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Emotion Comprehension and Executive Functions in Children with Attention-Deficit/Hyperactivity Disorder[1]

Abstract

Attention-Deficit/Hyperactivity Disorder (ADHD) was shown to be associated with an increased risk for delinquency and legal problems. Executive dysfunction and emotional dysregulation may be connected to this risk. However, less is known about the relationship between emotion comprehension and executive functioning in children with ADHD. The study aims to assess this relationship. A clinical sample of 133 children was assessed by the Test of Emotion Comprehension (TEC) and the Test of Attentional Performance for Children. Age was positively related to TEC total score, but no gender differences were found. Higher scores in TEC were related to lower variability of performance, and less error in KiTAP Divided Attention and Flexibility tasks. Emotion comprehension skills might be related to cool executive functioning, such as the ability to pay attention to two tasks at once and the ability to shift attention between different objects or levels of focus. Training executive functions in children with ADHD may enhance their emotional competence and may add to a better outcome.

Keywords: attention-deficit/hyperactivity disorder, emotion comprehension, executive function, school-aged children

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Introduction

Attention-deficit/hyperactivity disorder

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterised by attention deficit, hyperactivity and impulsivity (American Psychiatric Association 2013). ADHD is one of the most commonly diagnosed neuropsychiatric diseases in children, with a broad phenotypic spectrum and various severity (Dyck–Piek 2014). Diagnostic criteria based on the Diagnostic and Statistical Manual of the American Psychiatric Association, fifth edition (DSM-5, APA, 2013) include the presence of at least six symptoms from the attention deficit and/or hyperactivity/impulsivity symptom groups (including 9–9 symptoms each) for at least 6 months with their onset before ages 12 years and significant functional impairment in at least two domains. ADHD is associated with a high prevalence of other neuropsychiatric disorders. Specific learning disorders are one of the most common comorbidities as they are observed in up to 50% of all ADHD cases (Spencer 2006). A wide spectrum of accompanying neuropsychiatric diseases ranges from internalising symptoms (e.g. depression, anxiety, low self-esteem) to phenotypes with externalising features (e.g. oppositional defiant and conduct disorders, substance use disorders), pervasive developmental disorders and other frontostriatal disorders (Mak et al. 2022).

Executive functioning in ADHD

Executive dysfunction has been suggested to be a core feature of ADHD (Barkley 1997). The heterogeneous aetiology of ADHD contributes to considerable neuropsychological variability. Substantial clinical manifestations have been associated with early risk factors, such as tobacco or other substance use during pregnancy, premature birth, low birth weight and early trauma (Thapar et al. 2009). Notably, genetic risk factors have also been widely recognised in ADHD pathogenesis underlying the familiar nature of ADHD (Li et al. 2022). Environmental and genetic factors are together implicated in detrimental frontostriatal events with additional disturbances of the dopamine and noradrenaline neurotransmitter system (Pliszka 2005), and bottom-up and top-down regulatory systems of the brain. Disturbances of the delicate balance

of the two, particularly the down-regulated top-down responses are key mechanisms of ADHD pathogenesis (Petrovic–Castellanos 2016).

Executive functions are top-down mental processes, which enable the individual to effortfully adapt to novel or unanticipated challenges, when going on autopilot or relying on intuition is non-adaptive (Diamond 2020). Executive functioning includes core functions such as inhibitory control, working memory and cognitive flexibility, and more complex processes such as planning, reasoning and organisation. Based on the presence of affective factors, executive functions can be divided into cool and hot skills. Cool cognitive functions are independent of affective factors and encompass core executive functions which are associated with the dorsolateral part of the prefrontal cortex, while hot executive functions, associated with the ventral and medial area of the prefrontal cortex, including the anterior cingulate cortex, are highly dependent on emotions and motivation, and on their effect on cognitive functions (Emond et al. 2010).

In children, medium-sized relationships between ADHD symptoms and deficits in cold executive functions, such as inhibitory control, alertness, spatial working memory and planning have been described in a meta-analysis, but none of them was necessary or specific for ADHD (Willcutt et al. 2005). The importance of hot executive functioning, e.g. decision-making and reward processing has also been emphasised in ADHD (Sjöwall et al. 2013). Because of the high variability and low specificity of executive dysfunction, some theorists suggested that not specific deficits but high variability of the performance is the most important feature that may characterise ADHD (Castellanos et al. 2006).

