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A critical appraisal of the role of neuropsychological deficits in preschool ADHD

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ABSTRACT

The present study aimed at improving our understanding of the role of neuropsychological deficits in preschool Attention Deficit Hyperactivity Disorder (ADHD). The study included 52 children in the ADHD group and 72 controls (age 4–6 years). Both laboratory measures and teacher reports of executive deficits (i.e., working memory, inhibition, and shifting), delay-related behaviors (i.e., the preference for minimizing delay), and emotional functions (i.e., emotion recognition and regulation) were included. Variable-oriented analyses were complemented with person-oriented analyses (i.e., identifying the proportion of patients considered impaired). Results showed that the ADHD group differed from controls with regard to all measures of executive functioning and most measures of delay-related behaviors, but few differences were found for emotional functioning. A substantial subgroup (23%) of children with ADHD did not have a neuropsychological deficit in any domain. There were subgroups with executive or delay-related deficits only, but no pure emotional subgroup. The overlap between different neuropsychological deficits was much larger when teacher reports were used as opposed to laboratory measures. Regarding functional impairments, large mean differences were found between the ADHD group and controls. However, neuropsychological deficits were not able to explain individual variations in daily life functioning among children with ADHD. In conclusion, the present study identified some important methodological and theoretical issues regarding the role of neuropsychological functioning in preschool ADHD.

There is growing interest in being able to base psychiatric diagnoses such as Attention Deficit Hyperactivity Disorder (ADHD) on more biologically homogenous measures, such as neuropsychological functioning, rather than on heterogeneous sets of behavioral symptoms. However, investigations of neuropsychological deficits during the preschool years have shown only small to medium effect sizes in relation to ADHD (for meta-analyses, see Pauli-Pott & Becker, 2011; Schoemaker, Mulder, Dekovic, & Matthys, 2012). These previous findings raise important theoretical and methodological concerns, which we believe have not been properly addressed in previous research. In
the present study, we aimed to address the following issues: 1) Which neuropsychological deficits are related to preschool ADHD and what is the overlap between these deficits? 2) Which methodological challenges do we face when assessing neuropsychological deficits in preschool ADHD? 3) And what is the relation between neuropsychological deficits and functional impairments in daily life? We put a special emphasis on emotional functioning, as this construct has been shown to be linked to the disorder, but it has seldom been included in clinical studies of preschool ADHD or studied in relation to other neuropsychological deficits.

**Neuropsychological heterogeneity in ADHD**

In studies using DSM criteria, the prevalence of ADHD among preschool children has been shown to range from 2.0–7.9%, with the combined and hyperactive/impulsive subtypes being the most common (Egger, Kondo, & Angold, 2006). In their review, Sonuga-Barke and Halperin (2010) argued that previous research has shown that preschool ADHD is a serious condition, but that symptom levels can be improved through both pharmacological and non-pharmacological treatment. However, they also emphasized the need for more research to better understand the underlying causal processes of preschool ADHD and, thereby, improve early identification of young children at risk as well as identify targets for treatment. Several studies have shown that ADHD is a neuropsychologically heterogeneous disorder (e.g., Coghill, Seth, & Matthews, 2014; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005), indicating that separate neuropsychological pathways may give rise to the same disorder. More specifically, previous studies have shown that ADHD is related to executive processes such as working memory, inhibition, and shifting (e.g., Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) delay-related behaviors (e.g., Sonuga-Barke, 2003), and a more recent study has revealed its association with emotional processes (e.g., Bunford, Evans, & Wymbs, 2015). This heterogeneity has been proposed to constitute a barrier to unraveling the mechanisms underlying the disorder and laying the foundation for effective treatments (Marquand, Wolfers, Mennes, Buitelaar, & Beckmann, 2016). In line with this, the Research Domain Criteria (RDoC), presented by the National Institute of Mental Health (NIMH; Insel et al., 2010), states that mental disorders should be characterized by underlying neurobiological deficits rather than by heterogeneous sets of symptoms. Regardless of whether we eventually make the transition from a symptom-based to a more neuropsychologically informed nosology for ADHD, there are several important questions regarding the role of neuropsychological deficits that need to be addressed. Below, we raise some of the issues we believe are of the utmost importance.

With regard to the neuropsychological deficits related to preschool ADHD, two meta-analyses have shown that preschool ADHD is associated with deficits in response inhibition, interference control, delay aversion, working memory, flexibility, and vigilance/arousal (Pauli-Pott & Becker, 2011; Schoemaker et al., 2012). However, these meta-analyses did not address to what extent these deficits overlap or if there are distinct subgroups. Furthermore, emotional processes were not included, even though their importance in ADHD has been emphasized (e.g., Shaw, Stringaris, Nigg, & Leibenluft, 2014).
In previous studies, emotional functioning has been defined in many different ways. In the present study, we operationalize emotional processes as the ability to recognize emotions from facial expressions (i.e., emotion recognition) and the ability to regulate emotional states (i.e., emotion regulation). We consider emotional functioning to be a construct conceptually separate from delay-related behaviors, which has been defined as the tendency to choose a smaller more immediate reward rather than a larger reward that involves waiting (Sonuga-Barke, 2003). Studying the overlap between different functions is important, as this is a necessary step in the process of defining neuropsychological subgroups. The subgroups can then be used to better understand individual differences within the broader ADHD phenotype with regard to etiology, developmental pathways, treatment response, and functional impairments. Previous studies of school-age samples have indicated that although children with ADHD can have multiple neuropsychological deficits, substantial subgroups are affected in only one domain (e.g., SjöWall, Roth, Lindqvist, & Thorell, 2013; Sonuga-Barke, Bitsakou, & Thompson, 2010). Interestingly, it has also consistently been found that a substantial proportion of children with ADHD do not have deficits within any neuropsychological domain (Nigg et al., 2005; SjöWall et al., 2013; Sonuga-Barke et al., 2010; Wåhlstedt, Thorell, & Bohlin, 2009).

