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Neuropsychological deficits in preschool as predictors of ADHD symptoms and academic achievement in late adolescence

Douglas Sjöwall[1], Gunilla Bohlin[2], Ann-Margret Rydell[2], and Lisa B Thorell[1]

[1]Department of Clinical Neuroscience and Stockholm Brain Institute, Karolinska Institutet, Stockholm, Sweden
[2]Department of Psychology, Uppsala University, Sweden

High levels of ADHD symptoms are related to severe negative outcomes, which underscore the importance of identifying early markers of these behavior problems. The main aim of the present study was therefore to investigate whether neuropsychological deficits in preschool are related to later ADHD symptoms and academic achievement, over and above the influence of early ADHD symptom levels. The present study is unique because it includes a broader range of predictors compared to previous studies and the participants are followed over time for as long as 13 years (i.e., ages 5–18 years). Preschool data included measures of executive functioning and reaction time variability as well as emotional reactivity and emotion regulation of both positive and negative emotions. When controlling for early ADHD symptom levels, working memory, reaction time variability, and regulation of happiness/exuberance were significantly related to inattention whereas regulation of happiness/exuberance and anger reactivity were significantly related to hyperactivity/impulsivity. Furthermore, working memory and reaction time variability in preschool were significantly related to academic achievement in late adolescence beyond the influence of early ADHD symptoms. These findings could suggest that it is possible to screen for early neuropsychological deficits and thereby identify children who are at risk of negative outcomes. Furthermore, our results suggest that interventions need to look beyond executive functioning deficits in ADHD and also target the role of emotional functioning and reaction time variability. The importance of including both the positive and negative aspects of emotional functioning and distinguishing between emotion regulation and emotional reactivity was also demonstrated.

***Keywords*:** ADHD; Executive function; Emotion regulation; Academic achievement; Longitudinal.

Attention deficit hyperactivity disorder (ADHD; American Psychiatric Association, 1994) is one of the most common psychiatric disorders of childhood, and it has been shown to be

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Address correspondence to Lisa Thorell, Division of Psychology, Department of Clinical Neuroscience, Karolinska Institutet, Nobels Väg 9, 171 65 Solna, Sweden. E-mail: lisa.thorell@ki.se

associated with a range of negative outcomes during both childhood and adulthood (for a review, see, for example, Barkley, 2006). The severe negative impact of ADHD underscores the importance of identifying early markers of the disorder. These predictors should be identified as early as possible, because interventions are more likely to be successful if implemented early, before the disorder has been complicated by associated behavior problems (cf. Sonuga-Barke & Halperin, 2010). The major aim of the present study was therefore to investigate whether neuropsychological deficits in preschool are related to later ADHD symptoms, over and above the influence of preschool ADHD symptom levels. We also posed this question in relation to academic achievement as we argue that it is important to study predictors not only for ADHD, but also for the functional impairments associated with the disorder. The present study is unique, as it includes a broader range of predictors than previous studies and the participants are followed over time, for as long as 13 years.

The Role of Early Neuropsychological Deficits for Later ADHD Symptoms

Numerous studies have shown that ADHD is related to multiple neuropsychological deficits, with some individuals with the disorder displaying a single deficit, others multiple deficits, and yet others no clear neuropsychological deficits at all (for reviews, see Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Thus, it is important to take this neuropsychological heterogeneity into account when investigating the development of ADHD. The strongest empirical support has been found for links between ADHD and deficits in various executive functions, such as inhibition, working memory, and cognitive flexibility (e.g., Barkley, 2006; Schoemaker, Mulder, Deković, & Matthys, 2013). Two other candidate neuropsychological deficits in ADHD are reaction time variability (e.g., Castellanos et al., 2005; Tamm et al., 2012) and emotional dysregulation (Martel, 2009; Shaw, Stringaris, Nigg, & Leibenluft, 2014). Interestingly, previous studies of concurrent relations have also shown that emotion regulation deficits are related to ADHD independently of deficits in executive functioning both in school-aged children (e.g., Sjöwall, Roth, Lindqvist, & Thorell, 2013), and in preschool samples (Healey, Marks, & Halperin, 2011; Sjöwall, Backman, & Thorell, 2015). Similarly, independent effects of reaction time variability and executive functioning have also been found in relation to ADHD (Kuntsi, Oosterlaan, & Stevenson, 2001; Sjöwall et al., 2013; Wåhlstedt, Thorell, & Bohlin, 2009). By including a large range of different neuropsychological functions, the present study hopes to generate more in-depth knowledge of the overlap between different functions and determine how much of the variance in ADHD symptoms in adolescence can be explained by preschool neuropsychological deficits.

