



Functional Impairments in Attention Deficit Hyperactivity Disorder: The Mediating Role of Neuropsychological Functioning

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Attention deficit hyperactivity disorder (ADHD) is associated with multiple neuropsychological deficits and the present study aimed to investigate to what extent these deficits are related to the functional impairments associated with the disorder. The results showed that all executive functioning deficits and reaction time variability acted as mediators in the relation between ADHD and academic achievement. However, only the effect of working memory for language skills, and the effects of reaction time variability and working memory for mathematics, remained significant when studying independent effects. Regulation of anger was a significant mediator for peer problems. Gender or symptoms of oppositional defiant disorder (ODD) or conduct disorder (CD) did not moderate these findings.

In addition to the three major symptoms of the disorder—hyperactivity, impulsivity, and inattention—children diagnosed with attention deficit hyperactivity disorder (ADHD) often encounter problems in daily life, such as poor academic achievement (e.g., Daley & Birchwood, 2009; Loe & Feldman, 2007) and problematic peer relations (e.g., Hoza, 2007, and McQuade & Hoza, 2008 for reviews). As these functional impairments are associated to such a large extent with ADHD, theoretical models should be able to explain not only the symptoms of ADHD but also the functional impairments associated with the disorder. At the neuropsychological level, ADHD has been described as a heterogeneous disorder (e.g., Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005) that involves deficits in multiple functions such as executive functions (Barkley, 1997), delay aversion (e.g., Sonuga-Barke, 2002), reaction time (RT) variability (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006), and emotional functioning (e.g., Martel, 2009; Sjöwall, Roth, Lindqvist, & Thorell, 2013). However, it is not known to what extent this neuropsychological heterogeneity can explain why some individuals with ADHD develop functional impairments, whereas others manage relatively well in their daily life. In the present study, we therefore investigated a large range of neuropsychological deficits as possible mediators in the relation between ADHD and two of the most central aspects of daily functioning in childhood: academic achievement and peer problems.

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ADHD, ACADEMIC ACHIEVEMENT, AND NEUROPSYCHOLOGICAL FUNCTIONING

Most previous studies examining the link between ADHD and academic achievement have not taken the neuropsychological heterogeneity in ADHD into account, but have instead focused exclusively on executive function (EF) deficits. For example, Biederman and colleagues (2004) found that ADHD children with EF deficits performed worse than ADHD children without EF deficits, but a more recent study using the same analytical design showed no such differences (Lambek et al., 2010). In addition, some studies have used dimensional measures of EFs and found independent effects on academic performance, when controlling for ADHD (Barry, Lyman, & Klinger, 2002; Diamantopoulou, Rydell, Thorell, & Bohlin, 2007; Miller & Hinshaw, 2010; Miller, Nevado-Montenegro, & Hinshaw, 2012; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). One limitation of the studies mentioned above is that no formal mediation analyses were conducted, which means that they failed to investigate to what extent the relation between ADHD and academic achievement was significantly reduced when the effect of EF deficits was taken into account. When conducting such analyses, it was found that EF deficits partially mediated the relation between inattention and both language skills and mathematics in a non-clinical preschool sample (Thorell, 2007). A second limitation of previous studies is that executive functioning has often been analyzed as a composite of several functions. However, specific EFs may be differentially related to functional impairments. Non-clinical studies have shown, for example, that working memory appears to be of most importance for academic achievement (Lan, Legare, Pontiz, Li, & Morrison, 2011; Thorell, 2007; Thorell, Veleiro, Siu, & Mohammadi, 2013). Other possible mediators of the relation between ADHD and academic achievement have not been examined, although a few non-clinical studies have shown that motivationally based functions, such as delay aversion and delay of gratification, are not significantly related to academic achievement when EF deficits are controlled for (e.g., Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Thorell, 2007).

ADHD, PEER PROBLEMS, AND NEUROPSYCHOLOGICAL FUNCTIONING

Regarding the relation between ADHD, EF deficits, and peer problems, almost all previous studies have used broad measures of social functioning and/or composite EF measures. One exception is the study by Miller and Hinshaw (2010), which showed a small, but significant, effect of commission and omission errors on a continuous performance task on measures of peer acceptance. However, most other studies (but see Rinskey & Hinshaw, 2011) have found that EF deficits are not significantly related to more general measures of social functioning when the effect of ADHD symptoms is taken into account (Biederman et al., 2004; Diamantopoulou et al., 2007; Huang-Pollock, Mikami, Piffner, & McBurnett, 2009; Scholtens, Diamantopoulou, Tillman, & Rydell, 2012). With regard to other neuropsychological functions besides EF deficits, Scholtens and colleagues (2012) included RT variability, which was found to be related to social acceptance, but not when symptoms of ADHD were controlled for.