In previous studies measuring multiple neuropsychological domains in relation to preschool ADHD, executive deficits and delay aversion appear to constitute at least partly different subgroups (e.g., SjöWall, Backman, & Thorell, 2015; Sonuga-Barke, Dalen, & Remington, 2003). In the few studies that have included emotional functioning, executive deficits and emotion regulation have been shown to have independent effects on preschool ADHD symptoms (Forslund, Brocki, Bohlin, Granqvist, & Eninger, 2016; Healey, Marks, & Halperin, 2011; SjöWall et al., 2015). However, as described further below when discussing methodological challenges, these previous studies did not use the same type of measurement to assess executive deficits and emotional functioning, which means the overlap between different constructs might have been underestimated. Furthermore, it should be noted that they only included variable-oriented analyses (i.e., investigating group differences with regard to the mean value of different measures of neuropsychological functioning). As emphasized by, for example, Nigg and colleagues (2005), the proportion of individuals with impairment within a domain should be reported, because significant group differences for mean values (also with large effect sizes) can be found even though only a minority of the participants with ADHD have clear deficits when categorizing individuals into those with “impaired” versus “non-impaired” performance. Using this type of person-oriented analysis will make it easier to evaluate to what extent distinct neuropsychological subgroups can be identified.

Methodological challenges in assessing neuropsychological functioning

Another critical issue is to what extent laboratory measures and teacher/caregiver reports actually measure the same thing. If different methodological approaches target partially different constructs, this needs to be taken into consideration when comparing the effect sizes or investigating the overlap between different neuropsychological functions. For example, the vast majority of studies examining emotional functioning in
ADHD have used teacher/caregiver reports, whereas executive deficits have primarily been examined using laboratory measures. We argue that independent effects of different neuropsychological functions must be examined using the same measurement method. In support of this view, a meta-analysis by Toplak, West, and Stanovich (2013) showed that the convergence between teacher/caregiver reports and laboratory measures of executive deficits is on average very small. Another meta-analysis demonstrated that the relation between emotion regulation and ADHD was significantly stronger when measured using teacher/caregiver reports compared to laboratory measures (Graziano & Garcia, 2016). One possible explanation for the low concurrence between teacher/caregiver reports and laboratory measures is that reports capture typical performance whereas laboratory measures capture optimal performance (Toplak et al., 2013). Furthermore, laboratory measures are usually assessed only once and could be less sensitive when identifying deficits compared to teacher/caregiver reports, which capture behavior over longer periods of time (Barkley, 1997). However, reports provided by, for example, teachers or caregivers are limited in that they are affected by rater bias (e.g., Hoyt, 2000) and are also believed to capture more global levels of functioning rather than specific neuropsychological deficits (cf. Thorell & Nyberg, 2008). Use of a multimethod approach is also important in order to control for shared method variance when investigating the link between a predictor and an outcome, such as that between neuropsychological deficits and functional impairments, which is studied here. In the present study, we included both teacher/caregiver reports and laboratory measures, thus enabling evaluation of possible differences between these methods.

**The relation between neuropsychological functioning and functional impairments**

To further understand the role of neuropsychological functioning in ADHD, we also need to consider the functional impairments associated with the disorder. For preschoolers, this primarily includes impairments in social relations within the family and with peers (e.g., Barkley, 2014). However, just as with neuropsychological deficits, there are large individual variations in the functional impairments associated with ADHD, with some individuals showing very severe problems whereas others function relatively well. With regard to research focusing on the mechanisms underlying these differences, several previous studies have found that deficits in executive functioning are related to academic achievement (Biederman et al., 2004; Kofler et al., 2017; Miller, Nevado-Montenegro, & Hinshaw, 2012; Sjöwall, Bohlin, Rydell, & Thorell, 2017; Thorell, 2007). Some studies have also found significant relations between executive function deficits and social functioning (Kofler et al., 2011, 2017; Rinsky & Hinshaw, 2011) whereas others have failed to do so (e.g., Diamantopoulou, Rydell, Thorell, & Bohlin, 2007; Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2009; Sjöwall & Thorell, 2014). Delay-related behaviors do not appear to be primarily related to academic functioning (e.g., Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Thorell, 2007), but rather to addictive behaviors and risk taking (e.g., MacKillop et al., 2011; Sorensen et al., 2017). Emotion regulation deficits have been shown to be related to peer problems both concurrently (e.g., Anastopoulos et al., 2011; Melnick & Hinshaw, 2000; Sjöwall & Thorell, 2014) and longitudinally (Thorell, Sjöwall, Rydell, Diamantopoulou, & Bohlin,
Most studies mentioned above used dimensional analyses and did not include clinically-referred samples. Another limitation of previous studies is that they have not included preschool children. This should be considered important, especially as it has been argued that the functional impairments associated with ADHD may be better predictors of long-term clinical outcomes than the core symptoms (e.g., review by Pelham, Fabiano, & Massetti, 2005) and early detection of impairment is a major advantage (see review by Sonuga-Barke & Halperin, 2010).

**Aims of the present study**

The overall aim of the study was to characterize neuropsychological functioning in preschool ADHD. In order to contribute new knowledge and to address the critical issues raised above, we used a multiple-domain approach that included the following neuropsychological functions: executive deficits (i.e., working memory, inhibition, and reaction time variability), delay-related behaviors (i.e., the preference for minimizing delay), and emotional functions (i.e., emotion recognition and regulation). In addition, both variable-oriented and person-oriented analyses were conducted, and we included laboratory measures as well as teacher/caregiver reports of each investigated construct. Second, we addressed the issue of to what extent individual variations in neuropsychological functioning were related to the functional impairments (i.e., peer problems, prosocial behaviors, and family life functioning) associated with preschool ADHD. More specifically, the following specific research questions were addressed:

1. With regard to what aspects of neuropsychological functioning do preschool children with high versus low ADHD symptom levels differ?
2. Are there independent effects of different neuropsychological domains (i.e., how much do deficits overlap) in relation to preschool ADHD?
3. Are neuropsychological deficits related to individual differences in functional impairments?
4. Are there differences in findings regarding Question 1 and 2 above when neuropsychological functioning is assessed using teacher reports compared to laboratory measures?

