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## ADHD subtypes: do they differ in their executive functioning profile?

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### Abstract

The present study was designed to investigate the hypothesis that children with Attention Deficit Hyperactivity Disorder combined subtype (ADHD-C) have a generalized executive functioning (EF) [Barkley, R. A. (1997). Behavioural inhibition, sustained attention, and executive functions: Constructing a unifying theory of AD/HD. *Psychological Bulletin*, 121, 65–94; Barkley, R. A. (1997). *ADHD and the nature of self-control*. New York: The Guilford Press]. We tested whether ADHD-C and ADHD inattentive subtype (ADHD-I) can be differentiated from each other on EF measures. We compared 16 normally developing boys with 16 boys with ADHD-C and 16 with ADHD-I on five EF domains. The boys were all matched on age, IQ, and the presence of oppositional defiant disorder (ODD)/conduct disorder (CD). Despite carefully diagnosed groups and methodological controls, the results do not support the EF-hypothesis of ADHD-C. Children with ADHD-C differed from normal controls (NC) on tasks related to inhibition; they did not exhibit EF deficits on *all* EF tasks. Children with ADHD-C also exhibited deficits on non-EF tasks. Furthermore, the ADHD-C and ADHD-I subtypes did not differ from one another. Neuropsychological findings on the domains under study did not yield evidence for the distinctiveness of ADHD-C and ADHD-I subtypes.

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## 1. Introduction

The validity of the three subtypes of Attention Deficit Hyperactivity Disorder (ADHD) is a recurring diagnostic debate in ADHD (Milich, Balentine, & Lynam, 2001). Children with ADHD are characterized by symptoms of inattention, hyperactivity, and impulsivity (American Psychiatric Association [APA], 2000). Following the *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; APA, 2000)* ADHD can be divided into three subtypes: ADHD predominantly inattentive subtype (ADHD-I), ADHD predominantly hyperactive/impulsive subtype (ADHD-H), and ADHD combined subtype (ADHD-C). In the current categorical clinical view, these three subtypes belong to the same diagnostic entity. However, some argue that the inattentive subtype is a distinct diagnostic disorder and not a subtype of ADHD (Barkley, DuPaul, & McMurray, 1990; Milich et al., 2001). Milich et al. concluded in a recent review that ADHD-I and ADHD-C have almost nothing in common. The subtypes can be distinguished from each other on inattention symptoms, associated features, demographics, and responsiveness to stimulant medication (see also Carlson, Shin, & Booth, 1999). Nonetheless, the distinctiveness of the ADHD subtypes on neuropsychological measures is not clear-cut. For this reason, the current study focuses on the neuropsychological profiles of ADHD subtypes using Barkley's (1997a, 1997b) model on ADHD as a starting point.

Barkley (1997a, 1997b) postulated a model of ADHD in which only ADHD-C and ADHD-H, but not ADHD-I, are associated with executive function (EF) deficits. These EF deficits are, according to Barkley, caused by a primary deficit in inhibitory control. EF is an umbrella term, which encompasses different meta-cognitive domains that are commonly described as mental control processes that enable self-control (Denckla, 1996; Lezak, 1995; Pennington & Ozonoff, 1996) such as, planning, cognitive flexibility, and working memory. This influential theoretical model can be challenged if it can be shown that (1) ADHD-C and ADHD-H are not associated with a pervasive deficit in all domains of EF; (2) EF deficits are related to ADHD-C and ADHD-H, but also to ADHD-I; (3) EF deficits are not specifically related to ADHD-C and ADHD-H, but are due to common comorbidities; (4) ADHD-C and ADHD-H encounter not just EF deficits, but also show deficits in other cognitive domains (further called non-EF). The current study aimed at testing most of these challenges to Barkley's model by comparing normal controls (NC) with carefully diagnosed boys with ADHD-C and ADHD-I and to contrast these two ADHD subtypes with each other on an extensive battery of tasks that cover the major domains of EF and non-EF.

Support for Barkley's model (1997a, 1997b) is derived from studies, which have shown that a deficit in EF was related to ADHD-C, and was not observed in ADHD-I (Houghton et al., 1999; Klorman et al., 1999; Lockwood, Marcotte, & Stern, 2001; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). Klorman et al. showed that the ADHD-C group encountered deficits in planning and cognitive flexibility when compared to the ADHD-I group. In a subsequent study, Nigg et al. failed to replicate the planning finding. Nevertheless, Nigg et al. did show that boys with ADHD-C had more problems with response inhibition than boys with ADHD-I. Girls classified in these two subtypes did not differ in response inhibition. Lockwood et al. found a deficit in verbal fluency for the ADHD-C group but not for the ADHD-I group. Houghton et al. concluded that there are deficits in cognitive flexibility and inhibition

in the ADHD-C subtype but not in the ADHD-I subtype, when both subtypes were compared to a normal control group. However, when the two subtypes were directly compared with one another, no statistically significant difference was found between the two ADHD subtypes.

Other neuropsychological studies have failed to report reliable differences between ADHD-C and ADHD-I subtypes (Barkley, Grodzinsky, & DuPaul, 1992; Chhabildas, Pennington, & Willcutt, 2001; Faraone, Biederman, Weber, & Russell, 1998; Murphy, Barkley, & Bush, 2001). The studies compared these two subtypes with sufficient group-sizes and on numerous EF tasks. The study of response inhibition by Chhabildas et al. showed that symptoms of *inattention*, but *not* symptoms of *hyperactivity/impulsivity* accounted for the response inhibition deficit in ADHD. This is in sharp contrast to Barkley's model. Thus, the studies on ADHD subtypes indicate that the EF findings in ADHD subtypes are, at least, inconsistent. It remains unclear whether deficits in EF are specifically related to ADHD-C or also present in ADHD-I.