Altogether, the previous findings presented above indicate that EF deficits and RT variability are not strongly associated with social functioning, although there is a need to investigate independent effects of different EF functions in relation to specific aspect of social functioning such as peer problems. In addition, the effects of other neuropsychological functions have to be taken into

account. In the present study, we therefore included measures of emotional functioning, as this has been acknowledged to be of importance in ADHD (e.g., Martel, 2009; Nigg, 2006). We have chosen to focus on two aspects of emotional functioning that have been linked to ADHD in previous research: emotion recognition (e.g., Kats-Gold, Besser, & Priel, 2007; Sinzig, Morsch, & Lehmkuhl, 2008; Yuill & Lyon, 2007) and emotion regulation (e.g., Maedgen & Carlson, 2000; Walcott & Landau, 2004). Both emotion regulation and emotion recognition have been shown to be related to social abilities in studies in non-clinical samples (e.g., Eisenberg, Hofer, & Vaughan, 2007; Mostow, Izard, Fine, & Trentacosta, 2002), but very few clinical studies of children with ADHD have examined this relation. One exception is the study by Anastopoulos and colleagues (2011), which demonstrated that emotional liability partially mediated the relation between ADHD status and social skills. In addition, Kats-Gold and colleagues (2007) showed that difficulty with recognizing emotions was related to a general measure of social skills among children with ADHD, but not specifically to peer ratings of social acceptability. No previous study has investigated the effect of multiple mediators simultaneously. Thus, it is not known to what extent different neuropsychological mediators overlap in explaining the link between ADHD and peer problems. In addition, the mediating effects of different types of emotions (i.e., anger, fear, sadness, and happiness) on peer problems have not been investigated.

Finally, it is important to investigate possible moderators in the relation between ADHD and functional impairments. Few studies exist, although there are some indications that girls with ADHD have more peer problems than do boys with the same disorder (Henricsson & Rydell, 2006), and it has been suggested that EF deficits may be more strongly related to peer problems in girls than in boys (Diamatopoulou et al., 2007). In addition, some previous studies (e.g., Martel, 2009, for a review) have suggested that emotion regulation deficits may be particularly evident in the subgroup of children with ADHD and comorbid oppositional defiant disorder (ODD) or conduct disorder (CD).

AIMS

The aim of the present study was to investigate to what extent EF deficits, delay aversion, RT variability, and emotional functioning (deficits in emotional regulation and emotion recognition) function as mediators in the relation between ADHD and two of the most important aspects of daily functioning in middle childhood: academic achievement and peer problems. In order to address the limitations of previous research, we conducted full mediation analyses using a statistical method that allowed us to investigate the independent contributions of different neuropsychological deficits. As most previous studies have failed to investigate the moderating effects of gender and ODD/CD, we also explored this issue.

Based on the previous research presented above, we hypothesized that EF deficits would act as mediators in the relation between ADHD and academic achievement, but not between ADHD and peer problems. Among the EF measures, we expected working memory to be the strongest mediator for academic achievement. The lack of previous studies including RT variability in relation to functional impairments limits any a priori hypothesis. Regarding delay aversion, we hypothesized that this function would not mediate the relation between ADHD and academic achievement. Finally, we expected the emotional variables, but not the other neuropsychological variables, to be significant mediators in the relation between ADHD and peer problems.

METHOD

Participants

The present study included 102 children (56 girls) age 7–13 years ($M = 10.39$, $SD = 1.79$) and diagnosed with ADHD and a control group of 102 children ($M = 10.37$, $SD = 1.69$) individually matched to the clinical group with regard to gender and age (± 6 months). The ADHD sample included clinically referred children. As one aim was to study gender differences, girls were oversampled. All children had been formally diagnosed with ADHD by a psychiatrist, and the children's diagnostic status was confirmed at the time of the study using both parent and teacher ratings of the ADHD Rating Scale IV (DuPaul, Power, Anastopoulos, & Reid, 1998). The *mean* score for the ADHD Rating Scale IV was 30.20 ($SD = 7.58$) for parent ratings and 36.56 ($SD = 10.37$) for teacher ratings. We asked the parents at what age the child's symptoms had emerged and for how long time the symptoms had been present. In addition, we asked them to rate on a 4-point scale (0 = not at all, 3 = a great deal) how much the child's difficulties interfere with everyday life in the following areas: home life, friendships, classroom learning, and leisure activities. The two last questions were taken from the impact supplement of the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997). Based on these three questions and in line with DSM-IV criteria (APA, 1994), we confirmed that the symptoms had been present before age 7, for at least 6 months, and that impairment was found in multiple settings. Based on teacher and parent ratings, 71 children (70%) met the criteria for the combined subtype, 4 children (4%) met the criteria for the hyperactive/impulsive subtype and 27 children (26%) met the criteria for the inattentive subtype. Comorbid diagnoses included ODD/CD (44%), generalized anxiety disorder/anxiety NOS (7%), obsessive compulsive disorder (1%), and Tourette syndrome (4%). Children with an IQ < 70 were not recruited to the study. With regard to pharmacological treatment, 31 children (30%) did not receive any medication, 63 children (62%) were on stimulant medication, and 8 children (8%) were on non-stimulant medication (i.e., Atomoxetine). All children receiving pharmacological treatment for ADHD were asked to withdraw medication 24 hours prior to testing. Despite this, 10 children (4 taking stimulants and 6 taking non-stimulants) were on medication during the neuropsychological testing. However, excluding these 10 children did not result in any significant changes in the results.