**Methods**

**Participants and procedure**

The study included 124 preschool children (age 4–6 years). Descriptive data for background variables are presented in Table 1. The ADHD group consisted of 52 children who were recruited from a clinically referred sample. The children in the clinical sample had been diagnosed with ADHD by a psychiatrist using the DSM-5 criteria (APA, 2013). All children in the ADHD group also met the symptom criteria for ADHD using the ADHD Rating Scale IV (DuPaul, Power, Anastopoulos, & Reid, 1998), completed by parents or teachers. In line with DSM-5 criteria, we also used teacher/caregiver reports on the impact supplement included in the Strength and Difficulties Questionnaire (SDQ; Goodman, 1997) to confirm that symptoms had been present for at least
6 months, and that impairment (i.e., a score of “quite a lot” or “a great deal”) was found in at least two of the following settings: home life, friendships, classroom learning, and leisure activities. The exclusion criterion was a full scale IQ score ≤ 70 on the 4th editions of either the Wechsler Preschool and Primary Scale of Intelligence (WPSSI-IV; Wechsler, 2012) or the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003). Parents of the 21 children receiving pharmacological treatment were asked to withdraw their child’s medication 24 h prior to testing. The control group included 72 children (56% boys, mean age 66.2 months) with fewer than three items rated as “often” or “very often” within each ADHD symptom domain, as assessed by parents or teachers using the ADHD Rating Scale IV (DuPaul et al., 1998). The ADHD group and the control group differed significantly on child sex, $\chi^2 = 6.02, p < .01$ (i.e., more boys in the ADHD group), child age $t = 3.39, p < .001$ (i.e., controls younger than the ADHD group), and parental education, both $\chi^2 > 20.19, p < .001$ (i.e., higher educational level for parents of the controls). However, the groups did not differ significantly on birth country of the parents or the child, all $\chi^2 < 4.22, ns$. Written consent was obtained from the child’s caregiver, and the local ethics committee approved the study. The children received a toy worth approximately 10 Euros for participating in the study, and the parents and teachers received a gift voucher worth about 10 Euros for completing the questionnaire.

**Measures**

**Laboratory measures**

All neuropsychological laboratory measures have been used in previous studies, except for some of the measures of emotional functioning and delay-related behaviors designed for the current study. These measures were carefully piloted in typically developing preschoolers to ensure that they evoked emotional responses. Some measures were reversed so that higher values always indicated a larger deficit. See Table 2 for inter-relations between the different neuropsychological domains. The entire testing
session was filmed to allow subsequent coding of the child’s behavior. Inter-rater reliability was assessed for all measures not employed in previous studies using a subset of 20 randomly chosen individuals. The laboratory test was administered in a fixed order and the entire test session took about 1 h.

**Executive functions.** Four measures related to executive functioning were used in this study. *Inhibition* was measured using a go/no-go task (Berlin & Bohlin, 2002). In the first trial, the child is asked to press a key whenever they see a blue shape (red and blue squares or triangles appear on the screen). In the second trial, the task is to press the key when a square is shown, regardless of color. Number of commission errors (i.e., the number of times the child pressed the key in response to a no-go stimulus) was used as a measure of inhibition. Subsequently, *reaction time variability* was measured as the standard deviation of participants’ reaction time for correct answers on the go/no-go task. *Verbal working memory* was measured using the total score for the backward condition of the digit span subtest (Wechsler, 2003). *Spatial working memory* was measured using the “find the phone task,” previously used in SjöWall et al. (2013). They find the phone task has a similar design as the spatial working memory task in the Cambridge Neuropsychological Test Automated Battery (CANTAB; Owens, Downes, Sahakian, Polkey, & Robbins, 1990). Telephones are shown on the computer screen and the child is asked to remember which telephone that has already rung to avoid selecting that phone several times. The number of times the child returned to a phone that had already rung was used as a measure of working memory deficits.

**Delay-related behaviors.** Three measures of delay-related behaviors were included in order to capture both choice-related (situations where participants can avoid or minimize delay by choosing a small but immediate reward) and non-choice-related delay behaviors (situations when participants cannot escape delay; Sonuga-Barke, 2003).

*Delay aversion* (i.e., the tendency to choose a smaller immediate reward over a larger delayed reward) was assessed using the “flower task” (Thorell, 2007). The measure used in the present study was the number of times the child chose the larger delayed reward on the last 10 trials. Test–retest reliability for the ”flower task” has proven to be high ($r = .85$) in a previous study (Thorell, 2007).

Two non-choice aspects of delay were measured using the “the gift delay task,” which is based on a task originally developed by Kochanska, Murray, and Harlan (2000) and

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**Table 2.** Inter-correlations (two-tailed) between the three domains of neuropsychological functioning, with separate analyses being run for the ADHD group (bold-faced figures) and controls.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td><strong>Laboratory measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Executive deficits</td>
<td>–</td>
<td>.18</td>
<td>.24*</td>
</tr>
<tr>
<td>2. Delay-related behaviors</td>
<td>.10</td>
<td>–</td>
<td>.28*</td>
</tr>
<tr>
<td>3. Emotional functioning</td>
<td>.45***</td>
<td>.10</td>
<td>–</td>
</tr>
<tr>
<td><strong>Teacher reports</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Executive deficits</td>
<td>–</td>
<td>.77***</td>
<td>.60***</td>
</tr>
<tr>
<td>2. Delay-related behaviors</td>
<td>.71***</td>
<td>–</td>
<td>.65***</td>
</tr>
<tr>
<td>3. Emotional functioning</td>
<td>.75***</td>
<td>.76***</td>
<td>–</td>
</tr>
</tbody>
</table>