These inconsistent findings could be due to methodological differences among studies and to methodological imperfections in former studies. First, a number of other disorders such as autism spectrum disorders (ASD), Tourette syndrome (TS), obsessive-compulsive disorders (OCD), and externalizing disorders including oppositional defiant disorder (ODD) and conduct disorder (CD) are associated with executive dysfunctions (e.g., see Pennington & Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002). Some studies have controlled for comorbid disorders including TS, OCD, ODD, and CD, while others have not. However, it is remarkable that former studies did not rigorously exclude ASD, because ASD is known to be strongly associated with EF deficits (e.g., Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Hughes, Russell, & Robins, 1994; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997). Furthermore, the diagnosis of ADHD according to the *DSM-IV-TR* (APA, 2000) will only be correctly established, when the inattention and/or hyperactivity/impulsivity symptoms cannot be accounted for by ASD. Therefore, it is necessary to *exclude* children with possible ASD from an ADHD study in order to determine the specificity of the association between ADHD and EF deficits. The same line of reasoning applies to TS and OCD. The current study is the first to report on ADHD subtypes after employing stringent controls for the presence of ASD, TS, and OCD.

Second, to our knowledge, none of the previous studies have controlled for non-EF demands in the neuropsychological tests that were used to measure EF. EF tests are designed to measure EF, but in addition, they tap non-EF cognitive processes such as perception, motor activation, and even memory (Eslinger, 1996, p. 386). Hence, it is necessary to control for these non-EF demands, in order to draw the conclusion that poor performance on an EF test is due to an EF deficit (Denckla, 1996).

The current study is the first study with stringent controls for numerous possible confounders. We matched the comparison groups on age, IQ, and presence of ODD/CD. Moreover, boys with comorbid disorders such as OCD, TS, and ASD were excluded from this study. Based on Barkley's (1997a, 1997b) model, we expected that: (1) ADHD-C is associated with a *pervasive* EF deficit even though we controlled for OCD, TS, and ASD; (2) EF deficits are related to ADHD-C, but not to ADHD-I; (3) ADHD-C encounter solely EF deficits and will not show any deficits in the non-EF domains.

## 2. Method

### 2.1. Participants

All children who participated in this study were in the age range of 6–13 years. The children were required not to use any medication. If children were on medication, which could be discontinued, it was mandatory for medication to be discontinued for 20 h before testing took place to allow a complete wash-out. Furthermore, children with epilepsy, sight problems (except when children wore corrective lenses or glasses), or hearing problems were excluded from the present study.

The children were selected through a recursive multi-method selection procedure. First, the diagnostic instruments that were used in the selection procedure will be reported. Second, the selection procedure for each group will be shortly described (for a more detailed description of the selection procedure of the groups, please see Geurts et al., 2004).

### 2.2. Diagnostic measures

#### 2.2.1. Disruptive Behavior Disorder Rating Scale

The Disruptive Behavior Disorder Rating Scale (DBD; Pelham, Gnagy, Greenslade, & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers, & Sergeant, 2000) was developed to measure externalizing disorders. The DBD contains four scales composed of the *DSM-IV* items for ADHD-I, ADHD-H, ODD, and CD. The higher the score on the DBD, the more impaired is the child. Adequate psychometric properties have been reported (Oosterlaan et al., 2000). The DBD was used to make an initial selection of the children with ADHD.

#### 2.2.2. Dutch Revised Wechsler Intelligence Scale for Children

Four subtests of the Dutch Revised Wechsler Intelligence Scale for Children (WISC-R; Van Haasen et al., 1986) were administered to assess intelligence. These tests were: vocabulary, arithmetic, block design, and picture arrangement. These four subtests correlate between  $r = .93$  and  $.95$  with Full Scale IQ (FSIQ; Groth-Marnat, 1997).

#### 2.2.3. Diagnostic Interview Schedule for Children for DSM-IV, parent version

The Diagnostic Interview Schedule for Children for DSM-IV, parent version (DISC-IV; National Institute of Mental Health [NIMH]; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000; Dutch translation: Ferdinand, Van der Ende, & Mesman, 1998) is a structured diagnostic interview. The current version is based on the *DSM-IV* (APA, 1994) and the ICD-10 (WHO, 1992). The following sections were used: disruptive behavior disorders (ADHD, ODD, and CD), obsessive–compulsive disorder (part of the anxiety disorders section), and tic disorders (part of the miscellaneous disorders section). The latter two sections were included to exclude comorbid OCD and TS in the clinical groups. Adequate reliability and validity have been reported for precursors of the DISC-IV (Schwab-Stone et al., 1996).

#### 2.2.4. Revised Autism Diagnostic Interview

The Revised Autism Diagnostic Interview (ADI-R; Le Couteur et al., 1989; Lord, 1997; Lord, Rutter, & Le Couteur, 1994; Lord, Storoschuk, Rutter, & Pickles, 1993) is a

comprehensive semi-structured interview for parents or principal caregivers that probes for symptoms of ASD, and for the diagnosis of infantile autism in particular. The ADI-R covers a variety of behaviors that frequently occur in ASD and is currently considered as the “gold standard” diagnostic research instrument for autism (Filipek et al., 1999). The ADI-R was administered to exclude ASD in the ADHD group. Children were excluded from the current study, if they had scores above the specified cut off at two or more of the three domains and if the developmental abnormalities started before the age of three. The three domains are: (a) qualitative impairment in social interactions; (b) qualitative impairment in communication; (c) restricted, repetitive, and stereotypic patterns of behaviors, interests, and activities.