The control group was recruited through local schools. The exclusion criteria for the control group were: 1) severe psychiatric or somatic problems as reported by parents and 2) scores above the 75th percentile on either the inattention or the hyperactivity subscale on the ADHD Rating Scale IV (DuPaul et al., 1998) as assessed by both teachers and parents. In the control group, the mean score for the ADHD Rating Scale IV was 4.35 ($SD = 3.98$) for parent ratings and 7.59 ($SD = 4.42$) for teacher ratings. The local ethics committee approved the study.

Measures

Neuropsychological assessment. The tests included in this study have all been used in previous publications. The measures were standardized and some measures were reversed so that high values always indicated poor performance. If more than one measure was available within a domain, the mean value of the different measures was used in the analyses.

Working memory was measured using three tasks. Spatial working memory was measured by “Find the phone task” (Sjöwall et al., 2013) using the Psytools software (Delosis, London). This task is very similar in design to the spatial working memory task included in the Cambridge Neuropsychological Test Automated Battery (CANTAB; Owens, Downes, Sahakian, Polkey, & Robbins, 1990). In our version of the task, telephones are shown on the computer screen and the task is to remember which telephone that has already rung to avoid selecting that phone several times. The number of times the children returned to a phone that had already rung was used as a measure of working memory deficit. The Children’s Size-Ordering Task (McInerney, Hrabok, & Kerns, 2005) measured verbal working memory. In this task, the administrator reads aloud progressively longer lists of common objects (e.g., pencil, train, mountain) and the child is asked to repeat them ordered by size of the object, from smallest to largest. The objects included have been selected so that they are familiar to all children, can be visualized easily, and are unambiguous in their relative size. After at least two practice trials, the test begins with two items per trial, and becomes progressively more difficult to a maximum of seven items per trial. All children are administered all trials, regardless of their performance. The total number of word pairs organized in the correct order was used to measure working memory (maximum = 42). Verbal working memory was also measured using the total score for the backward condition of the digit span subtest (Wechsler, 1991). The score used was the total number of correct trials.

Inhibition was measured by two tasks using the Psytools software (Delosis, London). The first task was based on the Go/No-Go paradigm. The particular version used here was originally developed by Berlin and Bohlin (2002) and consists of pictures depicting a blue square, a blue triangle, a red square, and a red triangle, which are presented on a computer screen. During the first part of the task, the child is instructed to press a key (“go”) when a frequent stimulus (a blue figure) appears on the screen, but to make no response (“no-go”) when an infrequent stimulus (a red figure) appears. The same stimuli are used for the second part of the task, but the child is instructed to press a key every time a square is presented, and to inhibit his/her response every time a triangle is presented, irrespective of its color. Altogether the task includes 60 stimuli with a “go-rate” of 77%. The score derived from this task was number of commission errors (pressing the key when a “no-go” target was presented). The second task was a Navon-like task previously used by, for example, Miyake, Friedman, Emerson, Witzki, and Howerter (2000). A circle consisting of small squares, or the opposite, a square consisting of small circles, was displayed on the computer screen and the participants were instructed to either respond to local stimuli (e.g., the small squares making up the circle) or global stimuli (e.g., the circle made up by the squares). In each session, 20 objects (10 squares and 10 circles) were shown. The objects were displayed for 500 milliseconds and the participant had 3,500 milliseconds to give an answer. The score used was the total number of errors for the two sessions (maximum = 40).

Shifting was measured using the Navon-like task (see description above). A third session was performed in which participants were asked to shift between responding to local or global stimuli. A total of 40 trials were presented and a square and a circle in the lower corners of the computer screen indicated what stimulus to respond to (local trials = small circle/square, global trials = large circle/square). Number of errors during this last session was used to measure shifting. Two children in the ADHD group had missing data due to failure to understand the instructions.

Delay aversion was measured using the Choice Delay Task (Sonuga-Barke, Taylor, Sembi, & Smith, 1992). In this task, the child is asked to make 25 choices between an immediate small reward (two seconds for one point) and a delayed large reward (30 seconds for 2 points). Delay

aversion is measured as the number of times the child chooses the small, immediate reward during the final 10 trials. This task has previously been used in for example the NIMH Multimodal treatment study of ADHD (Solanto et al., 2001).

Reaction time variability was measured as the standard deviation of participants' RTs for correct answers on the non-shifting trials in the Navon-like task and correct answers on the Go/No-Go task (see descriptions above).

Emotion regulation was measured by parental ratings on the Emotion Questionnaire developed by Rydell, Berlin, and Bohlin (2003). In the present study, we included the questions measuring how well the child can self-regulate his/her own emotions. This includes a total of 12 questions related to regulation of anger, fear, sadness and happiness/exuberance. For each emotion, one general question is asked (e.g., If sad, my child has trouble calming down by him-/herself) and two questions regarding regulation in specific situations (e.g., if my child has fallen and hurt him-/herself, my child has trouble calming down by him-/herself). Ratings are made on a scale ranging from 1 (do not agree at all) to 5 (fully agree), with higher values indicating greater problems with emotion regulation. The mean score of the items for each emotion was used in the analyses. This instrument has been shown to have high test-retest reliability and it has been validated against both other rating instruments (Rydell et al., 2003) and self-report measures (Rydell, Thorell, & Bohlin, 2007). Six ADHD children had missing data because their parents did not consent to completing the rating scale.