Emotional functioning in ADHD

Deficits in emotional self-regulation are also characteristic of ADHD, influencing behaviour and social functionality (Barkley 2010; Bunford et al. 2015). In their meta-analysis, Graziano and Garcia (2016) found that ADHD in youth is associated with increased emotional reactivity/negativity/lability and deficits in emotion regulation skills with a large effect size, and is related to impaired empathy or higher levels of callous-unemotional traits and deficits in emotion recognition/understanding with medium effect size. That is, youth with ADHD may have stronger reactions to an emotional experience, may regulate their emotions less efficiently, and to a lesser

extent, may have problems in processing emotional information at a basic level, and may show lower levels of guilt, empathy and caring for others. It is important to note that when exploring the effects of possible moderators, Graziano and Garzia (2016) found that age and cognitive functioning moderated the relationship between ADHD and emotional reactivity/negativity/lability. Furthermore, the association between ADHD and empathy/callous-unemotional traits became weak when controlling for co-occurring conduct problems.

Executive functions and emotional functioning in ADHD

Though it was shown that emotional understanding requires intact executive functioning (Li et al. 2022), especially inhibitory control (Rhoades et al. 2009), working memory (Morra et al. 2011) and cognitive flexibility (Silkenbeumer et al. 2016), there is little research on the relationship between executive functions and emotional self-regulation in children with ADHD. Some studies showed that deficits in working memory (Groves et al. 2020; Tarle et al. 2021) but not in inhibitory control and set-shifting (Groves et al. 2022) were related to emotional dysregulation in ADHD. Sjöwall and colleagues (2013) found that emotional recognition and regulation skills for different emotions were related to inhibition, working memory and set-shifting skills. Effect sizes were small, only the association between set-shifting and the recognition of sadness reached medium effect. Importantly, emotion regulation skills, as well as the recognition of anger were inversely related to reaction time variability, and effect sizes were medium.

Aims of the present study

Previous studies focused on limited aspects of emotional understanding skills in children with ADHD. Therefore, there is a need for a comprehensive assessment of the skills in these samples. Our study aims to assess the performance of children aged 6 to 10 diagnosed with ADHD in a comprehensive battery of emotion comprehension and to explore the relationship of emotional understanding and cool executive functions.

Based on the literature review, we hypothesised that children with ADHD will show poorer performance in emotion comprehension tasks than described in non-clinical samples. We also hypothesised that poorer performance in emotion comprehension will be related to both increased reaction time variability and deficits in inhibitory control and set-shifting.

Methods

Sample and procedure

One hundred thirty-three children with ADHD diagnosis combined presentation were involved. Exclusion criteria were intellectual disability and pervasive developmental disorders. All children were newly diagnosed and, therefore without medication. The mean age was 8.36 years (*SD* = 1.28, range: 6–10 years). About three-fourth of the children were boys (N = 101, 76%), in line with the well-known gender difference in the prevalence of ADHD (DSM-5, APA, 2013). They all lived in the capital and the agglomeration.

The study was part of a larger research program focusing on the pragmatic skills of children with neurodevelopmental disorders. Ethical approval was obtained by the institutional ethical committee. Informed consent was given by the parents.

Measure ADHD Child Evaluation – ACE (Young 2015). ACE is a semi-structured diagnostic interview to assess the presence of the 18 symptoms of ADHD in both home and institutional settings and the degree of impairment in children aged 5–16 years. ACE also assesses potential risk factors and comorbid conditions with a series of questions to provide a comprehensive picture of the child's functioning. The scoring of the diagnostic interview allows for classification according to the DSM-5 and BNO-10 criteria by summing up the symptoms. The interview was recorded with the parent during the research, with the aim of confirming the clinical diagnosis of ADHD. The data obtained from the statistical analysis were not used in further analyses.