Previous longitudinal studies examining the link between neuropsychological functioning and ADHD are limited in that they have mostly investigated concurrent relations in school-aged children. As argued by, for example, Sonuga-Barke and Halperin (2010), early intervention is more likely to have an impact, as brain plasticity appears to be greatest during the early developmental stages, and associated behaviors and attitudes have not yet been consolidated. Thus, predictors of later problem behaviors are more valuable if they can be identified early. Here, studies of clinical samples need to be complemented with studies examining the predictive power of hypothetical markers of ADHD in community samples to avoid the referral bias associated with clinical samples (e.g., Goodman, Lahey, Fielding, & Dulcan, 1997).

In the few longitudinal studies that have conducted baseline measurement in early childhood, inhibitory control (i.e., response inhibition or interference control) and delay aversion have most often been significantly related to later ADHD symptoms, but the effect of working memory appear to be less consistent (Berlin, Bohlin, & Rydell, 2003; Bohlin, Eninger, Brocki, & Thorell, 2012; Brocki, Eninger, Thorell, & Bohlin, 2010; Brocki, Nyberg, Thorell, & Bohlin, 2007; Campbell & von Stauffenberg, 2009; Kalff et al., 2002; Marakovitz & Campbell, 1998). Only one longitudinal preschool study has investigated reaction time variability in relation to later ADHD symptoms and this study found a significant effect (Kalff et al., 2005). A general conclusion that can be drawn based on the previous longitudinal studies mentioned above is that the relations between neuropsychological functioning and ADHD appear to be dependent on age, with simple inhibitory tasks and delay tasks being most strongly related to ADHD when measured around 4–5 years of age, whereas working memory or more complex inhibitory control tasks appear to be most strongly related to ADHD symptoms in children who have recently entered school (i.e., around 6 years of age).

Due to the relatively low number of previous longitudinal studies examining early neuropsychological predictors of ADHD, the results presented above should be interpreted with caution, especially because available studies have important limitations. First, follow-ups were conducted only a few years after baseline, which means that we do not know the long-term significance of early neuropsychological deficits. Second, and perhaps more importantly, only three previous studies have taken the role of early ADHD symptom levels into account. As argued by, for example, van Lieshout, Luman, Buitelaar, Rommelse, and Oosterlaan (2013), preschool neuropsychological deficits may simply be a proxy of early ADHD symptom levels if they cannot explain some of the variance in the outcome variable, over and above ADHD severity at baseline. On the contrary, if effects of neuropsychological functioning are also found when controlling for early ADHD symptom levels, this would indicate that these deficits are of clinical relevance in that they are of importance for the development of ADHD.

In the few studies that did control for problem behaviors at baseline, Kalff et al. (2002) found that visuomotor abilities and working memory predicted ADHD symptoms one year later. In addition, there are two studies showing that delay aversion and/or inhibitory control in preschool were significantly related to ADHD symptoms in early school age (Bohlin et al., 2012; Campbell & von Stauffenberg, 2009). Finally, Wåhlstedt, Thorell, and Bohlin (2008) showed that children with executive deficits in preschool had higher symptom levels of inattention, but not hyperactivity, two years later, regardless of whether they had high or low ADHD symptom levels at baseline. It is important to note that none of these three studies included measures of either reaction time variability or emotional dysregulation, despite the fact that previous research has shown that these two functions have been shown to be of major importance for ADHD (for reviews, see Castellanos et al., 2006; Shaw et al., 2014). It is therefore of importance that future research investigate the predictive value of these functions in relation to later ADHD symptoms. Moreover, future research should conduct separate analyses of inattention and hyperactivity/impulsivity, as some of the above-mentioned studies indicate that different neuropsychological deficits may be differentially related to the two ADHD symptom domains.

ADHD and Neuropsychological Functioning in Relation to Later Academic Achievement

There is a need to study predictors not only for ADHD, but also for the functional impairments associated with the disorder. One of the major consequences of ADHD is poor academic achievement as it affects future personal finances, access and ability to pursue higher education, employment, as well as health (Huisman, Kunst, & Mackenbach, 2005; Mackenbach et al., 2008). It is well established that ADHD is associated with poor academic achievement, with up to 56% receiving special education and at least 30% repeating a grade (Barkley, 2010). However, much less is known regarding why problems are more pronounced for some children with the disorder than for others (for reviews, see Daley & Birchwood, 2009; Loe & Feldman, 2007; Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010). It is therefore of interest to examine to what extent early neuropsychological deficits are predictive of later academic problems. It will also be of importance to test a recent model in which ADHD symptoms and neuropsychological deficits are hypothesized to make independent contributions to overall impairment (Coghill, Hayward, Rhodes, Grimmer, & Matthews, 2014). In previous studies of both clinical and non-clinical samples, deficits in executive functioning, especially working memory, have been shown to be of importance in explaining the link between ADHD and poor academic achievement (e.g., Barry, Lyman, & Klinger, 2002; Biederman et al., 2004; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011; Sjöwall & Thorell, 2014; Thorell, 2007). In addition, recent findings suggest that reaction time variability may be another neuropsychological function related to academic problems in children with ADHD (Sjöwall & Thorell, 2014).