Emotion recognition was measured using facial images selected from the NimStim Set of Facial Expressions (672 images; <http://www.macbrain.org/resources.htm>). The NimStim pictures consist of naturally posed photographs (e.g., with hair, make-up) of 43 professional actors (25 male; 21 to 30 years old) and they have been shown to have both high reliability and high validity (Tottenham et al., 2009). In the present study, we used 36 different faces displaying 6 different emotions: anger, fear, sadness, happiness, surprise, and disgust. For each trial, six different emotions were displayed on the computer screen and the administrator asked the child to identify one emotion (e.g., Who is angry?). A total of 36 trials were used and the score used was number of correct responses for each emotion (maximum score = 6). One ADHD child had missing data. As argued by for example Kats-Gold et al. (2007), this type of simple emotion recognition task is preferable in studies of individuals with ADHD as it has very low demands on working memory compared to more complex tasks (e.g., matching facial effect to story stems).

Functional Impairments

Functional impairments were measured by peer problems and academic achievement. Peer problems were assessed using the "peer relationship subscale" from the SDQ (Goodman, 1997). The SDQ is available in over 30 languages and has been widely used in epidemiological, developmental and clinical research, as well as in routine clinical and educational practice. The peer problems scale in the SDQ includes items such as "generally liked by other children" and "has at least one good friend," and it has been shown to be highly correlated with the corresponding scale in the Child Behavior Checklist (Goodman & Scott, 1999). Ratings were made on a scale from 1 to 5 and the mean scores for parent and teacher ratings ($r = .69, p < .001$) were used. The measure of academic achievement consisted on two separate questions: How do you rate the child's school performance in relation to children in the same age for (a) mathematics (b) language skills. Ratings were made on a scale from 1 to 5 (1 = "much below average"; 2 = "below

average”; 3 = “average”; 4 = “above average”; 5 = “much above average”). Concerning the validity of such ratings, Henricsson and Rydell (2006) showed that teacher ratings of language skills and mathematics are very highly correlated with results on national tests in these two subjects ($r_s = .82, p < .001$). Thus, this measure should be considered a valid measure of children’s performance in school.

Covariates

Child age and sex were included as covariates in all analyses. In addition, intelligence (IQ) was measured using the block design subtest from the WISC–III (Wechsler, 1991), a test that has been shown to correlate highly with full-scale IQ ($r = .93$; Groth-Marnat, 1997). Mean values for the block design subtest were not significantly different when comparing individuals with ADHD ($M = 9.70, SD = 3.67$) and controls ($M = 10.36, SD = 2.88$) $t = 1.37, ns$. The results are reported both with and without controlling for IQ in order to let the reader make his/her own interpretation of the results. This procedure is recommended (e.g., Barkley, 1997) as it has been argued that IQ and executive functioning are not entirely separate constructs.

Statistical Analyses

First, the following three relations were examined: (1) the relations between the independent variable (i.e., ADHD status) and each one of the potential mediators (i.e., neuropsychological deficits), (2) the relation between the independent and the dependent variable (i.e., functional impairments), and (3) the relation between the mediator and the dependent variables when controlling for the independent variable. The first two relations were investigated using independent t -tests. The third relation was investigated using partial correlations, with group status, age and sex as covariates. Control for multiple comparisons was carried out using the Holm-Bonferroni method, which is a sequentially rejective version of the simple Bonferroni correction (Holm, 1979).

Next, we tested for simple and multiple mediation using Preacher and Hayes’ (2008) bootstrapping methodology for indirect effects based on 5000 bootstrap resamples. This method describes the confidence intervals (CI) of indirect effects such that no assumptions are made about the indirect effect being normally distributed. Interpretation of the bootstrap data is accomplished by determining whether zero is contained within the 95% CIs. This method has been argued to be superior to the commonly used Sobel test, as it has higher statistical power while maintaining adequate control over the Type I error rate (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). Age and sex were included as covariates. In line with previous studies (e.g., Anastopoulos et al., 2011; Huang-Pollock et al., 2009), the percentage of the total effect explained by each mediator (i.e., the standardized estimate for the indirect effect divided by the standardized estimate for the total effect) was calculated as a measure of effect size in the mediation analyses.

Finally, possible moderating effects of gender and comorbid ODD/CD were investigated. The main effects of gender and the interaction effects of ADHD status and gender were investigated by computing two-way ANCOVAs with ADHD status and gender as fixed factors, age as the covariate, and the neuropsychological and outcome measures as dependent variables. Next, we conducted a series of regression analyses in which one of the mediators and gender were

entered in the first step and the interaction effect of these two variables in the second step. A non-significant interaction effect indicates that gender is not a significant moderator (i.e., the relation between the mediator and the outcome is equally strong for boys and girls). As concerns ODD/CD, ADHD children with or without comorbid ODD/CD were compared with the control group with regard to the measures of emotional functioning. Second, regression analyses were conducted in which the main effects of emotional functioning and group (ADHD with or without ODD/CD) were entered in the first step and the interaction effect of group and emotional functioning in the second step. A non-significant interaction effect indicates that the relation between emotional functioning and peer problems is equally strong for ADHD children with or without ODD/CD.