*p < .05; **p < 0.1; ***p < .001.*
later used in ADHD research on preschoolers by for example Pauli-Pott, Dalir, Mingebach, Roller, and Becker (2014). In this task, the child is told that he/she will be given a gift, but it needs to be wrapped first. The child is asked to face the other direction and the experimenter then wraps the gift noisily for 1 min and thereafter tells the child that she/he is out of tape and needs to leave the room to get some more. The experimenter leaves the room for 30 s after informing the child that he/she will be back soon. Behaviors were coded based on the child’s ability to wait (i.e. not turning around) as well as self-stimulation behaviors while waiting (i.e. fidgeting, leaving seat). Gift delay waiting was coded as 0 = no peeking, 1 = peeks briefly over the shoulder, 2 = turns head around fully after a while, 3 = turns head around fully immediately, 4 = turns around and starts touching the gift. The intra-class correlation was .94. Delay stimulation was coded on a 3-point scale were 0 = no stimulation by moving or taking/singing, 1 = fidgets/sings/talks to him-/herself/moves slightly, 2 = leaves the chair/moves a lot. The intra-class correlation was .92.

**Emotional functioning.** Four tasks of emotional functioning were included. These tasks were selected so as to measure a variety of emotional aspects, including recognizing emotions from faces (i.e., emotion recognition task), frustration tolerance (i.e. puzzle cheating task and impossible Lego task), regulation of exuberance (i.e., disappointment task paradigm). Identical or similar versions of these tasks have also been shown to be related to ADHD symptom levels in previous studies (e.g., Berlin, Bohlin, Nyberg, & Janols, 2004; Chronaki et al., 2015; Walcott & Landau, 2004).

In the **Emotion recognition task** (SjöWall et al., 2013), facial images selected from the NimStim Set of Facial Expressions (http://www.macbrain.org/resources.htm) were used. The child is shown photos of four faces on a computer screen and is asked to point to the face that displays a specific emotion (e.g., “Who is sad?”). In total, 16 trials are included that display four different emotions (i.e., anger, fear, sadness, and happiness).

In the **disappointment paradigm** (inspired by Carlson & Wang, 2007), following the gift delay task, the experimenter enters the room and tells the child that he/she just realized the gift being wrapped was not such a fun gift and that they will have a lottery instead. The child is shown four gifts: three nice gifts and one bad gift (a sock). The experimenter asks the child which of the gifts he/she likes the most and the least. Then, the experimenter places all the gifts in a big bag and picks one up. The participant opens the gift and finds that it is the least favored one. Negative and positive emotional expressions are coded separately. Negative expressions were coded as 0 = no negative expressions, 1 = one or few mild negative expressions, 2 = several mild negative expressions, 3 = one strong negative expression, 4 = several strong or one very strong negative expression. Positive expressions were coded as 0 = no positive expressions, 1 = smiling, 2 = laughter or continuous smiling. The intra-class correlation was .92 for negative expressions and .97 for positive expressions.

In the **puzzle cheating task**, participants are left alone with the task of completing a puzzle inside a box. It is impossible to finish the task on time without peeking, and thus the purpose of the task is to see to what extent the child can self-regulate frustration and not peek. Behavior is coded on a 6-point scale were 0 = no peeking, 1 = peeks briefly once or twice, 2 = peeks briefly several times, 3 = peeks in length but spends time trying without peeking, 4 = spends a short time trying but ends up putting pieces in place...
while looking, 5 = spends no time trying but starts cheating immediately. The intra-class correlation was .95.

In the *impossible Lego task* (inspired by Walcott & Landau, 2004), the participant is shown a very simple model built with Legos® and is told that he/she will win a prize if he/she builds exactly the same model within 3 min. However, three of the pieces are missing. The Lego task was used to measure tolerance to frustration, and negative expressions were coded as 0 = no negative expressions, 1 = one or few mild negative expressions, 2 = several mild ongoing negative expressions, 3 = one strong negative expression, 4 = several strong or one very strong negative expression. The intra-class correlation was .95.

**Teacher/caregiver reports**

**Executive deficits.** Executive deficits were assessed by teachers using the Childhood Executive Functioning Inventory (CHEXI; Thorell & Nyberg, 2008), which is a 24-item inventory that includes subscales for working memory and inhibition. It has previously shown adequate test–retest reliability, as well as good diagnostic and cross-cultural validity (Catale, Meulemans, & Thorell, 2015; Thorell, Eninger, Brocki, & Bohlin, 2010; Thorell & Nyberg, 2008). Cronbach’s alpha for the ADHD group was .92. The corresponding value for the control group was .95.

**Delay-related behaviors.** Delay-related behaviors were rated by teachers using The Childhood Delay Questionnaire (CDQ), a new scale inspired by the Quick Delay Questionnaire (QDQ) developed for adults (Clare, Helps, & Sonuga-Barke, 2010). The CDQ includes eight items (e.g., “Gets sad/disappointed if he/she has to wait for something” and “Prefers something small that he/she can get immediately compared to something larger that he/she needs to wait for”) that are rated on a scale from 1 (do not agree at all) to 5 (agree fully). High values indicate high levels of delay-related behaviors. Test–retest reliability was calculated using 23 teacher reports collected two weeks apart from a local preschool and showed acceptable inter-class correlation (.83). Cronbach’s alpha for the ADHD group was .88. The corresponding value for the control group was .82.

**Emotion regulation.** Emotion regulation was rated by teachers using the Emotion Questionnaire (Rydell, Berlin, & Bohlin, 2003), which includes questions assessing the child’s ability to regulate fear, anger, sadness, and exuberance. Each statement was rated from 1 (does not apply at all) to 5 (applies very well), a higher value indicating more difficulties. The questionnaire has previously shown acceptable test-retest reliability ($r = .74-.79$) and high construct validity (Rydell et al., 2003; Rydell, Thorell, & Bohlin, 2007). Cronbach’s alpha for the ADHD group was .86 for regulation of anger and .74 for regulation of happiness. The corresponding value for the control group was .73 for regulation of anger and .90 for regulation of happiness.