One important limitation is that none of the studies mentioned above used a longitudinal design. However, previous research on the same non-clinical sample as that investigated in the present study found that ADHD symptoms and executive functioning deficits at 8½ years of age had additive effects on academic functioning (Diamantopoulou, Rydell, Thorell, & Bohlin, 2007). In addition, a study of girls with ADHD and controls found a relation between deficits in executive functioning at 6–12 years of age and academic functioning at both 11–17 years (Miller & Hinshaw, 2010) and 17–23 years (Miller, Nevado-Montenegro, & Hinshaw, 2012). In summary, more longitudinal studies investigating the additive effects of ADHD symptoms and neuropsychological functions are needed. Importantly, such studies should not only include different executive functions, but also reaction time variability.

Aim of the Study

The first aim of the study was to investigate whether neuropsychological functioning in preschool can predict ADHD symptoms in late adolescence (age 18), over and above early ADHD symptom levels. As it is important to also investigate predictors for the functional impairments associated with ADHD, a second aim was to investigate neuropsychological deficits also in relation to academic achievement in late adolescence, when controlling for early ADHD symptom levels. In order to capture the neuropsychological heterogeneity in ADHD (e.g., Castellanos et al., 2006; Nigg et al., 2005) and for the purpose of addressing the limitations of previous research, we included a broad range of neuropsychological functions (i.e., laboratory measures tapping various executive functions and reaction time variability, as well as parent ratings of emotion regulation) and conducted separate analyses for symptoms of inattention and hyperactivity/impulsivity. The present study has the advantage of including data on predictors as early as the preschool years (i.e., before most children are diagnosed with ADHD; American Psychiatric Association, 2013) and of extending over a much longer time period compared to previous studies with a similar design. By controlling for early ADHD symptom levels, we could examine whether possible relations between neuropsychological deficits and later ADHD symptoms were not simply a proxy of early problem levels, but could contribute to the prediction of future impairment over and above early ADHD symptom levels.

Based on the previous research mentioned above, we hypothesized that preschool neuropsychological functioning would be predictive of future ADHD symptoms (especially for symptoms of inattention) and that executive functioning (especially working memory and reaction time variability) would predict academic functioning.

METHOD

Participants and Procedure

The present study included 128 children (49% boys) who were part of a longitudinal study investigating neuropsychological functioning in children from preschool until late adolescence. A national population-based register, which includes all residents, was used to recruit a random sample of 1000 children, and a few months before the child's fifth birthday, parents received a postal questionnaire covering several areas of the child's socioemotional functioning. A total number of 705 parents completed and returned the questionnaire. From this sample, we selected a subsample of 150 children based on a screening measure for ADHD, which included questions related to impulsivity (e.g., "Has a tendency to do things without thinking of the consequences") and inattention (e.g., "Is easily distracted when performing a task"). To obtain a sample more evenly distributed on this screening measure, we oversampled at both the low and high ends of the distribution (i.e., we selected 50 children from the lowest 30% of the distribution, 50 children from highest 30% of the distribution and 50 children from the middle 40% of the distribution).

At the age of 5 years (*M* = 5 years, 3 months, *SD* = 1.12 months) and 6½ years (*M* = 6 years, 7 months, *SD* = 1.17 months), the subsample of 151 children was seen in the department laboratory. The children were administered a number of different tasks (see detailed descriptions below), and ratings of emotional functioning were collected at the laboratory visit at age 6½. Teacher ratings of ADHD symptoms were collected at age 6 (*M* = 5 years, 11 months, *SD* = 2.54 months). Finally, parent ratings of ADHD symptoms and academic achievement and self-ratings of academic achievement were collected at the age of 18 (*M* = 17 years, 9 months, *SD* = 2.59 months). Only the 128 children (85% of the original sample) who participated at all three data collection points (i.e., at ages 5, 6½ and 18 years) are included in the present study. No significant differences in neuropsychological functioning or ADHD symptoms at age 5–6 years were found between the 128 children who were included in the study and the 23 children who did not have complete data (all *t*s < .81).