### 2.3. Selection of the groups

#### 2.3.1. ADHD

Children were recruited in The Netherlands and Belgium from the Dutch parent association of children with ADHD and special educational services for children with extreme behavioral problems (Scheres, Oosterlaan, & Sergeant, 2001). Children could be included in the ADHD group if (1) both the parent and teacher ratings were at or above the 95th percentile on at least one of the two ADHD-related DBD scales to be sure that the pervasiveness criterion for ADHD (*DSM-IV-TR*, 2000) was met; (2) their estimated FSIQ was at or above 80; (3) the ADHD diagnosis was confirmed with the DISC-IV and there were no signs of OCD or TS; (4) they had no characteristics of ASD as measured with the ADI-R. We started with 385 parents and 252 teachers who completed the DBD and after applying all the aforementioned exclusion criteria, 64 children were assigned to the ADHD group (16 inattentive subtype, 3 hyperactive/impulsive subtype, and 45 combined subtype). Thirty-four of the children with ADHD had comorbid ODD and eight were comorbid for CD as measured with the DISC-IV.

#### 2.3.2. Normal controls

Approximately 165 parents of children from eight regular schools located throughout The Netherlands and Belgium filled out the DBD. At the same time, teacher DBDs were sent to the child’s teacher. The short version of the WISC-R was administered to assess intelligence in the controls. Children were excluded from the study if (1) the parent or the teacher stated that the child had ever met a clinical diagnosis (e.g., a behavioral problem or a learning disability); (2) their FSIQ estimate was below 80; or (3) the score on one of the four scales of the parent or teacher DBD exceeded the 75th percentile. In total, 80 children were assigned to the NC group.

Sixteen boys with ADHD-I were matched with both 16 boys with ADHD-C and 16 NC boys on age and FSIQ. Furthermore, the clinical groups were matched on the presence or absence of comorbid ODD/CD. Table 1 provides the ages, estimated FSIQs, rating scale, and interview scores for the three groups. Group differences for the measures were studied using an overall alpha level of .05. The three groups did not differ from each other with respect to age ( $F(2, 48) < 1$ , ns,  $\eta^2 = .00$ ) and FSIQ ( $F(2, 48) < 1$ , ns,  $\eta^2 = .02$ ). Furthermore, the ADHD-I and ADHD-C groups did not differ from one another with respect to ODD ( $F(1, 32) = 3.36$ ,  $p = .08$ ,  $\eta^2 = .08$ ) and CD ( $F(1, 32) < 1$ , ns,  $\eta^2 = .00$ ). This implies that the groups were successfully matched on these variables.

Table 1  
ADHD subtypes and normal control: group means and standard deviations for gender, age, IQ, rating scales, and clinical interviews

Measure	Groups						Bonferonni group comparisons
	NC ( <i>n</i> = 16)		ADHD-C ( <i>n</i> = 16)		ADHD-I ( <i>n</i> = 16)		
	<i>M</i>	S.D.	<i>M</i>	S.D.	<i>M</i>	S.D.	
Age	9.9	1.8	10.0	1.9	10.1	1.9	ns
FSIQ	100.4	10.6	98.3	9.3	97.9	6.6	ns
DBD parent							
Inattention	3.3	2.4	18.1	4.6	17.1	4.4	NC < ADHD-I = ADHD-C ( <i>p</i> < .001)
Hyperactivity/impulsivity	2.1	1.8	18.4	4.1	11.4	4.5	NC < ADHD-I < ADHD-C ( <i>p</i> < .001)
ODD	1.4	1.7	11.3	3.7	8.6	4.5	NC < ADHD-I = ADHD-C ( <i>p</i> < .001)
CD	.2	.4	4.1	4.7	2.4	2.6	NC < ADHD-C ( <i>p</i> < .005)
DBD teacher							
Inattention	2.3	2.4	13.0	6.0	11.3	3.9	NC < ADHD-I = ADHD-C ( <i>p</i> < .001)
Hyperactivity/impulsivity	1.1	1.4	14.4	5.7	10.6	6.1	NC < ADHD-I = ADHD-C ( <i>p</i> < .001)
ODD	0	0	10.8	6.8	7.3	4.8	NC < ADHD-I = ADHD-C ( <i>p</i> < .001)
CD	0	0	3.3	2.7	1.1	1.1	NC < ADHD-C ( <i>p</i> < .001)
DISC-IV							
ADHD inattentive	–	–	16.0	2.9	14.6	2.8	ns
ADHD hyperactive	–	–	15.1	2.4	8.1	2.2	ADHD-I < ADHD-C ( <i>p</i> < .001)
ODD symptoms	–	–	4.6	1.9	3.1	2.7	ns
CD symptoms	–	–	.8	1.3	.9	1.4	ns
ADI-R							
Social interaction	–	–	4.9	4.4	3.3	3.0	ns
Communication	–	–	5.4	3.3	2.4	2.5	ADHD-I < ADHD-C ( <i>p</i> < .01)
Repetitive/stereotyped	–	–	1.6	1.9	.6	.6	ADHD-I < ADHD-C ( <i>p</i> < .001)

Note: The number of participants differ for each dependent variable due to missing data (see text). ADI-R, Revised Autism Diagnostic Interview; ADHD, Attention Deficit Hyperactivity Disorder; C, combined subtype; CD, conduct disorder; DBD, Disruptive Behavior Disorder Scale; DISC-IV, Diagnostic Interview Schedule for Children; I, inattentive subtype; NC, normal controls; ODD, oppositional defiant disorder.