Test of Attentional Performance for Children – KiTAP (Zimmermann et al. 2002). The KiTAP test, a validated and reliable neuropsychological test measuring attention-related functions through nonverbal attention components, assesses several parameters including Alertness, Go/no-go (inhibitory control), Distractibility, Divided Attention and Flexibility (set-shifting). The computer-based test is set in an enchanted castle

where the child is faced with various tasks involving ghosts, dragons, owls, witches and other magical creatures. We used the t-scores of the median and SD of reaction time and the number of errors and omissions for statistical analyses. Norm values are given taking age and gender into account.

Test of Emotion Comprehension (Pons–Harris 2000). TEC assesses nine domains of emotional understanding, namely, the recognition of emotions, based on facial expressions; the comprehension of external emotional causes; memory influence on emotions; the impact of desire on emotions; emotions based on beliefs; the possibility of hiding an emotional state; the possibility of emotional regulation; having mixed emotions; and contribution of morality to emotional experiences. Components of the test are interrelated and developmentally hierarchical, following 3 stages: the external phase in 3–6-year-old children (recognition, external, reminder), the mental phase in 5–9-year-old children (desires, belief, hidden) and the reflective phase in 8–11-year-old children (regulation, mixed, moral). Originally, TEC was a picture book composed of 23 cartoon scenarios. We used a computerised version which was created by Róbert Korényi in cooperation with our research group. For the first five boards, the child is asked to identify the correct facial expression corresponding to the target emotion (happy, sad, angry, scared, well). Each remaining board presents a story with a main character's face left blank, and the child is asked to select the appropriate emotion for the story character from four choices. Good psychometric properties of the TEC have been reported by several studies (Albanese et al. 2006; Pons et al. 2004; Rocha et al. 2013). For the analyses, we used the binary evaluation of each task (completed – not completed), and calculated the total score, that is, the number of completed tasks ranging from 1 to 9.

Statistical analyses

Descriptive statistics for the TEC and KiTAP parameters are provided. Pearson's correlation was used for assessing the relationships between TEC total score and KiTAP parameters (t-scores). The relationships between age and TEC total score, as well as KiTAP performance were assessed by means of Pearson's correlations, and gender differences were assessed by means of independent sample t-tests. Bonferroni correction for multiple statistical tests was used ($\alpha' = .05/13 = .004$).

Results

Performance in TEC

The average number of completed tasks in TEC was 5.38 (SD = 1.79, range: 1–9). Age was positively related to the number of completed tasks (r = .288, p = .001), but no gender differences were found (M_{boys} = 5.36, SD = 1.83, M_{girls} = 5.47, SD = 1.67, t(131) = .309, p = .758).

About 60% of the children completed each of the three tasks of the external component of emotional understanding (Table 1). In the second, mental component, the picture is a bit complicated. While less than 60% of the children completed the task requiring the understanding of the role of emotion beliefs, more than 80% of them were able to understand the role of emotion desires and to identify hidden anger. In the third component (reflection), half of the children failed to recognise mixed emotions and most of them (90%) failed to complete the task requiring the ability to understand the effect of morality on emotions. However, a relatively large proportion of the children identified well the most adaptive way of emotion regulation (72%).

Table 1: *The proportion of children who completed each TEC task*

Age (years)	*6 yrs*	*7 yrs*	*8 yrs*	*9 yrs*	*10 yrs*	*Total*
N	N = 11	N = 27	N = 30	N = 33	N = 32	N = 133
External component						
Recognition N (%)	9 (82)	16 (59)	19 (63)	20 (61)	24 (75)	88 (66)
External causes N (%)	5 (46)	13 (48)	19 (63)	20 (61)	24 (75)	81 (61)
Reminder N (%)	5 (46)	18 (67)	16 (53)	19 (58)	17 (53)	75 (56)
Mental component						
Desire N (%)	9 (82)	18 (67)	27 (90)	25 (76)	31 (97)	110 (83)
Believes N (%)	5 (46)	12 (44)	17 (56)	19 (58)	25 (78)	78 (59)
Hidden N (%)	8 (73)	22 (82)	27 (90)	24 (73)	26 (81)	107 (81)
Reflective component						
Regulation N (%)	7 (64)	16 (59)	24 (80)	23 (70)	26 (81)	96 (72)
Mixed N (%)	4 (36)	9 (33)	8 (37)	19 (58)	24 (75)	67 (50)
Moral N (%)	1 (9)	1 (4)	3 (10)	5 (15)	4 (13)	14 (11)

Note: TEC: Test of Emotion Comprehension.