MEASURES

The neuropsychological measures were collected at either 5 (response inhibition and reaction time variability) or 6½ years of age (interference control, working memory and emotional functioning). For all neuropsychological measures, high values indicated poor functioning.

Measures Collected at Preschool

Response Inhibition. This was measured using a go/no-go task developed by Berlin and Bohlin (2002). In this task, four different stimuli (a blue square, a blue triangle, a red square, and a red triangle) were presented on a computer screen. During the first part of the task, the children were instructed to press a key when a blue figure appeared on the screen, but to make no response when a red figure appeared. The same stimuli were used for the second part of the task, but the children were instructed to press a key every time they saw a square, and to inhibit their response every time they saw a triangle, irrespective of color. Altogether the task included 60 stimuli with a "go-rate" of 77%. Number of commission errors (i.e., responding to a "no-go stimulus") was used as a measure of poor inhibition.

Interference Control. This was measured using a Stroop-like task developed by Berlin and Bohlin (2002). Participants were presented with four pairs of pictures, where the pictures in each pair were each other's opposites (day–night, large–small, boy–girl, up–down). After ensuring that the child understood what each picture represented, the child was instructed to say the opposite as fast as possible every time he or she saw a picture on the computer screen (e.g., to say "boy" every time a girl was presented). Each stimulus was presented during a time interval of 1500 ms (1000 ms for the second part of the task), followed by a response time of 1500 ms and a waiting period of 1500 ms before the next stimulus was presented. Number of errors on this task was used as a measure of interference control.

Working Memory. This was measured using the Kaufman Hand Movements Test (Kaufman & Kaufman, 1983), in which the child is presented with a sequence of hand movements and then asked to repeat the sequence. Altogether the child was presented with 17 different sequences of hand movements, ranging in length from two to six movements per sequence using "fist", "palm", and "side". The result was registered as number of errors, that is, how many times the child was unable to reproduce the sequence of hand movements correctly.

Reaction Time Variability. This was measured using the standard deviations in reaction time on correct trials from the go/no-go task (see description above).

Emotional Functioning. This was measured through parental ratings (95% mothers, 5% fathers) using the Emotion Questionnaire (for a complete version of the questionnaire, see Rydell, Berlin, & Bohlin, 2003). Most studies of emotion regulation have used ratings that include questions both on how often and intensely the child displays different emotions (i.e., emotional reactivity) and on how well he or she can regulate different emotions (i.e., emotion regulation). However, reactivity and regulation have been suggested to be two different aspects of temperament (for a review, see Cole, Martin, & Dennis, 2004). In support of this distinction, regulation and reactivity have been shown to be differentially related to behavioral and functional outcomes (e.g., Eisenberg et al., 1995; Melnick & Hinshaw, 2000; Thorell, Sjöwall, Diamantopoulou, Rydell, & Bohlin, 2014). In the present study, we therefore aimed to generate more in-depth knowledge in this area by using a rating instrument that allowed us to separate emotion regulation from emotional reactivity with regard to both anger and happiness/exuberance. The items measuring emotional reactivity ask how often and intensely the child displays a certain emotion (e.g., "My child often becomes angry and falls in a bad mood"; "When angry or in a bad mood, my child reacts strongly and intensely"; "When my child is forbidden to do something he or she wants to do, he or she reacts strongly and intensely"; "When my child gets in conflict with a peer, he or she reacts strongly and intensely"). Items measuring emotion regulation focus specifically on the regulatory ability of the child in relation to the same emotions (e.g., "When angry, he or she has difficulties calming down on his or her own"; "When my child is forbidden to do something that he or she wants to do, he or she has difficulties calming down on his or her own"; "When my child gets into a conflict with a peer, he or she has difficulties calming down on his or her own"). For both emotional reactivity and emotion regulation, ratings are made on a scale ranging from 1 (do not agree at all) to 5 (fully agree), where higher values indicate higher reactivity or greater emotional dysregulation. This instrument has been shown to have high test-retest reliability and has been validated against other rating instruments (Rydell et al., 2003) and self-report measures (Rydell, Thorell, & Bohlin, 2007).