In general, findings for the rating scale scores support the behavioral distinctiveness of the groups. As expected, the parents and teachers of the children with ADHD reported more problems when compared to normal controls on all scales. Teacher ratings on the DBD hyperactivity/impulsivity scale did not differentiate between the two subtypes (see Table 1). The ADHD-C group had a higher score on the parent DBD hyperactivity/impulsivity scale and DISC-IV hyperactivity/impulsivity scale in comparison with the ADHD-I group.

#### 2.4. Neuropsychological measures

Both EF and non-EF control tasks were administered in this study. The EF tasks were selected to measure the five major domains of EF (response inhibition, visual working memory, planning, cognitive flexibility, and verbal fluency) as suggested by Pennington and Ozonoff

(1996, p. 53). For each task, the original measurement goal and the main dependent measures are noted. However, research showed that it is difficult to make predictions as to which domain a given EF measure is related. The tasks are never “pure” measures of a *single* EF domain but are related to a number of domains.

## 2.5. EF tasks and dependent measures

### 2.5.1. Change task

The change task (De Jong, Coles, & Logan, 1995; Logan & Burkell, 1986; Oosterlaan & Sergeant, 1998) was included to measure: (1) inhibition of a prepotent response, (2) response execution, and (3) cognitive flexibility. The change task is a modified version of the stop task. The task consists of two types of trials: 192 go-trials and 64 stop-trials. Subjects were required to locate the position of an aircraft that was displayed to the left or right of a fixation point on a computer screen. On go-trials, children were required to press the right button on a response box, if the stimulus appeared on the right side, and the left button, if the stimulus appeared on the left side of the screen. Stop-trials were identical to go-trials but in addition an auditory stop signal was presented, which directed children to (1) inhibit their response, and (2) immediately perform a different response, the change response. The change response involved pressing a third button. A detailed description of the change task used here is provided by Oosterlaan and Sergeant (1998).

The following dependent measures were derived from the change task: (1) stop signal reaction time (SSRT), a measure of the latency of the inhibitory process (Logan, 1994); (2) MRT, a measure of the latency of the response execution process; (3) variability in the latency of the response execution process (response variability); (4) accuracy of responding as measured by the number of errors on the go trials (including both omission and commission errors); (5) change MRT as a measure of the latency of the set-shifting process; (6) accuracy of cognitive flexibility (set-shifting) as measured by the number of change response errors.

### 2.5.2. Circle drawing task

The circle drawing task (Bachorowski & Newman, 1985, 1990) was used as a measure of inhibition of an ongoing response. The task consisted of a small circle with the words “start” and “stop” indicating the starting and the finishing points of the tracing. The task was administered twice: first with neutral instructions (“trace the circle”) followed by inhibition instructions (“trace the circle again, but this time as slowly as you can”). The dependent variable in this task was the time used to trace the circle in the slow condition minus the tracing time in the neutral condition. The greater the time difference, the better a participant was able to inhibit (slow down) the continuous tracing response.

### 2.5.3. Opposite Worlds of the Test of Everyday Attention for Children

The Opposite Worlds of the Test of Everyday Attention for Children (TEA-Ch; Manly et al., 2001) requires the child to suppress an automatic or prepotent verbal response. There were two conditions in this task. First, there was the Same World condition, where the child is required to name the digits 1 and 2 that are scattered along a path. In the Opposite World condition, the child was required to say “one” when he saw a 2, and “two” when he saw a 1. In this second

condition, the child has to perform the task in a novel way and suppress the routine manner of performing it. The dependent variable was the difference between the mean time needed to complete the Opposite World conditions and the mean time needed to complete the Same World conditions.

#### 2.5.4. *Self-Ordered Pointing Task (abstract designs)*

The Self-Ordered Pointing Task (SoP; Petrides & Milner, 1982) was included to measure visual working memory capabilities. Children were presented four series of cards containing 6, 8, 10, and 12 abstract designs, respectively. For each series, children were presented one card at a time (the positions were varied randomly) and were instructed to point to a different design on each of the cards. Following the administration procedure of Petrides and Milner (1982), each series was presented three times in succession.

The demand on working memory increased as the number of designs on each card increased during the task. The number of errors was calculated for each difficulty level (i.e., the number of times a design was responded to more than once). Difficulty level (6, 8, 10, and 12 items) was taken into account in calculating the dependent variable. It was expected that there would be a linear relation between difficulty level and the dependent variable. For each subject, a regression analysis was conducted with difficulty level (four levels; 6, 8, 10, or 12 items) being the predictor, and number of errors being the dependent variable. The regression coefficient (beta weight) of this regression analysis was taken as the dependent variable of the SoP. It was expected that, if children have a deficit in working memory, the regression coefficient for errors would be larger for such children compared to children without a working memory problem.

#### 2.5.5. *Tower of London*

The Tower of London (ToL; Krikorian, Bartok, & Gay, 1994) was selected to tap planning (Shallice, 1982). Materials and procedures for administration and scoring were derived from Krikorian et al. The ToL consists of three pegs of different lengths mounted on a strip, and three colored balls (red, blue, and yellow) that can be manipulated on the pegs. Starting from a fixed arrangement of the balls on the pegs, the child is required to copy a series of depicted end-states by re-arranging the balls. Upon presentation of a problem, participants were informed on the number of moves required to solve that problem correctly. Twelve problems of graded difficulty were presented and a problem is solved correctly when the end state is achieved in the prescribed number of moves. A maximum of three trials was allowed to solve each problem.