Source: Compiled by the authors

Performance in KiTAP

The standard deviation of the reaction times was high (Alertness SD t-score < 40) in almost half of the children (48%), that is, their performance was characterised by high variability (Figure 1). The percentage of children with poor performance (t-score < 40) was highest for errors in the Flexibility task (42%), in the Go/No-go task (37%), in the Distractibility task (29%) and omissions (35%) in the Go/No-go task. The percentage of children with a t-score < 40 in at least one parameter of the tasks was 62% for the Go/No-go, 52% for the Distractibility, 40% for the Divided Attention and 47% for the Flexibility task. Only 14% of the children had no t-score < 40 in any parameter.

Age was negatively related to t-scores of omissions in the Distractibility task, that is, performance increased with age ($r = -.300$, $p = .001$). After Bonferroni correction, no gender differences were found (Figure 1).

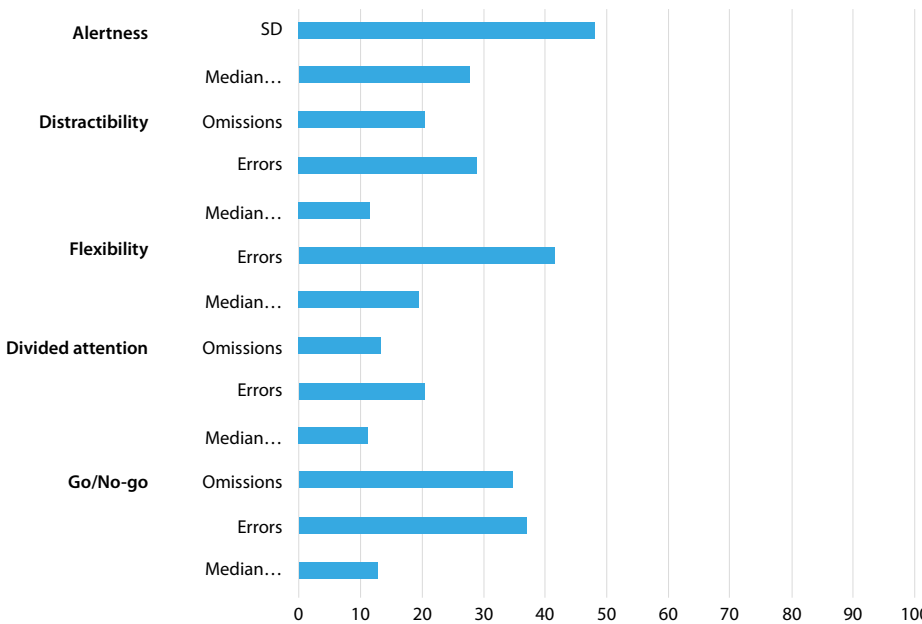

Figure 1: *Percentage of children with t-scores less than 40 in KiTAP parameters*

Note: Some children were unable to complete the whole neuropsychological battery, therefore, sample size varied: $N_{Alertness} = 133$, $N_{Go/No-go} = 133$, $N_{Distractibility} = 130$, $N_{Divided\_attention} = 99$, $N_{Flexibility} = 112$.

Source: Compiled by the authors

The relationship between emotional understanding and cool executive functions

Pearson's correlational coefficients were calculated between TEC total scores and KiTAP parameters (t-scores). After Bonferroni correction, higher TEC total scores were related to lower variability of performance in KiTAP Alertness ($r = .320, p < .001$), and fewer errors in the Divided Attention task ($r = .299, p = .003$). As a tendency, errors in the Flexibility task were also related to the TEC total score ($r = .231, p = .014$). Effect sizes were small to medium.