RESULTS

Group differences were seen for all proposed mediators except delay aversion and recognition of disgust (see Table 1). Significant group differences were also seen for all three outcome variables.

TABLE 1
Means, Standard Deviations, Results of *t*-Tests, and Effect Sizes Comparing ADHD Children With Controls for All Main Variables in the Study (One-Tailed)

	<i>ADHD</i>	<i>Controls</i>	<i>t</i>	<i>Effect Size</i>
	<i>M (SD)</i>	<i>M (SD)</i>		<i>D</i>
Neuropsychological functions				
Inhibition	0.33 (1.05)	-0.35 (0.71)	5.39***	0.76
Working memory	0.31 (0.96)	-0.29 (0.94)	4.50***	0.63
Shifting	0.29 (1.01)	-0.29 (0.84)	4.44***	0.62
Reaction time variability	0.54 (1.06)	-0.51 (0.59)	8.72***	1.22
Delay aversion	0.08 (1.07)	-0.09 (0.93)	1.18	0.17
Emotion regulation				
Regulation of sadness	3.29 (1.00)	2.06 (0.93)	8.98***	1.27
Regulation of fear	3.05 (1.17)	1.96 (0.86)	7.55***	1.06
Regulation of anger	3.43 (1.09)	1.82 (0.72)	12.45***	1.75
Regulation of happiness	3.36 (1.06)	2.04 (0.89)	9.60***	1.35
Emotion recognition				
Recognition of anger	4.50 (1.37)	5.45 (0.82)	6.01***	0.84
Recognition of fear	2.77 (1.32)	3.64 (1.43)	4.47***	0.63
Recognition of happiness	5.20 (0.95)	5.67 (0.59)	4.28***	0.59
Recognition of sadness	3.33 (1.01)	3.76 (0.83)	3.34***	0.47
Recognition of surprise	3.70 (1.35)	4.28 (1.21)	3.24***	0.45
Recognition of disgust	4.20 (1.44)	4.36 (1.31)	0.82	0.12
Functional impairments				
Language skills	2.34 (0.92)	3.34 (1.02)	7.13***	1.03
Mathematics	2.44 (0.98)	3.47 (1.04)	7.08***	1.02
Peer problems	2.57 (0.76)	1.54 (0.50)	11.43***	1.60

Note. ADHD = attention deficit hyperactivity disorder.

* $p < .05$. ** $p < .01$. *** $p < .001$.

TABLE 2
 Partial Correlations Between Mediators and Functional Impairments, Controlling for Group,
 Gender, and Age (One-Tailed)

	<i>Language Skills</i>	<i>Mathematics</i>	<i>Peer Problems</i>
Neuropsychological functions			
Inhibition	-.21**	-.18**	-.01
Working memory	-.33***	-.41***	.04
Shifting	-.19**	-.20**	.05
Reaction time variability	-.26***	-.33***	.02
Emotion regulation			
Regulation of sadness	.02	-.04	.13*
Regulation of fear	.04	.05	.14*
Regulation of anger	.04	-.11	.20**
Regulation of happiness	.08	.11	.14*
Emotion recognition			
Recognition of anger	.18**	.03	-.14*
Recognition of fear	.12	-.02	.01
Recognition of happiness	.03	-.10	-.09
Recognition of sadness	.10	.03	-.01
Recognition of surprise	.13*	.11	-.07

Note. Bold-faced numbers indicate relations that remained significant when controlling for multiple comparisons. Cursive numbers indicate where a significant interaction effect with gender was found.
 * $p < .05$. ** $p < .01$. *** $p < .001$.

Effect sizes were medium to large ($d = .45$ – 1.75) for the significant mediators and large ($d = 1.02$ – 1.60) for the outcome variables. All significant effects survived control for multiple testing.

Next, we investigated the relation between the mediators and the outcomes when controlling for ADHD status, sex, and age. Delay aversion and recognition of disgust were not included in these analyses, as group differences had not been found for these two variables. The results (see Table 2) showed that all three EFs as well as RT variability were significantly related to both areas of academic achievement but not to peer problems. In addition, recognition of anger and surprise were related to language skills, but none of the other emotion variables were related to academic achievement. Regulation of sadness, anger, fear and happiness, as well as recognition of anger, were significantly related to peer problems. When controlling for multiple comparisons (see bold-faced figures in Table 2), all relations except recognition of surprise remained significant for language skills and all relations except inhibition remained significant for mathematics. However, only regulation of anger remained significantly related to peer problems.

Simple Mediation

Mediation was thereafter examined using the bootstrapping procedure presented by Preacher and Hayes (2008). Only variables for which the relation between the proposed mediator and the outcome was significant when controlling for ADHD status, and which survived control for multiple testing, were included in these analyses. Regarding language skills, simple mediation effects were found for all three EFs as well as for RT variability and recognition of anger (see Table 3).