Three measures were derived. The main dependent variable was the ToL score, which was calculated by assigning points based on the number of trials required to solve a problem. There were three difficulty levels: two or three moves necessary to solve the problem (lowest difficulty level), four moves required to solve the problem (medium difficulty level), and five moves (highest difficulty level). Total item scores were calculated for each of the three difficulty levels. The maximum ToL score for each level of difficulty was 12 points.

Two temporal measures were derived for each level of difficulty: (1) decision time, which is the time between the presentation of a problem and the initiation of the first move on a trial (ball leaves peg); (2) execution time, which is the time between the initiation of the first move to the completion of the final move on a trial (regardless of whether a correct or an

incorrect solution has been achieved). These measures were derived for the first attempt on each problem. Like in the SoP, difficulty level was taken into account in calculating the dependent measures. Again, it was expected that there would be a linear relation between difficulty level and the dependent variables. Therefore, the regression coefficients (beta weights) for the three dependent variables were calculated for each individual, with difficulty level (low, medium, and high) being the predictor, and ToL score, decision time, and execution time being the dependent variables, respectively.

#### 2.5.6. Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948; Heaton, 1981; Heaton, Chelune, Talley, Kay, & Curtiss, 1993) is a widely used measure to tap cognitive flexibility or set-shifting. The paper and pencil version of Grant and Berg (1948) was used here (see Heaton, 1981; Heaton et al., 1993). The dependent variables of interest were the percentage of perseverative responses. These percentages were calculated from the number of trials in which the child continues sorting by a previously correct category despite negative feedback, and the total number of cards the child needed to complete the task. A computer-based scoring program was used to calculate the dependent variables (Harris, 1990).

#### 2.5.7. Verbal fluency

An adaptation of the Controlled Word Association Task (COWAT) was used to measure the capacity to generate novel responses (Benton & Hamsher, 1978). Children were required to name as many examples of a particular category within a time limit of 1 min. The categories were items from the semantic categories ‘animals’ and ‘food’, as well as words beginning with the letters K and M. Children were instructed to exclude names of persons and the same word with a different suffix. If incorrect words were given, the children were briefly reminded of the rules. The dependent measures in this task were the total number of admissible words across the semantic categories ‘animals’ and ‘food’, as well as across the letters K and M.

### 2.6. Non-EF control tasks and dependent measures

#### 2.6.1. Benton Visual Retention Test

The Benton Visual Retention Test (BVRT; Sivan, 1992) measures visuo-spatial abilities and immediate spatial memory abilities. This task was included to control for visual short-term memory in the SoP. The BVRT (form C) consists of ten designs with each design containing one or more figures. Each of these designs was presented to the child for 10 s. The child was then required to reproduce the designs immediately after presentation of the designs (method A for administration). The number of correct designs was the dependent measure in this task (Lezak, 1995; Sivan, 1992).

#### 2.6.2. Corsi Block Tapping Test

The Corsi Block Tapping Test (Corsi, 1972; Milner, 1971; Schellig, 1997) was designed to test memory impairments in patients with temporal lobe damage. The test taps visuo-spatial memory-span (Berch, Krikorian, & Huha, 1998; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Lezak, 1995) and was included to control for visual short-term memory in the

SoP. The Corsi requires maintenance of spatial information but does not involve any explicit concurrent processing requirements. A detailed description of this task is provided by Schellig. In short, in this task the child has to begin to copy a three-block item, and the number of items was increased by one after a particular difficulty level was completed successfully. There were three trials for each difficulty level. The test ended after three consecutive errors within a particular difficulty level or as the eight-block items were administered. The dependent variable was the visual memory span of the child, which is defined as the difficulty level for which the child was able to finish at least two trials successfully.

#### 2.6.3. *Categories of the Snijders–Oomen Non-Verbal Intelligence Test Revised*

The subtest Categories is one of the subtests of the Snijders–Oomen Non-Verbal Intelligence Test Revised (SON-R 5 $\frac{1}{2}$ -17) and measures semantic memory and the ability to categorize (Snijders, Tellegen, & Laros, 1989; Tellegen & Laros, 1993). This test was included for two reasons. First, Categories was used to control for semantic memory capacity in verbal fluency. In previous research, the fluency task has not only been used for tapping EF, but also as a semantic memory task (e.g., Elwood, 1997; Rosen, 1980). Second, Categories was included to control for the ability to categorize, which is needed in the WCST (Grant & Berg, 1948; Heaton, 1981).

In Categories, the child was first shown three pictures and has to decide what the three pictured objects have in common. Next, five pictures were presented to the child and the child was required to choose those two pictures that depict the same concept. After practicing, a maximum of 27 items was administered. Items were divided into three different series. Each series was terminated when the child made two consecutive errors. The dependent variable was the number of correct items.

#### 2.6.4. *Beery Visual Motor Integration*

The Beery Visual Motor Integration (Beery-VMI; Beery, 1997) was designed to assess visual–motor integration or the degree to which visual perception and finger–hand movements are coordinated. The task consists of 27 geometric forms of increasing complexity presented on paper. The child was required to copy these forms. The Beery standard score was used as the dependent variable.