ADHD Symptoms. In the preschool years ADHD symptoms were measured by teacher ratings using the abbreviated, ten-item version of the Conners Rating Scale (ATRS; Conners, 1990), sometimes referred to as the Conners ADHD Index. Factor analysis (Parker, Sitarenios, & Conners, 1996) has shown that the first six items of the scale tap hyperactivity/impulsivity and inattention (e.g., restless, impulsive, constantly moving around, failing to concentrate), whereas the last four items of the scale measure emotional lability (e.g., temper tantrums, cries easily). As it was important to not use a measure of ADHD symptoms that also included emotional functioning, the last four items were excluded from the scale. This resulted in a six-item scale with an internal consistency, expressed as a Cronbach's alpha of .89. Items were rated on a 4-point scale ranging from 0 (does not apply at all) to 3 (applies very well). Mean score for the six items was used. This scale has been shown to correlate highly with both the hyperactivity/impulsivity subscale (r = .81) and the inattention subscale (r = .78) on the ADHD Rating Scale IV (DuPaul, Power, Anastopoulos, & Reid, 1998), using teacher ratings from 135 8-year-old children (unpublished data). Thus, it corresponds very well with the symptom criteria for ADHD as they are presented in the Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition (DSM-IV; American Psychiatric Association, 1994). We chose to use teacher ratings of early ADHD symptom levels to avoid halo effects as emotional functioning was assessed using parent ratings.

Socioeconomic Status (SES). This was assessed on a scale measuring the parents' highest level of education on a scale from 1 (compulsory school, i.e., 9 years in Sweden) to 6 (doctorate degree). The mean value for the mother's and father's highest educational level was used as a covariate in the analyses.

Measures Collected at Follow-Up in Late Adolescence

ADHD Symptoms. In late adolescence ADHD symptoms were measured using parent ratings on the ADHD Rating Scale IV (DuPaul et al., 1998), which contains items directly corresponding to the 18-symptom criteria as they are described in the DSM-IV (American Psychiatric Association, 1994). Items were rated on a 4-point scale: never or rarely (0), sometimes (1), often (2), or very often (3). The scores presented in the present study are mean scores for the nine items of hyperactivity/impulsivity and the total score for the nine items of inattention.

Academic Achievement. This was measured using the child's grade point average. At the time of the study, Sweden (where the study was conducted) used a grading system where each school subject was scored on a 4-point scale. Information about grade point average was collected from both the adolescent and his/her parent. There was a very high concordance between the grades reported by the two raters ($r = .89$, $p < .001$). In the present study, the grade point average reported by the adolescents themselves was used, except for the ten cases in which only parent ratings were available.

STATISTICAL ANALYSES

First, intercorrelations between the different neuropsychological predictors in preschool were investigated. Next, these predictors were examined in relation to inattention, hyperactivity/impulsivity and academic achievement in late adolescence, controlling for SES and gender. We also reran the analyses controlling for early ADHD symptom levels to ensure that the predictors were not simply a proxy of early symptom levels (cf. van Lieshout et al., 2013). Next, the combined effects of the different predictors were examined using hierarchical regression analyses. In the first step, we entered early ADHD symptom levels, SES, and gender, and in the second step we entered the neuropsychological predictors that were significantly related to the outcome measures when controlling for SES, gender and early ADHD symptoms in the correlation analyses. In line with Cohen (1992), correlation coefficients were interpreted as small ($r = .10$), medium ($r = .30$) or large ($r = .50$).

RESULTS

Early Neuropsychological Functioning in Relation to Later ADHD Symptoms

First, descriptive data for all variables included in the study are presented in Table 1. Second, we examined interrelations between the predictors as well as to what extent the predictors in preschool were related to ADHD symptoms in late adolescence (see Table 2), controlling for SES and gender. The results showed that measures of response inhibition, working memory, and reaction time variability were significantly related to symptoms of inattention, whereas only response inhibition was significantly related to symptoms of hyperactivity/impulsivity at age 18. With regard to the emotional variables, regulation of happiness and anger reactivity were significantly related to both inattention and hyperactivity/impulsivity, whereas regulation of anger was only significantly related to inattention.

Second, we controlled for early ADHD symptom levels in the relation between neuropsychological deficits and later ADHD symptoms, in order to establish that the predictors were not simply a proxy of early symptom levels. The results showed that the relations for working memory, reaction time variability, and regulation of happiness

Table 1 Descriptive Data for All Variables Included in the Study.

	Mean	*SD*	Min–Max
Measures collected at age 18			
Inattention	0.48	0.49	0.00–2.07
Hyperactivity/impulsivity	0.26	0.35	0.00–1.35
Academic achievement	15.15	3.42	5.00–20.00
Measures collected in preschool			
ADHD symptoms	1.48	0.68	1.00–4.00
Response inhibition	1.50	1.41	0.00–6.00
Interference control	1.84	1.45	0.00–6.71
Working memory	6.59	2.39	1.00–12.00
Reaction time variability	0.31	0.17	0.10–1.30
Emotion dysregulation			
Anger	2.41	0.89	1.00–5.00
Happiness/exuberance	2.47	0.87	1.00–4.67
Emotional reactivity			
Anger	2.81	1.03	1.00–5.00
Happiness/exuberance	3.56	0.86	1.25–5.00

Table 2 Intercorrelations (two-tailed) between All Neuropsychological Predictors in Preschool (Upper Part) and Relations between Neuropsychological Predictors in Preschool and Outcomes at Age 18 (Lower Part).