TABLE 3
Results of Simple Mediation, Including Estimates, Standard Errors (SE), and Confidence Intervals (CI); The Percentage of the Total Effect Is Also Reported

	<i>Estimate</i>	<i>SE</i>	<i>Lower CI</i>	<i>Upper CI</i>	<i>Indirect Effect %</i>
Language Skills					
Inhibition	-.0743	.0282	-.1382	-.0277* ^a	16
Working memory	-.1098	.0342	-.1862	-.0507* ^a	24
Shifting	-.0578	.0254	-.1199	-.0161*	13
Reaction time variability	-.1581	.0485	-.2594	-.0685* ^a	35
Recognition of anger	-.0712	.0314	-.1404	-.0173* ^a	16
Mathematics					
Working memory	-.1289	.0360	-.2062	-.0674* ^a	28
Shifting	-.0600	.0244	-.1178	-.0207*	13
Reaction time variability	-.1903	.0439	-.2837	-.1102* ^a	41
Peer Problems					
Regulation of anger	.1357	.0515	.0377	.2455* ^a	22

*Significant mediator (i.e., zero is not contained within the confidence intervals).

^aIndicate where a mediation is significant when controlling for IQ.

Working memory, shifting and RT variability were significant mediators for mathematics, and regulation of anger was a significant mediator for peer problems. As also shown in Table 3, the significant mediators varied with regard to how much of the total effect they were able to explain. For example, shifting explained as little as 13% of the total effect of ADHD status on language skills, whereas the corresponding percentage for RT variability was 35%. Finally, all simple mediation analyses were re-run with control for IQ. As shown in a footnote to Table 3, most of the mediation effects remained significant for the two measures of academic achievement, whereas regulation of anger remained significant for peer problems.

Multiple Mediation

Multiple mediation analyses were conducted to obtain estimates of the total indirect effect, as well as the independent contribution of each mediator (i.e., the effect of each mediator when controlling for the effect of the other significant mediators in the model). Multiple mediation analysis was not performed for peer problems, as only one significant mediator (i.e., regulation of anger) had been identified for this variable. For the relation between ADHD status and language skills (see Figure 1A), the mediators together explained 53% of the total effect (i.e., multiple $\beta = .24$ divided by the total effect $\beta = .45$), but only the effect of working memory was significant. For mathematics (Figure 1B), the mediators together explained 54% of the total effect (i.e., multiple $\beta = .25$ divided by the total effect $\beta = .46$). Both working memory and RT variability had significant independent effects. As can be seen in Figures 1A and 1B, the direct effect of ADHD status on the dependent variables remained significant for both language skills and mathematics, which means that only partial mediation was demonstrated. Partial mediation was also demonstrated for peer problems ($\beta = .63$, $p < .001$ for the direct path between ADHD and peer problems when the mediator was not included, and $\beta = .49$, $p < .001$ when the effect of regulation of anger was taken into account).

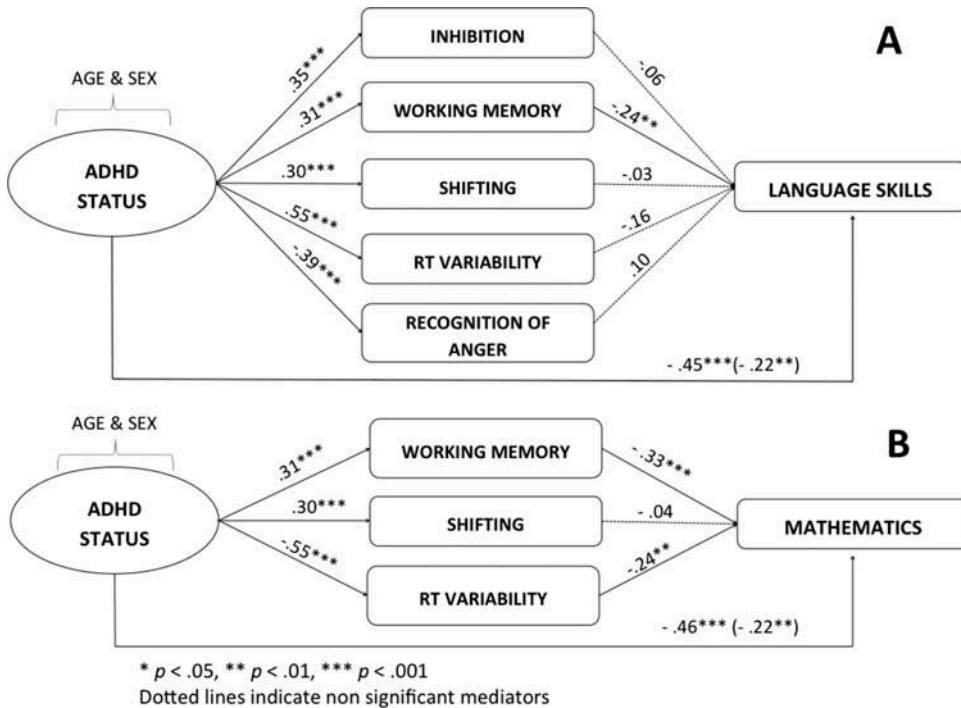


FIGURE 1 Multiple mediation models for the association between attention deficit hyperactivity disorder (ADHD) and academic achievement. Values on paths are standardized path coefficients (β). For the direct relation between ADHD and academic achievement, the value outside parentheses indicates the zero-order correlation, whereas the value inside parentheses indicates the partial correlation (i.e., the size of the direct effect when taking the effect of all mediators into account).