**Functional impairments.** Functional impairments were assessed using teacher and caregiver reports on the “peer problems” and “prosocial behavior” subscales from the Strength and Difficulties Questionnaire (SDQ; Goodman, 1997). Cronbach’s alpha for the ADHD group was .76 for parent-rated peer problems and .67 for teacher-rated peer
problems. The corresponding value for the control group was .38 for parent-rated peer problems and .53 for teacher-rated peer problems. Furthermore, Cronbach’s alpha for the ADHD group was .81 for parent-rated prosocial behaviors and .83 for teacher-rated prosocial behaviors. The corresponding value for the control group was .69 for parent-rated prosocial behaviors and .86 for teacher-rated prosocial behaviors.

Also used were caregiver reports on the “family” and the “social activities” domains from the Weiss Functional Impairments Scale, which have been shown to have acceptable psychometric properties in previous research (Gajria et al., 2015). Cronbach’s alpha for the ADHD group was .88 for “family domain” and .76 for “social activities domain”. The corresponding value for the control group was .55 for “family domain” and .66 for “social activities domain”.

**Statistical analyses**

Overall, only a small amount of data were missing (1.5 % in total). For teacher/caregiver reports, 0% was missing. For the laboratory measures, the range was between 0% and 4.8%. The reasons for missing data were the experimenter forgetting to move the camera (obstructing subsequent coding), the child wanting to quit in the middle of a test, or a technical error involving the computer. Univariate outliers were handled using the outlier labeling rule for each group (Hoaglin & Iglewicz, 1987). Sex and age were used as covariates in all analyses. First, one-way ANCOVAS were used to study group differences in neuropsychological functioning. Effect sizes were calculated using partial eta-squared ($\eta^2$), and effects were interpreted in accordance with Cohen (1988), who stated that $\eta^2$ of .01 is a small effect size, a $\eta^2$ of 0.06 is a medium effect size and a $\eta^2$ of .14 is a large effect size. Second, the single test scores were standardized and mean values for each domain (including only those variables for which significant group differences had been found) were created. A logistic regression analysis was then performed with group (ADHD vs. control) as the dependent variable and mean values for each neuropsychological domain (executive deficits, delay-related behaviors and emotional functioning) as independent variables. This analysis was conducted to examine independent effects of the different neuropsychological domains in relation to ADHD and to obtain measures of sensitivity and specificity.

Thereafter, person-oriented analyses were performed by defining impairment as performing more poorly than the 90th percentile of the children in the control group, in accordance with previous studies (e.g., Nigg et al., 2005; SjöWall et al., 2013; Sonuga-Barke et al., 2010; Wåhlstedt et al., 2009). The single test scores were age-adjusted using standard regression procedures, and chi-square analyses were used to investigate group differences. Venn diagrams were used to investigate the overlap between different neuropsychological domains, using mean scores for the measures within each domain. Similarly, to the logistic regression analyses, only variables for which group differences had been found were included in the Venn diagrams (see Table 3).

For functional impairments, we first used ANCOVAs with sex and age as covariates to compare the two groups with regard to mean levels of impairment. Second, correlation analyses were used to study the association between neuropsychological deficits and functional impairments. Only laboratory measures were included in these
correlation analyses as studying neuropsychological deficits through teacher reports would most likely overestimate the relation to functional impairments due to shared method variance as both the predictor and the outcome would then be measured using questionnaires.

Results

With regard to the ANCOVAs examining group differences, the results showed that children in the ADHD group performed more poorly than controls on all laboratory measures of executive deficits. Group differences were also found for two out of three measures of delay-related behaviors. With regard to emotional functioning, group differences were found for positive reactions in the Disappointment paradigm and emotion recognition. Effect sizes for the significant group differences were medium or above ($\eta^2 = .06$–.20), except for emotion recognition ($\eta^2 = .03$). When studying the same domains using teacher reports, the results showed that all group differences were significant for executive deficits, delay-related behaviors, and emotional functioning. All

Table 3. Means and standard deviations for all predictors included in the study and results of ANCOVAs using age and sex as covariates. The table also shows the proportion of children in the ADHD group with a deficit and the results for the $\chi^2$-tests comparing the ADHD group and controls with regard to the proportion of children with deficits.