	1	2	3	4	5	6	7	8
Preschool predictors								
1. Response inhibition								
2. Interference control	.22*							
3. Working memory	.15	.31**						
4. Reaction time variability	.17	.27**	.28**					
5. Regulation of anger	−.01	−.18	.11	−.08				
6. Regulation of happiness/exuberance	−.04	−.06	.10	−.05	.43***			
7. Anger reactivity	.09	.03	.13	.13	.44***	.35***		
8. Happiness/exuberance reactivity	−.03	.02	.13	−.04	.15	.32***	.45***	
Outcomes at age 18								
9. Inattention	.24**	.12	**.23***	**.24****	.19*	**.22***	.22*	.04
10. Hyperactivity	.26**	.06	.07	.16	.17	**.25****	**.27****	.08
11. Academic achievement	−.23**	−.19*	**−.36*****	**−.27****	−.10	−.10	−.10	−.04

Note. *$p < .05$; **$p < .01$; ***$p < .001$. All correlations with control for SES and gender (n = 98–128). Bold font indicates significance between neuropsychological predictors and outcomes when controlling for ADHD symptoms in preschool.

remained significant for inattention (see Table 2). For hyperactivity/impulsivity, regulation of happiness and anger reactivity remained significant.

Regression Analyses

In the next step, we used hierarchical regression analyses to investigate the combined effect of different neuropsychological functions in relation to ADHD symptoms in late adolescence. The results showed that preschool ADHD symptoms, gender and SES explained about 12% of the variance in inattention, with

Table 3 Regression Analyses Examining Independent Effects and Overall Explained Variance of Early Predictors of ADHD Symptoms and Academic Achievement at Age 18.

	ß	R^2 change
Inattentive symptoms		
Step 1		.12**
ADHD	.28**	
SES	−.06	
Gender	.15	
Step 2		.17***
Working memory	.15	
Reaction time variability	.28**	
Dysregulation of happiness	.27**	
Hyperactivity/impulsivity		
Step 1		.08*
ADHD	.24*	
SES	−.16	
Gender	−.05	
Step 2		.08*
Dysregulation of happiness	.17†	
Anger reactivity	.18†	
Academic achievement		
Step 1		.15**
ADHD	− .29**	
SES	.23*	
Gender	−.05	
Step 2		.15***
Working memory	−.25**	
Reaction time variability	−.24*	

Note. †$p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$.

neuropsychological functioning contributing an additional 17% (see Table 3). Reaction time variability as well as regulation of happiness/exuberance contributed independently to the explained variance in inattention. With regard to symptoms of hyperactivity/impulsivity, preschool ADHD, gender and SES explained about 8% of the variance in hyperactivity/impulsivity in the first step, and neuropsychological functioning an additional 8% in the second step. Regarding independent effects, no significant effects were found.

Neuropsychological Deficits in Relation to Academic Achievement

Our next research question concerned to what extent neuropsychological functioning in preschool is related to academic achievement in late adolescence. The results showed that none of the emotional variables, but all other neuropsychological variables, were significantly related to academic achievement (see Table 2). We also reanalyzed the data using separate measures of mathematics, Swedish and English rather than grade point average and the same pattern of results was found. In the regression analyses, the results showed that early ADHD symptom levels, SES, and gender explained about 15% of the variance in academic achievement, with early ADHD symptom levels having an independent effect (see Table 3). In the second step of the regression analysis, neuropsychological functioning added an additional 15%. Working memory and reaction time variability contributed independently when controlling for early ADHD symptom levels, SES, as well as for the overlap between different neuropsychological functions.

DISCUSSION

Previous studies have also found longitudinal relations between neuropsychological deficits and ADHD (for a review, see van Lieshout et al., 2013). However, the present study also extends previous findings by showing that these relations remain even when studying the predictors in preschool, conducting the follow-up in late adolescence, and controlling for early ADHD symptom levels. In contrast to previous studies, we also included a broad range of neuropsychological deficits and analyzed the symptom domains separately. Together, the findings of the present study could be interpreted as indicating that it is possible to screen for early neuropsychological deficits and thereby identify children who may be at risk for long-term negative outcomes with regard to both ADHD symptoms and academic achievement.

