2,64) = 2.39$, $p = .10$ respectively). The trend was driven by a difference in arousal ratings for positive pictures ($F(1,65) = 4.84$, $p = .031$; children with ADHD rated positive pictures as more arousing) and to a lesser extent by a difference in ratings for neutral pictures ($F(1,65) = 3.01$, $p = .087$; children with ADHD tended to rate neutral pictures as more arousing). There was no difference in the arousal ratings for negative pictures ($F(1,65) = .25$, $p = .62$).

Table 2

Means (and Standard Deviations) for the Rating of Arousal and Valence of Negative, Neutral and Positive Pictures

	TD			ADHD		
Rating variable	Negative	Neutral	Positive	Negative	Neutral	Positive
Valence	1.83 (.70)	2.98 (.57)	4.20 (.63)	1.85 (.58)	2.91 (.58)	4.27 (.42)
Arousal	3.69 (.87)	1.43 (.60)	2.93 (1.10)	3.58 (.89)	1.70 (.67)	3.48 (.87)

Note. TD = typically developing children.

3.2 Performance on the E-n-back task

An overall repeated measures ANOVA including all four distractor types revealed a significant interaction effect of group and distractor type ($F(3,57) = 3.73$, $p = .016$). This interaction was further analyzed with two separate repeated measures ANOVAs in order to address our specific hypotheses of a generic interference deficit versus a specific emotion regulation deficit. In the ANOVA, comparing neutral to emotional pictures, main effects on RT were found for memory load ($F(1,59) = 4.77$, $p = .033$) and distractor type ($F(2,58) = 9.35$, $p < .001$). Responses were slower in the 1-back than in the 0-back condition (640.52 ms and 622.03 ms respectively) and as demonstrated in Figure 1, comparisons revealed slower RT for negative compared to neutral and positive pictures ($p < .001$ and $p = .005$ respectively). A main group effect indicated that children with ADHD reacted in general slower than TD children ($F(1,59) = 6.75$, $p = .012$). The interaction between group and distractor type was however not significant ($F(2,58) = 1.15$, $p = .32$) neither was any other interaction effect. Entering age as a covariate did not change any of the significant effects. To control for comorbidity with ODD, we excluded the children with ADHD and comorbid ODD (n = 11) because our sample size is too small to compare a group with and without ODD.