<table>
<thead>
<tr>
<th></th>
<th>ADHD M (SD)</th>
<th>Control group M (SD)</th>
<th>ANCOVA ($\eta^2$) F</th>
<th>Proportion of ADHD group with a deficit</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive deficits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhibition</td>
<td>2.47 (1.52)</td>
<td>1.49 (1.20)</td>
<td>12.38 (.10)***</td>
<td>40</td>
<td>14.84***</td>
</tr>
<tr>
<td>Verbal working memory (backwards digits)</td>
<td>12.45 (1.50)</td>
<td>11.71 (1.45)</td>
<td>17.33 (.13)***</td>
<td>35</td>
<td>12.06***</td>
</tr>
<tr>
<td>Spatial working memory (find phone)</td>
<td>31.52 (7.86)</td>
<td>28.46 (9.55)</td>
<td>7.48 (.06)**</td>
<td>27</td>
<td>4.01*</td>
</tr>
<tr>
<td>Reaction time variability</td>
<td>297.72 (126.16)</td>
<td>226.74 (79.19)</td>
<td>29.54 (.20)***</td>
<td>43</td>
<td>18.14***</td>
</tr>
<tr>
<td>Reports of executive deficits</td>
<td>3.77 (.69)</td>
<td>1.54 (.51)</td>
<td>374.47 (.76)***</td>
<td>90</td>
<td>79.91***</td>
</tr>
<tr>
<td>Delay-related behavior</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay aversion (sunflower task)</td>
<td>8.72 (2.71)</td>
<td>7.90 (3.08)</td>
<td>3.14 (.03)</td>
<td>26</td>
<td>7.01**</td>
</tr>
<tr>
<td>Gift delay (waiting for a gift)</td>
<td>1.82 (1.37)</td>
<td>.80 (1.17)</td>
<td>21.67 (.16)***</td>
<td>40</td>
<td>15.38***</td>
</tr>
<tr>
<td>Delay stimulation (while waiting)</td>
<td>1.43 (.54)</td>
<td>.99 (.71)</td>
<td>14.18 (.11)***</td>
<td>30</td>
<td>9.50**</td>
</tr>
<tr>
<td>Reports of delay-related behaviors</td>
<td>3.51 (.90)</td>
<td>1.47 (.47)</td>
<td>220.14 (.65)***</td>
<td>88</td>
<td>76.49***</td>
</tr>
<tr>
<td>Emotional functioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emotion recognition</td>
<td>3.52 (2.58)</td>
<td>2.61 (1.62)</td>
<td>4.00 (.03)*</td>
<td>33</td>
<td>10.21***</td>
</tr>
<tr>
<td>Puzzle cheating task</td>
<td>3.42 (1.61)</td>
<td>2.81 (1.70)</td>
<td>1.72 (.02)</td>
<td>29</td>
<td>5.91*</td>
</tr>
<tr>
<td>Disappointment paradigm (negative)</td>
<td>1.14 (1.14)</td>
<td>.97 (.97)</td>
<td>.04 (.00)</td>
<td>18</td>
<td>1.82</td>
</tr>
<tr>
<td>Disappointment paradigm (positive)</td>
<td>.57 (.84)</td>
<td>.24 (.43)</td>
<td>10.26 (.08)**</td>
<td>24</td>
<td>5.69*</td>
</tr>
<tr>
<td>Impossible Lego task</td>
<td>.50 (.78)</td>
<td>.66 (1.04)</td>
<td>3.26 (.03)</td>
<td>0</td>
<td>5.33*</td>
</tr>
<tr>
<td>Reports of emotion regulation (anger)</td>
<td>3.59 (1.15)</td>
<td>1.44 (.54)</td>
<td>157.01 (.57)***</td>
<td>77</td>
<td>57.93***</td>
</tr>
<tr>
<td>Reports of emotion regulation (exuberance)</td>
<td>3.56 (1.03)</td>
<td>1.61 (.80)</td>
<td>117.55 (.50)***</td>
<td>73</td>
<td>52.42***</td>
</tr>
</tbody>
</table>

*p < .05; **p < .01; ***p < .001
effect sizes for the teacher reports were well beyond the limit for what is generally considered a large effect ($\eta^2 = .50–.76$). The results from the ANCOVAs remained the same when controlling for parents’ educational level, with the exception of emotion recognition, $F(1,113) = 3.03; p = .07$.

When investigating independent effects for the laboratory measures using logistic regression analyses, there was a significant effect of executive deficits, Wald = 13.55, $p < .001$, and delay-related behaviors, Wald = 12.25, $p < .001$. The model successfully predicted 73% of the ADHD cases (i.e., sensitivity) and 81% of the controls (i.e., specificity). For teacher reports, the model successfully predicted 100% of the ADHD cases (i.e., sensitivity) and 100% of the controls (i.e., specificity). No independent effects were found when using teacher reports.

Next, person-oriented analyses were performed. Please refer to the heading “statistical analyses” in the methods section for further information regarding how the categories were created. Chi-square analyses (see Table 2, rightmost column) showed that the results were similar to the ANCOVAs, except that significant group differences were also found for the Flower Delay Task and regulation during the Puzzle Cheating Task. In addition, a significant group difference was found for the Impossible Lego Task, but in contrast to all other measures, the controls performed more poorly (i.e., displayed lower regulation) than the children in the ADHD group. When studying the overlap between the three different neuropsychological domains (see Figure 1), it was shown that, for the laboratory measures, 23% of the children in the ADHD group had no deficits, 38% had a single deficit, and 39% had multiple deficits. The corresponding figures for the controls were 72%, 26%, and 1%. In the ADHD group, as few as 4% had emotional deficits only, whereas 19% had executive deficits and 15% delay-related deficits that did not overlap with any other domain. When conducting the same analyses for the teacher reports, only 4% of the children in the ADHD group did not have any deficits, 6% had a single deficit, and as many

![Figure 1](image.png)

Figure 1. Venn diagrams showing the number of children in the ADHD group who had impaired performance with regard to the three domains: executive deficits (EF), delay-related behaviors (Delay), and emotional functioning (Emotion) using either laboratory measures or teacher reports.
as 90% had multiple deficits. The corresponding figures for the controls were 82%, 11%, and 7%.

Finally, with regard to functional impairments, the results showed significant group differences between the ADHD group and controls for both teacher- and parent-rated peer problems, prosocial behaviors, as well as for parental perceived family life and social activities, Fs ranging between 40.04 and 324.36 ps < .001. Effect sizes were all large (η² = .25–.73). However, it should also be noted that even though group differences were large, there was a substantial subgroup of children with ADHD (between 12 and 45% for the different subscales) who received a mean score between 1.00 and 2.00 (between 4.00 and 5.00 for prosocial orientation for which low scores indicated impairment). Thus, there were large variations in functional impairments also within the ADHD group. When investigating associations between neuropsychological deficits and functional impairments, the results (see Table 4) showed that significant correlations were found between all three neuropsychological domains and all measures of functional impairments, except for the association between delay-related behavior and prosocial behaviors as rated by parents. When conducting the same analyses but only including the ADHD group, a very different pattern emerged with no significant relations between neuropsychological deficits and functional impairments, except the unexpected finding that high levels of delay-related behaviors were associated with high levels of prosocial behaviors as rated by parents. Next, scatterplots were used to investigate the influence of bivariate outliers. It was found that the five children in the ADHD group with the lowest levels of delay-related behaviors all had high levels of prosocial behavior whereas there was no association between these two variables for the remaining children in the ADHD group. When removing these bivariate outliers, the relation between delay-related behaviors and prosocial behaviors as rated by parents were significant in the analyses for the entire sample (r = -.18, p < .05) and the significant relation between delay-related behaviors and prosocial behaviors within the ADHD group was completely reduced (r = .01, ns).