Gender Effects and Effects of Comorbid ODD/CD

Finally, two possible moderators were examined: gender and comorbid ODD/CD. With regard to gender, no significant main effects of gender and no significant interaction effects of ADHD status and gender were found for any of the neuropsychological variables. For the functional impairments, two significant main effects of gender were found. Girls had significantly lower scores than boys did in mathematics and they were rated as having higher levels of peer problems, but no main effects of gender were found for language skills. No significant interaction effects of ADHD status and gender were found for any of the functional impairments, which indicate that the obtained gender differences were equally large among children with and without ADHD.

In order to determine whether the relation between the mediators and the outcomes were equally strong for boys and girls, we also examined interaction effects of gender and each one of the mediators (i.e., altogether 45 interaction effects, as the study involved 15 mediators and 3 outcomes). The results showed that only three interaction effects were significant (see

boldfaced figures in Table 2). When conducting separate mediation analyses for boys and girls for these three relations, the results for both genders were similar to the results reported above for the whole sample. Thus, gender was not found to be a significant moderator in our mediation models.

Finally, we investigated ODD/CD as a potential moderator in the relation between emotional functioning and peer problems. The results showed that both ADHD subgroups (ADHD without ODD/CD and ADHD with ODD/CD) differed significantly from the control group with regard to peer problems and all measures of emotional functioning (all f 's > 4.66, and p 's < .05), except for recognition of disgust, for which none of the subgroups differed significantly from the controls (both f 's < .74, *ns*). Second, no interaction effects of ODD/CD and emotional functioning on peer problems were noted (all β 's < .14, *ns*). In conclusion, the relations between the different measures of emotional functioning and peer problems were equally strong in the two ADHD subgroups.

DISCUSSION

The overall aim of the present study was to investigate the role of neuropsychological functioning in explaining the link between ADHD and functional impairments associated with the disorder. The main findings were that it was primarily deficits in working memory and RT variability that mediated the relation between ADHD and academic achievement and that regulation of anger mediated the relation between ADHD and peer problems. Neither gender nor symptoms of ODD/CD were shown to moderate these findings.

Academic Achievement

First, and in line with previous research, the present study showed that children with ADHD performed worse than controls on tests of executive functioning (e.g., Barkley, 1997), RT variability (Castellanos et al., 2005), and were rated lower on academic achievement (e.g., Loe & Feldman, 2007). Our results are also in line with previous findings showing that EF deficits in general are related to poor academic achievement (e.g., Biederman et al., 2004; Diamantopoulou, 2007; Miller & Hinshaw, 2010; Thorell, 2007). By conducting formal mediation analyses, we extend previous findings by showing that all included EF deficits, as well as RT variability, were significant mediators in the relation between ADHD and poor academic achievement. However, only the effect of working memory for language skills, and the effects of RT variability and working memory for mathematics, remained significant when controlling for the overlap between different mediators. Yet another finding of the present study was that the neuropsychological predictors explained about 50% of the group difference in performance for the academic outcomes. This is to be considered a substantial effect given that the difference between ADHD and controls are large for academic achievement (cf. Preacher & Kelley, 2011). However, it also points out the need to find other possible mediators.

The present study is, to our knowledge, the first to examine whether RT variability mediates the relation between academic achievement and ADHD. RT variability is believed to arise from an inability to mobilize an appropriate amount of energy in relation to what the task

or the situation requires (Sergeant, 2005). However, the exact nature of high RT variability in ADHD is still uncertain, and there has been some discussion as to whether RT variability should be regarded as inherent in other neuropsychological functions or whether it constitutes a unique entity (cf. Castellanos et al., 2005; Sonuga-Barke, Wiersma, van der Meere, & Roeyers, 2010). Most previous findings support the latter interpretation, as RT variability has been shown to have an independent effect on ADHD when analyzed together with other candidate endophenotypes (Kuntsi, Oosterlaan, & Stevenson, 2001; Sjöwall et al., 2013; Wåhlstedt, Thorell, & Bohlin, 2009). Here, we demonstrate that RT variability is independent of other neuropsychological deficits, also when examining the relation between ADHD and academic achievement.

Altogether, the present findings emphasize the advantages of using multiple mediation models to provide a more in-depth understanding of the link between ADHD and poor academic achievement. Most importantly, this analytical approach has allowed us to investigate both the independent contributions and the cumulative effects of several different neuropsychological functions. For a more detailed account of the advantages of this statistical approach, please refer to Preacher and Hayes (2008).