### 2.7. *Procedure*

All children were tested individually. Testing took place on three different occasions and tests were administered in a fixed order. During the first session, the WISC-R was administered. At the second testing session, the circle drawing task, SoP, verbal fluency, WCST, and the BVRT were administered. One week later, the change task, Corsi, Categories, ToL, TEA-Ch Opposite World, and Beery VMI were administered. Some children from the clinical group were on methylphenidate, but discontinued medication at least 20 h prior to testing (Barkley, DuPaul, & Connor, 1999) allowing for a complete wash-out (Greenhill, 1998). Children discontinued the use of methylphenidate after their morning dose on the day before testing. All children received a small gift (worth approximately 1 USD) at the end of the study. The parents or caregivers were sent detailed reports on their child's performance on the tests.

## 2.8. Statistical analyses

First, the dependent measures (EF and non-EF) were analyzed using ANOVAs with group (three levels) as the between-subject factor. When for one task there was more than one dependent variable, MANOVAs were conducted. When a main group effect was obtained, post-hoc tests with Bonferonni correction were performed to investigate the precise differences between the three groups.

Second, groups were compared on the EF measures, while covarying the non-EF measures. In this way, we investigated whether differences between the groups on the EF-measures were due to non-EF capacities or whether the differences were due to EF capacities. In the case of the SoP, the dependent measure of the BVRT and the Corsi were entered as covariates. For the WCST, the dependent measure of the SON-R categories task was the covariate. This SON-R measure was also entered as covariate for verbal fluency. For most of the other EF tasks, non-EF was controlled for in the calculation procedure of the main dependent measures.

## 2.9. Missing data and outliers

Due to technical difficulties or to the child refusing to do the task, there were missing data for some children. This never resulted in excluding more than one case from an analysis.

Extreme cases were identified in each of the groups separately for each dependent measure (extreme cases were defined as values more than three box plot lengths from the upper or lower edge of the box). Only those cases were excluded from the MANOVAs and MANCOVAs that were extreme cases for more than one of the dependent measures in an analysis. This resulted in excluding no more than three cases from an analysis. Results are presented with exclusion of the extreme cases.

## 3. Results

The results of the data analyses are presented in [Tables 2 and 3](#).

### 3.1. EF tasks

#### 3.1.1. Change task

As expected, there was a main effect for group on SSRT ( $F(2, 46) = 6.01, p < .005, \eta^2 = .22$ ). Post-hoc comparisons with Bonferonni correction revealed that children with ADHD-C ( $p < .02$ ) and ADHD-I ( $p < .02$ ) had slower SSRTs than normal controls, indicating greater difficulty in response inhibition for the two clinical groups.

#### 3.1.2. Circle drawing task

In line with the prediction, there was a significant effect of group for circle time difference ( $F(2, 46) = 3.44, p < .05, \eta^2 = .14$ ). Post-hoc comparisons showed that children with ADHD-C have difficulties in slowing down their response compared to normal controls ( $p < .05$ ).

Table 2  
ADHD subtypes and normal controls: group means and standard deviations for executive function tasks

Measure	Groups						Bonferonni group comparisons
	NC ( <i>n</i> = 16)		ADHD-C ( <i>n</i> = 16)		ADHD-I ( <i>n</i> = 16)		
	<i>M</i>	S.D.	<i>M</i>	S.D.	<i>M</i>	S.D.	
<b>Inhibition</b>							
SSRT	208.7	59.5	307.2	140.0	313.1	63.9	NC < ADHD-I ( <i>p</i> < .02) and NC < ADHD-C ( <i>p</i> < .02)
Circle time difference	142.3	108.0	60.9	39.7	114.1	89.1	NC > ADHD-C ( <i>p</i> < .05)
TEA-Ch time difference	5.2	2.8	4.2	3.1	2.6	2.3	NC > ADHD-I ( <i>p</i> < .05)
<b>Visual working memory</b>							
SoP beta errors	.9	.6	1.4	.9	1.0	.7	ns
<b>Planning</b>							
ToL beta score	−1.6	.6	−1.6	1.1	−2.0	1.2	ns
ToL beta decision time	.5	1.2	.1	.9	.4	.9	ns
ToL beta execution time	3.3	1.3	2.8	1.7	2.7	1.4	ns
<b>Flexibility</b>							
Change MRT	489.4	86.5	554.4	109.4	521.1	68.1	ns
Change number of errors	6.4	7.6	15.5	12.9	9.7	7.8	NC < ADHD-C ( <i>p</i> < .05)
WCST, % perseverative responses	12.0	5.8	16.3	7.1	13.1	6.3	ns
<b>Verbal fluency</b>							
Semantic number correct	32.2	6.9	33.1	13.0	29.8	5.9	ns
Letter number correct	17.3	4.2	13.0	8.8	13.8	6.2	ns

Note: The number of participants differ for each dependent variable due to missing data and exclusion of extreme cases (see text). ADHD, Attention Deficit Hyperactivity Disorder; C, combined subtype; I, inattentive subtype; NC, normal controls; MRT, mean reaction time; SoP, self-ordered pointing task; SSRT, stop signal reaction time; TEA-Ch, Test of Everyday Attention for Children; ToL, tower of London; WCST, Wisconsin Card Sorting Test; %, percentage.

### 3.1.3. Opposite Worlds of the TEA-Ch

There was also a significant group difference for TEA-Ch time difference ( $F(2, 46) = 3.47$ ,  $p < .05$ ,  $\eta^2 = .14$ ). The ADHD-I group did differ from the normal controls on the TEA-Ch ( $p < .05$ ). In contrast to the predictions, children with ADHD-I seem to be less sensitive to interference than normally developing children.

### 3.1.4. SoP

In contrast to the predictions, no significant group effects were found for the SoP beta number of errors ( $F(2, 48) = 1.54$ , ns,  $\eta^2 = .06$ ). In other words, the increase in the number of errors with increasing visual working memory load was similar for both groups.