Early Neuropsychological Functioning and Later ADHD Symptoms

The strength of the correlations between the neuropsychological variables and ADHD symptoms at follow-up were slightly smaller (in the small-to-medium range rather than medium) compared to what has been found in previous longitudinal studies (van Lieshout et al., 2013). However, these studies investigated the predictive relations over just a few years whereas our time span was as long as 13 years. It should also be noted that the strength of the relation between early neuropsychological functioning and later ADHD symptoms exceeded the strength of the relation between early ADHD symptoms and outcomes with regard to both inattention and hyperactivity/impulsivity. Below, we discuss our findings in more detail with regard to the different aspects of neuropsychological functions that were included in the study.

Executive Functioning and Reaction Time Variability

When studying partial correlations, we found effects of preschool inhibition and working memory on later ADHD symptoms. This is in line with previous longitudinal studies on preschoolers that have also found a significant effect of early inhibitory control (Bohlin et al., 2012; Brocki et al., 2007, 2010; Marakovitz & Campbell, 1998; Rydell et al., 2003), but previous longitudinal studies are less consistent regarding effects of preschool working memory, with one study showing an effect (Brocki et al., 2010) and the other failing to do so (Brocki et al., 2007). It should be noted that none of the previous studies referred to above controlled for early ADHD symptom levels. As argued by, for example, van Lieshout et al. (2013), the neuropsychological predictors may, at best, be viewed as a proxy of early ADHD severity if no such control is applied. When controlling for early ADHD symptom levels, we showed that of the executive functions, only the effect of working memory remained significant in relation to inattention. In the few previous studies that investigated relations to later ADHD symptoms and controlled for early symptom levels, effects have been found for memory and visuomotor abilities (Kalff et al., 2002), as well as for delay aversion and/or inhibitory control (Bohlin et al., 2012;

Campbell & von Stauffenberg, 2009). With regard to relations to the two ADHD symptom domains, our finding that working memory deficits are primarily related to inattention is in line with both theoretical formulations and previous empirical data (e.g., Nigg et al., 2005; Wåhlstedt et al., 2008).

Attempting to draw a more general conclusion based on the results of both the present study and previous findings is difficult due to the few studies available. However, it would seem that differences between studies could perhaps be explained as an effect of participant age and difficulty of the tasks used to study executive functioning. For example, Brocki et al. (2010) showed that a simple go/no-go task measured at 4–6 years of age was significantly related to ADHD symptoms two years later, but not the same task when measured at 5–7 years of age. However, both working memory and a more complex inhibitory task at 5–7 years of age were related to later ADHD symptoms. This is in line with the idea that in order to obtain significant relations between neuropsychological deficits and ADHD symptoms, the task has to be easy enough so that normally developing children can master it, but difficult enough so that children with ADHD, who are believed to be delayed with regard to these functions, will not yet be able to perform well (Barkley, 1997).

Yet another significant effect in relation to symptoms of inattention was that of reaction time variability. This was also seen in a previous study, where reaction time variability measured at 5–6 years of age discriminated between ADHD children and both pathological and healthy controls at follow-up 18 months later (Kalff et al., 2005). The present study provides important new information regarding the role of reaction time variability in ADHD by showing that (1) it predicts future ADHD independent of both other neuropsychological functions and early ADHD symptoms, and (2) it is not only related to ADHD symptoms but to secondary impairments of the disorder such as poor academic achievement (see discussion below).

Emotional Functioning

Several aspects of emotional functioning were related to both ADHD symptom domains when studying partial correlations. Few previous studies have acknowledged the role of positive emotions in the development of ADHD, and the present study therefore contributes with new important findings regarding the long-term significance regulation of happiness/exuberance. In previous research, the general assumption has been that having a positive and cheerful mood is associated with adaptive outcomes, but the present study suggests that more unrestrained excitement, like being too wound up at a party or being overly excited when one wins a contest, is something qualitatively different. The findings of two previous studies investigating the role of positive emotions in relation to ADHD were similar to those obtained in the present study, with a significant concurrent relation found between regulation of happiness/exuberance and ADHD symptoms, even when controlling for other neuropsychological deficits (Sjöwall et al., 2013, 2015). In conclusion, there are both clinical and non-clinical studies, conducted among preschool as well as school-aged children, suggesting that the role of positive emotions needs to be acknowledged if we are to fully understand the link between ADHD and emotional functioning. The present results are also in line with previous findings showing that it is important to distinguish between reactivity and regulation, as these two constructs do not show the same relations to different outcomes (Eisenberg et al., 1995; Melnick & Hinshaw, 2000; Thorell et al., 2014). As emphasized by Shaw et al. (2014), there is a need for a clearer conceptualization of the different aspects of emotional functioning within the field of ADHD research. The present study contributes important new information to such efforts by (1) acknowledging the overlap with other predictors (e.g., executive functions), (2) including both positive and negative emotions, and (3) separating emotional reactivity and emotion regulation.