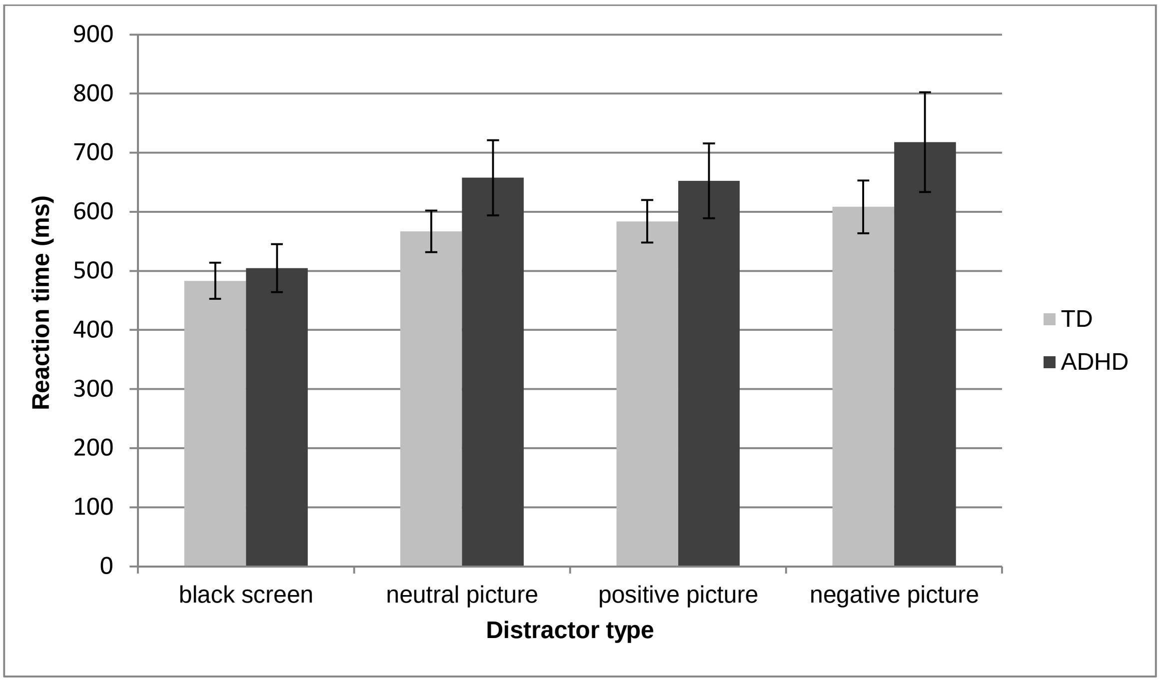

Figure 1. Estimated marginal means and 95% confidence intervals for reaction time for the different distractor types.

Excluding the children with comorbid ODD did not importantly change the results. Only the main effect of load became marginally significant ($F(1,50) = 3.27$, $p = .076$). Exclusion of the children with the hyperactive / impulsive type of ADHD (n = 4), who might be characterized by different cognitive deficits than the other subtypes (e.g., Chhabildas, Pennington, & Willcutt, 2001; Schmitz et al., 2002), also did not change the results.

Results of the second analysis (comparing a black screen versus neutral pictures) revealed a significant main effect of distractor type (slower responses when a neutral picture was presented) and of group (children with ADHD being slower) ($F(1,62) = 90.75$, $p < .001$ and $F(1,62) = 5.20$, $p = .026$ respectively). In addition, a significant distractor type by group effect was observed ($F(1,62) = 4.35$, $p = .041$) indicating a greater difference in RT between a black screen and a neutral picture in children with ADHD compared to TD children, resulting from slower responding of children with ADHD when a neutral picture was presented ($p = .011$), while being equally fast when a black screen was used as background ($p = .16$). Hence, together these results illustrate that the children with ADHD were more distracted when pictures were presented in the background but irrespective of the valence of the pictures. There were no significant effects of WM load. Entering age as a covariate again did not change any of the significant results. Excluding the children with ADHD comorbid with ODD or the children with the hyperactive / impulsive type of ADHD, also did not change the results. Although there had been a wash-out of 24 hours prior to testing, the effects of medication use were explored by entering medication use as a covariate and by removing those children who used medication on a regular base. None of the results changed.

Correlational analyses in the ADHD group between ADHD symptomatology (as measured by the DISC-IV and DBDRS) and the interference effect (RT of negative or positive trials minus RT of neutral trials and RT of neutral trials minus RT of black trials) revealed no significant correlations.

Accuracy was very high in both groups for all conditions (TD > 96%; ADHD > 93%) suggesting ceiling effects, hence results regarding accuracy cannot be reliably interpreted.

4 Discussion

In the current study we aimed to investigate emotion regulation in children with ADHD, more specifically, we asked the question: Is the ability to suppress attention to task irrelevant distractors, which has been shown before in previous studies, exacerbated when the content of those distractors is emotional in nature? Put in another way, is apparent evidence of emotional dysregulation due to fundamental deficits in interference control that children with ADHD also show on emotionally neutral tasks? The data from the current study indicate a generic problem with interference control in our sample of children with ADHD whereas a specific emotion regulation deficit could not be statistically proven.