Table 3  
ADHD subtypes and normal controls: group means and standard deviations for control tasks

Measure	Groups						Bonferonni group comparisons
	NC ( <i>n</i> = 16)		ADHD-C ( <i>n</i> = 16)		ADHD-I ( <i>n</i> = 16)		
	<i>M</i>	S.D.	<i>M</i>	S.D.	<i>M</i>	S.D.	
Response execution							
MRT	483.6	78.5	498.4	121.2	431.9	128.5	ns
Response variability	113.2	36.4	144.8	56.1	107.6	39.5	ns
Number of errors	2.8	2.8	12.1	13.0	7.3	9.8	ADHD-C > NC ( <i>p</i> < .03)
Short-term memory							
Corsi memory span	5.1	.9	4.7	1.0	4.6	1.0	ns
BVRT number correct	6.4	1.3	5.0	2.5	7.0	2.1	ADHD-C < ADHD-I ( <i>p</i> < .05)
Visual–motor integration							
Beery-VMI	115.5	15.3	100.1	11.3	101.4	6.8	ADHD-C < NC ( <i>p</i> < .005) and ADHD-I < NC ( <i>p</i> < .005)
Categorization							
SON-R total score	14.1	4.8	12.0	4.6	12.1	3.9	ns

*Note:* The number of participants differs for each dependent variable due to missing data and exclusion of extreme cases (see text). ADHD, Attention Deficit Hyperactivity Disorder; Beery-VMI, Beery Visual Motor Integration; BVRT, Benton Visual Retention Test; C, combined subtype; Corsi, Corsi Block Tapping Test; I, inattentive subtype; MRT, mean reaction time; NC, normal controls; SON-R, Snijders–Oomen Non-verbal Intelligence Test Revised.

### 3.1.5. ToL

Contrary to predictions, none of the dependent measures for planning led to a significant group effect: ToL beta score ( $F(2, 44) < 1$ , ns,  $\eta^2 = .04$ ); beta for the decision time ( $F(2, 44) < 1$ , ns,  $\eta^2 = .04$ ); beta for the average execution time ( $F(2, 44) < 1$ , ns,  $\eta^2 = .03$ ). The children with ADHD did not differ from the normal controls on any of the planning measures with increasing planning load.

### 3.1.6. Change task

The group effect on the cognitive flexibility measures of the change task was not significant for change MRT ( $F(2, 46) = 2.08$ , ns,  $\eta^2 = .09$ ), but was significant for numbers of errors ( $F(2, 46) = 3.48$ ,  $p < .05$ ,  $\eta^2 = .14$ ). Compared with normal controls, children with ADHD-C committed more errors ( $p < .05$ ), indicating less accuracy in being cognitive flexible.

### 3.1.7. WCST

On this second cognitive flexibility task, were no significant group effects for the percentage of perseverative responses ( $F(2, 45) = 1.80$ , ns,  $\eta^2 = .08$ ). This indicates that children with ADHD-C and ADHD-I did not show difficulties with cognitive flexibility on the WCST in comparison with normal control children.

### 3.1.8. Verbal fluency

Contrary to the expectations, there were no statistically significant group effects for the number of correct responses in the letter category ( $F(2, 47) = 1.83$ , ns,  $\eta^2 = .08$ ), or the semantic category ( $F(2, 47) < 1$ , ns,  $\eta^2 = .02$ ). Children with ADHD-C or ADHD-I did not differ from normal controls or from each other.

## 3.2. Non-EF tasks

### 3.2.1. Change task

Children with ADHD-C, ADHD-I, and normal controls did not significantly differ from one another on two response execution measures: MRT ( $F(2, 47) = 1.51$ , ns,  $\eta^2 = .06$ ); response variability ( $F(2, 47) = 3.12$ , ns,  $\eta^2 = .12$ ). However, there was a significant group difference for the number of errors ( $F(2, 47) = 3.79$ ,  $p < .05$ ,  $\eta^2 = .15$ ). Children with ADHD-C committed more errors than normal controls ( $p < .03$ ).

### 3.2.2. BVRT

There was a significant group difference on this measure of visual short-term memory ( $F(2, 48) = 4.07$ ,  $p < .03$ ,  $\eta^2 = .15$ ). Children with ADHD-C, compared to children with ADHD-I, showed more difficulties with this visual short-term memory task ( $p < .05$ ).

### 3.2.3. Corsi

The groups did not differ on this second visual short-term memory task ( $F(2, 48) = 1.46$ , ns,  $\eta^2 = .06$ ).

### 3.2.4. Categories of the SON-R

No group differences emerged for the number of correct responses on the categorization task of the SON-R ( $F(2, 48) = 1.15$ , ns,  $\eta^2 = .05$ ).

### 3.2.5. Beery-VMI

There was a significant group effect on this task for visual–motor integration ( $F(2, 47) = 8.39$ ,  $p < .001$ ,  $\eta^2 = .28$ ). Both subtype groups had lower scores, implying more difficulties with this task, than the normal developing children (both  $p < .005$ ).

## 3.3. EF tasks while covarying for non-EF

None of the results for the EF measures altered when we covaried for performance on the non-EF control tasks. This implies that the differences we found on the EF measures are not due to difficulties with the non-EF tasks.