Neuropsychological Deficits in Relation to Academic Achievement

In addition to studying relations to ADHD symptoms, it should also be considered important to investigate to what extent neuropsychological deficits are related to the functional impairments associated with the disorder and the present study therefore studied relations to academic achievement. Our finding that neuropsychological functioning and ADHD symptoms in preschool had additive effects on academic achievement in late adolescence is in line with the theoretical model recently presented by Coghill et al. (2014), in which neuropsychological deficits and ADHD symptoms are described as being at the same level of analysis, with both functions making independent contributions to overall impairment. In addition, the present results are in line with previous empirical studies revealing a link between executive functioning and academic achievement while taking ADHD into account (e.g., Barry et al., 2002; Biederman et al., 2004; Miller & Hinshaw, 2010; Rogers et al., 2011; Sjöwall & Thorell, 2014; Thorell, 2007). The importance of working memory deficits was also demonstrated in a longitudinal design that stretched into early adulthood, much like in the present study, but that sample consisted only of girls (Miller et al., 2012). Moreover, the present study added to previous research by showing that not only working memory, but also reaction time variability, shows independent effects in relation to academic achievement. This is in line with a previous study showing that reaction time variability partially mediates the relation between ADHD and academic achievement (Sjöwall & Thorell, 2014). Of importance is that both the present longitudinal study of a non-clinical sample and the clinical study by Sjöwall and Thorell (2014) showed that an effect of reaction time variability on academic achievement was also found when controlling for the overlap between different neuropsychological functions. Thus, the results of the present study provide further support for the notion that reaction time variability should not be considered a secondary complication of a primary deficit in executive functioning. In fact, high reaction time variability appears to reflect a central deficit in ADHD that is of almost equally large importance for later academic achievement as working memory deficits, and this needs to be acknowledged in future research.

Finally, it is worth noting that while preschool emotional functioning deficits (especially dysregulation of happiness/exuberance) were strongly related to ADHD symptoms in late adolescence, no such effects were seen in relation to academic achievement. This indicates that, unlike working memory deficits or high reaction time variability, emotional deficits (i.e., at least not reactivity or regulation with regard to anger and happiness/exuberance) do not pose an additional risk for poor academic achievement. However, previous research has shown that the subgroup with emotional deficits may be at risk for encountering other secondary impairments, such as peer problems (e.g., Sjöwall & Thorell, 2014; Thorell et al., 2014) or substance abuse (e.g., Sobanski et al., 2010).

Limitations, Future Directions and Conclusions

The results of the present study raise some questions that could not be addressed within the current design. First of all, the present study did not include any measure related to motivational aspects such as delay aversion, even though the effect of delay aversion on ADHD symptoms appears to be strongest during the preschool years (Pauli-Pott & Becker, 2011), and delay aversion in preschool has also been shown to be predictive of later ADHD symptoms (Campbell & von Stauffenberg, 2009). In addition, future studies need to include laboratory measures of emotional functioning, as there is always a risk of overestimating a relation when both the predictor and the outcome variable are measured using rating scales. Moreover, future studies should include multiple informants, as there may be differences in the association between predictors and ADHD symptoms due to the source of the rater (Kooij et al., 2008). Also, we would like to emphasize the need for future studies to collect data from large samples of preschool children, preferably including both clinical and non-clinical samples, and follow these children over time to investigate whether it is possible to identify neuropsychological subtypes that are at especially high risk for developing ADHD symptoms and serious functional impairments. Using larger samples would also increase the power to detect interaction effects between different neuropsychological functions and would also enable the use of structural equation modeling to investigate relations to the two ADHD symptom domains using factor scores (e.g Martel, Roberts, Gremillion, von Eye, & Nigg, 2011).

Conclusively, our findings show that preschool neuropsychological deficits have an impact on ADHD symptoms and academic achievement in late adolescence, beyond the influence of early ADHD symptoms. Thus, early neuropsychological deficits have a true predictive value for the development of these outcomes. With regard to specific neuropsychological functions, our results indicate that we need to look beyond executive functioning deficits in ADHD and also investigate the role of emotional functioning and reaction time variability.

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