Peer Problems

In line with previous research (e.g., Hoza, 2007; McQuade & Hoza, 2008), the present study showed that the children with ADHD were rated as having much more peer problems compared to the controls. Interestingly, regulation of anger was shown to be a mediator in the relation between ADHD and peer problems. This finding is in line with Anastopoulos and colleagues (2011), who found that a measure of emotional lability mediated the relation between ADHD and social skills. However, our study also contributes new information. First, we show that the mediating effect of regulation of anger cannot be accounted for by other neuropsychological deficits. Second, we focused on emotion regulation specifically, rather than using a measure that includes both reactivity and regulation of emotions (Mullin & Hinshaw, 2007). Third, we investigated the effect of different emotions and were able to show that it is specifically regulation of anger, and not other emotions, that is related to peer problems. Fourth, comorbid ODD/CD did not moderate the relation between ADHD and peer problems (i.e., the relation between emotional functioning and peer problems was equally strong for ADHD children with or without ODD/CD).

Our findings, showing a lack of significant relations between EFs and peer problems, are in line with previous research (Biederman et al., 2004; Diamantopoulou et al., 2007; Huang-Pollock et al., 2009; Scholtens et al., 2012). However, they stand in contrast to results reported by Hinshaw and colleagues (Miller & Hinshaw, 2010; Rinsky & Hinshaw, 2011), showing the involvement of EFs in peer functioning or social abilities more in general. In these two studies, the outcomes were measured in adolescence, and it is possible that well-functioning peer relations are more dependent on executive skills in adolescence than in childhood. In addition, these studies included only girls. However, the present results indicate that although boys and girls with ADHD may differ in the extent to which they develop different peer problems, the underlying neuropsychological deficits mediating the relation between ADHD and peer problems appear to be similar for both genders.

Limitations

Some limitations should be taken into consideration. First, no standardized clinical interview was used. Nonetheless, a licensed child psychiatrist conducted the diagnostic procedure, and all diagnoses were confirmed using teacher and parent ratings on a standardized rating instrument. In addition, the children's symptoms were reported to cause significant impairment in several settings, and both the duration and age-of-onset criteria were met. A second limitation was that peer problems were only assessed by ratings, and it would be of interest to try to replicate our findings using peer nominations. This was not possible in the present study as all children participating in the study were in different classrooms. Thus, with an average of about 25 children in each classroom, this would have resulted in more than 5,000 peer nominations. Third, the effect of comorbid ODD/CD was investigated in the present study, but it would have been interesting to also include other comorbidities such as learning disorder and autism spectrum disorder. Finally, it should be noted as a limitation that IQ was only assessed using one single measure.

CONCLUSIONS AND FUTURE DIRECTIONS

The present study provides further support for the importance of EF deficits in explaining poor academic achievement among children with ADHD. Within the EF construct, working memory was shown to be of primary importance. This calls for teaching strategies that better suit the needs of these children (e.g., giving one instruction at a time and repeating the important parts of longer instructions, Raggi & Chronis, 2006). In addition, computerized training programs have been shown to improve working memory (e.g., Klingberg et al., 2005) and there is also some evidence of enhanced mathematics ability after working memory training (Holmes, Gathercole, & Dunning, 2009).

Our findings also suggest that it is important to identify children with ADHD who have variable RTs. It has been suggested that variable RTs reflect difficulties maintaining attention while processing information. Specific adjustments in academic settings for children with variable RT have not been postulated but two aspects suggested to be of importance are rewards and the speed/intensity of presentation (cf. Tamm et al., 2012).

With regard to peer problems, the present study added valuable information to this research field by showing that emotion regulation needs to be further acknowledged. Regulation of anger explained 22% of the effect of ADHD on peer problems. As pointed out by Preacher and Kelley (2011), it is generally more impressive to explain a smaller percentage of a large total effect compared to explaining a large percentage of a very small total effect. Thus, 22% should be considered important given that ADHD was so strongly related to peer problems. In addition, it has been shown that poor emotional functioning in children with ADHD has many other negative consequences besides the aspects investigated here (e.g., Wehmeier, Schacht, & Barkley, 2010), indicating that future research on interventions aimed at improving emotional functioning is of great importance. However, it is also important to remember that a substantial part of the relation between ADHD and peer problems could not be explained by the neuropsychological variables included in the present study. Thus, future research needs to examine other possible mediators. In addition, it would be of interest to investigate neuropsychological functioning in relation to other aspects of peer relations (e.g., peer-rated social status), as well as different aspects of social functioning, in children diagnosed with ADHD.

Building on our findings, future research needs to look beyond the executive function deficits that have been in focus in much of the ADHD research during the past decade and also include deficits in emotional functioning. In this line of research, it will be important to investigate what specific aspects of emotional functioning that are of greatest importance to ADHD and the functional impairments associated with this disorder. In research on executive functioning deficits, it has been fruitful to study independent effects of different functions such as working memory and inhibition rather than using composite measures that include many different functions. Similar attempts should be made in the area of emotional functioning in order to better differentiate between constructs such as emotional lability, emotional intensity, and emotion regulation. Finally, it will be important to use more person-oriented analyses to determine what specific cut-offs should be used to obtain the highest sensitivity and specificity when trying to predict different functional impairments in children with ADHD.

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