The results show a generic interference control deficit in children with ADHD. Poor interference control has been argued to be one of the core deficits of ADHD (Barkley, 1997) and many studies have indeed found support for an interference control deficit, although findings across studies are not fully consistent (for meta-analyses, see Lansbergen, Kenemans, & van Engeland, 2007; Mullane, Corkum, Klein, & McLaughlin, 2009; Schwartz & Verhaeghen, 2008; van Mourik, Oosterlaan, & Sergeant, 2005). The mixed findings may be explained by several factors, such as the task used, the calculation of the interference effect, and the heterogeneity of ADHD. For example, the Stroop Color-Word Interference Test is often used to assess interference control in ADHD, which according to some researchers is not a valid measure of interference control in ADHD, as differences in reading ability or naming speed may confound interference scores (van Mourik et al., 2005). Findings from studies incorporating other paradigms such as the Erikson Flanker Task may be more (but also not fully) consistent (Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009; Mullane et al., 2009; Samyn, Wiersema, Bijttebier, & Roeyers, 2014). The findings of weakened inhibition of task-irrelevant backgrounds in children with ADHD in the current study, using an n-back task, adds to the evidence of an interference control deficit in ADHD.

The enhanced distracting effect of stimuli in children with ADHD has in previous studies been related to the arousal level of the stimuli (López-Martín et al., 2013). One could therefore ask the question whether an arousal explanation can also account for the findings in the current study, as a neutral picture as background may be more arousing than a black screen. Children with ADHD tended to report higher arousal ratings for the neutral pictures than TD children. An arousal explanation seems unlikely though, because one would expect an increased distractibility for negative and positive versus neutral backgrounds as well, which was not found. Furthermore, additional correlation analyses were not indicative for a relationship between the interference control effect and arousal ratings.

Importantly, also adding emotional valence to background pictures did not exacerbate the interference deficit in our sample of children with ADHD. This finding does not fit with the hypothesis that children with ADHD would especially show an inability to suppress attention to task irrelevant emotional distractors and that emotion regulation is an independent contributor to symptoms of ADHD beyond cold EFs (Berlin et al., 2004; Sjöwall et al., 2013). However, the lack of such an effect may be attributed to the limited number of participants and hence limited power and the findings may not generalize to other samples of ADHD.

The absence of a group difference in emotional-specific interference is in line with some studies (Passarotti et al., 2010a, 2010b) but does not correspond to others where emotional interference has been shown when individuals with ADHD were performing EF tasks (Köchel et al., 2014; López-Martín et al., 2013; Marx et al., 2011; Posner et al., 2011).

There are several factors that may have contributed to the inconsistent findings across previous studies or the absence of emotion-induced dysregulation in ADHD in the current study. It may be that differential emotional interference effects may appear only when certain EF paradigms are applied, which would raise doubts about a general emotion regulation problem. The findings from the existing studies do however not provide us with enough information to support this notion, and further research administering different emotional EF tasks in a group of children with ADHD is warranted to shed a light on this issue. One could also argue that in the current study perhaps the salience of the pictures presented was not sufficiently high. However, despite the fact that groups did not differ in this respect, emotional interference effects were present in the current study (negative backgrounds eliciting slower responses than neutral backgrounds). In addition, a greater interference effect was found for ADHD when comparing the neutral versus no background condition. Hence, these observations argue against such an interpretation.

Differences in sample characteristics may also account for inconsistencies in results across studies. First of all, age could play a role because the ability to regulate emotions increases from early childhood to adolescence (Zeman, Cassano, Perry-Parrish, & Stegall, 2006).