Table 4. Associations between the three neuropsychological domains (only including laboratory measures) and functional impairments, with separate analyses being conducted for the entire sample and for only the ADHD group.

<table>
<thead>
<tr>
<th></th>
<th>ADHD group and controls (n = 124)</th>
<th>ADHD group only (n = 52)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Executive deficits</td>
<td>Emotional deficits</td>
</tr>
<tr>
<td><strong>Strength and Difficulties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Questionnaire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peer problems (parents)</td>
<td>.36***</td>
<td>.22*</td>
</tr>
<tr>
<td>Peer problems (teachers)</td>
<td>.26**</td>
<td>.23**</td>
</tr>
<tr>
<td>Prosocial behaviors (parents)</td>
<td>−.26**</td>
<td>−.22*</td>
</tr>
<tr>
<td>Prosocial behaviors (teachers)</td>
<td>−.37***</td>
<td>−.28**</td>
</tr>
<tr>
<td><strong>Weiss Functional Impairments Scale</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family Life (parents)</td>
<td>.42***</td>
<td>.29**</td>
</tr>
<tr>
<td>Social activities (parents)</td>
<td>.33***</td>
<td>.24**</td>
</tr>
</tbody>
</table>

*p < .05; **p < .01; ***p < .001,
Note. a = −.18, p < .05 when excluding the six bivariate outliers, b = .00 when excluding the six bivariate outliers
Discussion

The present study aimed at providing a better understanding of the role of neuropsychological deficits in preschool ADHD. As deficient neuropsychological functioning has been proposed to be an underlying causal factor in ADHD, and because it could possibly serve as an alternative method of classifying ADHD, a critical perspective is necessary. The results of the present study raise some important concerns. First, a substantial proportion of preschool children with ADHD did not have neuropsychological deficits in any domain. This was found even though we included executive, delay-related, as well as emotional aspects. Second, significant group differences with large effect sizes were found for all measures of functional impairments. However, within each domain of functioning there were also subgroups of children without impairment. The results also showed that neuropsychological deficits could not explain these individual variations in daily life functioning among children with ADHD. Finally, we demonstrated very clearly that the type of measurement method chosen has a great impact on which children were considered to have a neuropsychological deficit. Below, we discuss each of these critical issues in more detail.

Neuropsychological subgroups in ADHD

Regarding the laboratory measures, group differences were found within all neuropsychological domains. However, in line with previous meta-analyses (Pauli-Pott & Becker, 2011; Schoemaker et al., 2012), the effect sizes were most often in the medium range. In line with recommendations (e.g., Nigg et al., 2005), we also included person-oriented analyses and were able to show that although significant group differences were found within all neuropsychological domains, the proportion of children categorized as having a deficit was never above 43% for any single test. In addition, the present study included more neuropsychological domains than previous preschool studies, but there was still a substantial proportion (i.e., 23%) of children in the ADHD group for whom no deficits were found. Similar estimates have been reported in previous studies of school-age children (Coghill et al., 2014; Nigg et al., 2005; Sonuga-Barke et al., 2010; Wåhlstedt et al., 2009). This indicates that if we classify children based solely on neuropsychological deficits, many will not be classified as having a disorder even though they show clinically significant impairments in at least two settings, as specified in the DSM-5 criteria for ADHD (American Psychiatric Association [APA], 2013). It should be noted that the cut-off for what is considered a “deficit” in the neuropsychological domain is arbitrary. The cut-off employed here was chosen based on previous studies using the same analysis so as to enable comparison (Nigg et al., 2005; SjöWall et al., 2013). It is beyond the scope of the present study to determine where the cut-off should best be made, but we consider this type of analysis useful in illustrating that a substantial proportion of preschool children are not considered to have neuropsychological deficits as measured using laboratory tasks. These results were found even though the cut-off was based on the scores of a control group with low ADHD levels and the number of children with a neuropsychological impairment in the ADHD group was therefore most likely overestimated rather than underestimated.
When investigating the overlap between different neuropsychological deficits, the results of the present study are in line with those from previous studies (Sonuga-Barke et al., 2010, 2003), in that executive deficits and delay-related behaviors both contributed independently to the explained variance. However, deficits in emotional functioning almost completely overlapped with the other neuropsychological deficits included in the study. More specifically, about one fifth of the ADHD group had executive deficit only and one fifth had delay-related deficits only, whereas the proportion with emotional deficits only was very small (i.e., 3%). This finding is in contrast with results from previous studies of preschoolers, which have found independent effects of executive deficits and emotional functioning (Forslund et al., 2016; Healey et al., 2011; SjöWall et al., 2015). However, it is important to emphasize that previous studies have used teacher/caregiver reports to examine emotional functioning, whereas laboratory measures were used to assess executive deficits. It is, therefore, likely that previous research has underestimated the overlap between emotional functioning and other neuropsychological functions. In line with this interpretation, there was an 86% overlap between the three neuropsychological domains in the present study when teacher reports were used. It is also important to emphasize that all previous studies investigating the overlap between executive and emotional functioning have used variable-oriented analyses and studied relations to ADHD symptom severity, not ADHD diagnosis. Thus, the present study contributes valuable new information by examining the overlap between executive and emotional functioning in a clinical sample using a person-oriented approach, and this allows the results to be more easily applied in clinical practice (cf. Nigg et al., 2005).