Discussion

Between 24% and 50% of children with ADHD experience emotion dysregulation (Shaw et al. 2014), which contributes to functional impairment, especially social difficulties associated with ADHD (Biederman et al. 2012). Emotional dysregulation may be due to both deficits in emotion comprehension and executive functioning (Graziano–Garcia 2016; Shaw et al. 2014). However, there is little research on the relationship between emotion comprehension and executive functions in children with ADHD (Groves et al. 2020; Groves et al. 2022; Tarle et al. 2021). Therefore, the aim of the present study was to explore the associations between emotion comprehension and executive functioning in children aged 6–10 years, diagnosed with ADHD.

We found no gender differences in emotion comprehension but found, in line with Pons et al. (2019) that this ability increases with age in children with ADHD as well. Compared to previous studies in typically developing children (Cavioni et al. 2020; Pons et al. 2004; Rocha et al. 2013), we found that fewer children with ADHD were able to complete the tasks in the first domain related to external situational causes of emotions. In non-clinical samples, 90–100% of children above 6 years old completed the first two tasks of the TEC assessing emotional recognition and external situational causes of emotions, and more than 80% of them responded correctly to the task assessing the role of reminder on emotions, while in our sample, less than two-thirds of the children completed these tasks. These results suggest that children with ADHD may have a developmental delay in the first (external) component of emotion comprehension.

In the tasks of the mental component of emotional understanding, 44–78% of the children in our sample were able to recognise the role of emotion beliefs, which is

comparable to the results of Cavioni and colleagues (2020), who found completion rates of 49–76% in this age groups. Similarly, children with ADHD performed relatively well in understanding emotions caused by desires (67–97% in our sample and 75–95% in Cavioni et al. 2020) and recognising hidden anger (73–90% in our sample and 55–90% in Cavioni et al. 2020). The results suggest that children with ADHD may be as good as typically developing children in understanding internal causes of emotions, probably due to their intense experience of desires and emotions.

Research in non-clinical samples revealed that the reflective component of emotion comprehension is under development in children aged 6 to 10. In line with these results, we found that a large proportion of children with ADHD had difficulties recognising mixed emotions and understanding the effect of morality on emotions. However, it is important to note that children with ADHD showed comparable performance in recognising the most adaptive way of emotion regulation. Completion rates ranged between 59 and 81%, whereas in non-clinical samples it was between 43–75% (Cavioni et al. 2020), 70–79% (Rocha et al. 2013) and 35–80% (Pons et al. 2004). These results contradict previous studies showing that children with ADHD have substantial difficulties in regulating their emotions (Graziano–Garcia 2016), and suggest that children with ADHD may have knowledge about adaptive ways of emotion regulation, but they may be unable to utilise this knowledge in emotionally significant situations.

In line with previous studies (Willcutt et al. 2005), we found that most of the children with ADHD showed executive dysfunction in at least one domain, mostly in response inhibition and set-shifting. An increased variability of reaction times was also present in almost half of the children (Castellanos et al. 2006). The correlation of medium effect size between emotional understanding and variability of performance suggests that it may partly explain the deficits in emotional understanding, as previous research found (Sjöwall et al. 2013). Fewer errors in the Divided Attention and Flexibility tasks were also related to better emotional understanding in our sample. Though previous studies showed mixed results (Groves et al. 2020; Groves et al. 2022; Sjöwall et al. 2013; Tarle et al. 2021), our results add to this filed by revealing that specific executive functions such as the ability to divide attentional focus and to flexible shift attentional focus may be important in emotional functioning. Our results are in line with the notion that cognitive flexibility may be an important factor in social-emotional competence (Silkenbeumer et al. 2016).

The results can be viewed in light of the study's limitations. First, the cross-sectional design does not allow for testing causal relationships. Second, we did not control the

analyses for possible confounders such as socio-ecological factors and comorbidity. Third, we did not have a control group; we compared the performance of the clinical group to the normative data from previous studies. Fourth, we did not assess working memory, though it may be relevant in emotion comprehension.

Despite these limitations, our results underline the importance of the comprehensive assessment of the emotional functioning of children with ADHD. Our results suggest that children with ADHD may pay less attention to external stimuli, but they may experience their desires more intensively which may have an effect on their emotional understanding in different situations. Furthermore, emotional understanding in children with ADHD may be related to both the increased variability of performance and specific deficits in cold executive functioning. Therefore, training in executive functions in children with ADHD may enhance their emotional competence and may contribute to a better outcome.

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