Entering age as a covariate did however not change any of the significant results in the current study. There are also differences between studies in gender ratio, distribution of subtypes and the presence of comorbid disruptive behavior disorders. Gender ratio may affect the results because previous studies found girls to be more reactive to unpleasant pictures and to experience more difficulties in regulating negative emotions than boys (Bender, Reinholdt-Dunne, Esbjørn, & Pons, 2012; McManis et al., 2001; Neumann, van Lier, Gratz, & Koot, 2010; Suveg & Zeman, 2004). It should however be noted that in the current study both groups had an equal gender ratio, and the fact that earlier studies that included exclusively boys did also find emotion regulation deficits in ADHD, goes against this view (Köchel et al., 2014; López-Martín et al., 2013). With respect to subtypes, one previous study attempted to evaluate unique contribution of subtypes and reported a link between emotion regulation problems and symptoms of hyperactivity/impulsivity but not symptoms of inattention (Maedgen & Carlson, 2000). Due to our restricted sample size we could not investigate whether our results would be different for different subtypes. Because it has been argued that the hyperactive / impulsive type of ADHD may not be associated with the same cognitive deficits as the other subtypes (e.g., Chhabildas et al., 2001; Schmitz et al., 2002), the data were reanalyzed excluding the children with the hyperactive / impulsive type. This did however not change any of the results. In addition, correlations between ADHD symptomatology and the interference effects were calculated. No association was found between symptoms of inattention or hyperactivity / impulsivity and the generic interference effect, or between ADHD symptoms and the emotional interference effect. Our sample size might however been too small to detect significant correlations. Hence, the possible influence of different subtypes warrants further research. Finally, comorbidity with disruptive behavior disorders may have influenced the results. Melnick and Hinshaw (2000) reported maladaptive emotional coping in children with ADHD and high comorbid aggression but not in children with ADHD and low comorbid aggression. In addition, it has been suggested that abnormalities in hot EF are associated with disruptive behavior disorders, and less with ADHD (Rubia, 2011). Unfortunately, there were not enough children with comorbid oppositional defiant disorder (ODD) in the current study to systematically compare children with ADHD with and without comorbid ODD and further studies are needed to address this issue. An additional analysis, excluding the children with comorbid ODD did however reveal that the general interference deficit remained in ADHD, indicating that this effect cannot be attributed to comorbid ODD. Since medication use could also have had an influence despite the washout period of 24 hours, the effect of medication use was taken into account in additional analyses. The results remained the same.

One of the important strengths of the current study is the inclusion of the no background condition as a result of which a clear distinction could be made between generic interference effects and specific interference effects of emotional information. Also, the children rated the arousal and valence level of the stimuli used, which is often lacking in other studies (e.g., Ladouceur et al., 2005). In addition, children were recruited in such a way that groups were matched for age, gender and IQ, and it was made sure that the group of TD children did not exhibit behavioral or emotional problems. Because previous studies were sometimes restricted to boys and children with ADHD combined type, the current study included both genders and all subtypes to obtain a more complete picture of emotion regulation in ADHD. However, the number of participants hampers direct comparisons of gender and different subtypes, and future studies are warranted to evaluate gender and subtypes effects. In addition, the sample size was not large enough to give statistical power to test all possible factors that may have contributed to the findings in the current study (see above). Also, due to time limits, only one module of the DISC was administered, limiting the knowledge on other comorbid disorders (e.g., depression, anxiety) that could be associated with impairments in emotional interference control. A number of other limitations also have to be noted.

First, the number of trials per block was limited and future studies should include more trials to increase reliability. Second, accuracy was not sensitive to the background manipulations (see also Ladouceur et al., 2005), due to ceiling effects. In addition, manipulation of WM load was not successful and stronger manipulations may be needed in future studies. Third, across groups, increased interference was found for negative pictures but not for positive pictures, which may be explained by negative pictures being rated as more arousing than positive ones. Fourth, here we only examined one aspect of emotion regulation, namely inhibition of irrelevant emotional distracters, and we cannot generalize our findings to other emotion regulation strategies such as cognitive reappraisal. Fifth, more importantly, ADHD is a clinically and etiologically heterogeneous disorder and therefore the current findings may not generalize to the ADHD population as a whole or to other ADHD samples. Finally, to exclude the possibility that at the behavioral level no deficit was apparent because of compensatory strategies (Passarotti et al., 2010a), studies may need to adopt neuroimaging measures (e.g., electroencephalography, functional Magnetic Resonance Imaging).

Our findings may have clinical implications, as increased distractibility to emotionally valenced stimuli in children with ADHD in clinical settings and daily life may suggest a specific emotion regulation problem in these children. We could not reject the null-hypothesis with regard to emotional interference, meaning that there is not enough support within the current study for a specific emotional interference deficit in children with ADHD. The findings however indicate a generic interference control deficit in the current sample of children with ADHD, which adds to the existing literature on interference control deficits in ADHD (e.g., Lansbergen et al., 2007; Mullane et al., 2009). Future research is warranted investigating the relationship between emotional dysregulation in daily life and generic interference control difficulties in individuals with ADHD.

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