The relation between neuropsychological deficits and functional impairments

Significant differences with large effect sizes were found between controls and children with ADHD with regard to all measures of functional impairments. When investigating the link between neuropsychological deficits and functional impairments, results showed that after excluding a few bivariate outliers, all relations were significant when including all participants, whereas no significant relations were found in the analyses including only the ADHD group. These results should not be related to restriction of range as there were variations in the scores within each domain of functioning also within the ADHD group. As described in the introduction, previous studies have been inconsistent with regard to the link between executive deficits and social functioning with peers and family (e.g., Diamantopoulou et al., 2007; Huang-Pollock et al., 2009; Kofler et al., 2011, 2017; Rinsky & Hinshaw, 2011; whereas deficits in emotion regulation have consistently been shown to be associated with peer functioning (e.g., Anastopoulos et al., 2011; Melnick & Hinshaw, 2000; Sjöwall & Thorell, 2014; Thorell et al., 2017). Delay-related behaviors have primarily been shown to be associated with addictive behaviors and risk taking (e.g., MacKillop et al., 2011; Sørensen et al., 2017). These inconsistencies may be related to how neuropsychological deficits are operationalized (i.e., index scores or single measures). In addition, it should be noted that spurious relations between neuropsychological deficits and functional impairments can be found when including two discrete subgroups within the same correlation analysis. This could also explain why we in the present study consistently
found significant correlations between neuropsychological deficits and functional impairments when studying the whole sample, but not within the ADHD group. Conclusively, the results of the present study indicate that identifying neuropsychological subgroups within an ADHD sample does not appear to be so important for understanding variations in daily life functioning, at least not in preschool. However, further studies within this area of research are clearly needed as previous studies have not examined relations between neuropsychological deficits and functioning impairment within children with ADHD and only school-aged samples have been investigated. It should also be important for future to examine to what extent neuropsychological deficits identified in preschool are predictive of functional impairments as the child makes the transition into school.

**Methodological challenges in the assessment of neuropsychological deficits**

As noted above, the measurement chosen to assess different neuropsychological deficits will have a great impact on the results, and we argue that both laboratory measures and teacher/caregiver reports have their own strengths and limitations. Toplak and colleagues (2013) suggested that one important distinction is that between typical and optimal performance. In line with this, we suggest that some children with ADHD have a maximum capacity within the normal range when tested on neuropsychological laboratory measures in a structured situation, but still have serious functional impairments, because they are unable to access this capacity in daily life when left unsupervised. This might explain why the present study as well as previous studies have found that a relatively large proportion of children with ADHD are not categorized as having neuropsychological deficit when laboratory measures are used, whereas almost all of them are classified as impaired when teacher reports are employed. Teacher/caregiver reports have been argued to have higher ecological validity (Barkley & Murphy, 2010), but unfortunately they do not appear to be specific enough. As seen in the present study, teacher reports of executive deficits, delay-related behavior and emotion regulation were shown to overlap almost completely. Because this finding is not in line with the results from laboratory measures, it could be taken as an indication that raters are influenced by their view of the child as generally problematic and that raters are less able to pinpoint specific neuropsychological deficits.

Given that most previous studies have assessed emotional functioning using teacher/caregiver reports only, we included several laboratory measures. However, as discussed above, few significant differences between children with ADHD and controls were found. One likely reason why most previous studies have used teacher/caregiver reports to assess emotional deficits is that it is challenging to design reliable and valid tasks that evoke specific emotions in a laboratory setting. Moreover, children react differently to the same situation based on their previous experiences. For example, we noted that although all children noticed that pieces were missing in the Impossible Lego Task, the children in the ADHD group appeared to not fully trust their own judgment that pieces were missing, possibly because they were more used to experiencing failure. This may explain why fewer children with ADHD reacted with negative emotions in this task compared to controls. Further research assessing emotional functioning in preschoolers
with ADHD is clearly needed to establish that there is no pure emotional subgroup. In this respect, we believe further methodological development is of great importance.

**Limitations, conclusions, and future directions**

Some limitations need to be considered. The sample size was relatively small in comparison with previous ADHD studies of school-age children. However, in comparison with previous preschool studies, the sample size was large, and all children in the ADHD group were clinically referred. Another issue concerns the choice of tasks. Although the present study had the advantage of including many ways of measuring emotional functioning, it is possible that other laboratory measures are more suitable for capturing these deficits. With regard to reliability of the measures, the internal consistency was low for the subscales “peer problems” and “family life” when rated by parents. However, Cronbach alpha values were acceptable for all other subscales and the results were highly consistent across all subscales in showing larger functional impairments in children with ADHD as compared to controls. In addition, the internal consistency was only low for the control group. In order to avoid source bias, we used teacher ratings for assessing neuropsychological functioning and ratings from both teachers and caregivers for assessing functional impairments. Unfortunately, we did not collect information about teacher characteristics, which is a limitation. Finally, it should be mentioned that the current findings might not generalize to preschool children with low cognitive functioning, as children with an IQ score below 70 were excluded from the study.

In conclusion, the present study shows that the type of measurement used (i.e., teacher/caregiver reports or laboratory measures) can greatly influence the results, regarding both the overlap between different functions and associations with ADHD. In addition, previous indications of a pure emotional subgroup within ADHD could be questioned, at least in preschool children. Finally, a substantial subgroup of preschool children with ADHD do not have any neuropsychological deficits. Neuropsychological deficits could not explain individual variations in functional impairments among children with ADHD. Taken together, in our view we are currently not at a stage where we can implement an ADHD nosology based on neuropsychological deficits. A major problem with such a classification system is that we end up with a substantial subgroup of children who have severe functional impairments in daily life, but who show no neuropsychological deficits and are, therefore, “undiagnosed” in the new system. However, regardless of whether or not neuropsychological subgroups within ADHD can be used for diagnostic purposes, future longitudinal follow-up studies should be conducted to determine whether neuropsychological deficits could act as moderators of treatment effects or development. Such longitudinal investigations should preferably begin during the preschool years, because early identification of problem behaviors must be considered a priority (cf. Sonuga-Barke & Halperin, 2010). As clearly shown in the present results, it is also essential that future research focus on making methodological advancements.

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References