## 4. Discussion

The present study was designed to investigate the EF hypothesis proposed by Barkley (1997a, 1997b) for children with ADHD. Barkley postulated that children with ADHD-C, but

not ADHD-I, encounter pervasive EF deficits due to a primary deficit in inhibitory control. His idea has been addressed here by comparing age, gender, FSIQ, and ODD/CD comorbidity matched children with ADHD-C, ADHD-I, and normal controls on five major domains of EF: response inhibition, visual working memory, planning, cognitive flexibility, and verbal fluency. Thus, the current study investigated the hypothesis that ADHD-C and ADHD-I subtypes are two qualitatively different disorders in terms of EF (Milich et al., 2001).

The results reported here are not in line with the expectations based on Barkley's model (1997a, 1997b). First, although children with ADHD-C showed difficulties in two areas of inhibition, inhibiting a prepotent response and inhibiting an ongoing response, there was no general executive dysfunction in the ADHD-C group compared with normal controls (except one of the cognitive flexibility measures). This is in contrast with the predictions based on Barkley's model, because Barkley argued that ADHD children would encounter secondary problems in *all* other EF domains. The current study failed to find deficits in children with ADHD on working memory as measured by the SoP, planning as measured by the ToL, cognitive flexibility as measured with the WCST, and verbal fluency.

Following the introduction of the *DSM-IV* (APA, 1994), two studies have been published that compared children with ADHD and normal controls on the SoP (Scheres et al., 2004; Wiers, Gunning, & Sergeant, 1998). In line with our findings, Scheres et al. failed to distinguish between ADHD and normal controls. However, Wiers et al. reported significant difference on the SoP, but did not find a significant group by difficulty interaction. Therefore, we can conclude that our findings are in concordance with both studies. Two of the three earlier ToL studies failed to distinguish children with ADHD from normal controls (Houghton et al., 1999; Wiers et al., 1998). In the third study (Scheres et al., 2004), the difference between children with ADHD and normal controls disappeared after covarying non-EF demands, IQ, and age, which imply that the ToL finding is not a robust one. The WCST has differentiated children with ADHD from normal controls in a number of studies (Sergeant et al., 2002), but the effects seem to depend on which dependent variables are used. In the current study, the percentage perseverative responses was used as the dependent measure. Like Scheres et al. (2004), no group differences emerged with this dependent measure for the WCST. Three recent studies using verbal fluency concur with the results here (Lockwood et al., 2001; Murphy et al., 2001; Scheres et al., 2004). Although some differences were observed, these differences disappeared after taking account of IQ. Hence, our findings are in agreement with recent studies on EF in ADHD.

Second, in contrast to the expectation based on Barkley's model (1997a, 1997b), children with ADHD-C showed deficits on two of the four non-EF domains (visual-motor integration and visual short-term memory). These two domains require motor functioning, since the boys were required to make drawings. Therefore, the difficulties with these tasks might be due to more general motor problems. Barkley (1997a, 1997b) predicts that children with ADHD-C and ADHD-H will have difficulties especially with executing complex motor sequences. ADHD is associated with difficulties in movement skills (Harvey & Reid, 2003) and comorbidity with developmental coordination disorder (DCD; Barkley et al., 1990; Pitcher, Peik, & Barrett, 2002). In Scandinavia, this overlap has led to a diagnosis of deficits in attention, motor control, and perception (DAMP; Gillberg, 1999). Based on a comparison between children with ADHD only and children with ADHD and a motor dysfunction, Tervo, Azuma, Fogas,

and Fiechtner (2002) concluded that specifically children with ADHD-C exhibited motor problems. It may be that the children in our ADHD-C group encountered general motor deficits. However, this remains speculative because we did not focus on measuring motor capabilities. This finding implies that children with ADHD-C do not specifically encounter EF deficits.

Third, the ADHD-C and ADHD-I groups did not differ from each other on any of the EF domains, while EF deficits were specifically predicted in the ADHD-C group. Children with ADHD-I encountered difficulties with inhibiting a prepotent response, visual–motor integration and were remarkably good in interference control, compared to normal developing children. The ADHD-I group's difficulties in inhibitory control were *not* predicted based on the model of Barkley (1997a, 1997b), but are in line with the findings of Chhabildas et al. (2001), who showed that symptoms of inattention, but not symptoms of hyperactivity/impulsivity, accounted for the deficit in response inhibition in ADHD. Milich et al. (2001) proposed that ADHD-I and ADHD-C are distinctive diagnostic entities. However, this study revealed only significant differences on one visual short-term memory task. This is not the first study that has failed to find neuropsychological evidence for the proposed distinctiveness of these two groups (Barkley et al., 1992; Chhabildas et al., 2001; Faraone et al., 1998; Murphy et al., 2001). Milich et al.'s conclusion was based on the results of studies on inattention symptoms, comorbidity, demographics, and responsiveness to stimulant medication. However, based on the neuropsychological measures (both EF and most non-EF) used here, the two ADHD subtypes cannot be differentiated from one another. The exclusion of ASD in our ADHD groups might be an explanation of the null results in the current study. This is the first study that excluded children with ASD in a rigorous fashion. Thirty-three out of the 97 children with a clinical and DISC-IV diagnosis of ADHD were excluded (34%) because of comorbid ASD. Especially, deficits in attention are quite common in children with ASD (e.g., Casey, Gordon, Mannheim, & Rumsey, 1993; Courchesne et al., 1994; Plaisted, O'Riordan, & Baron-Cohen, 1998). It may be that previously reported differences between the two ADHD subtypes were confounded by the presence of ASD.

A major issue is whether the current study had sufficient power (the observed power ranged from .08 [time difference on the circle drawing task] to .88 [SSRT]). Fortunately, the study had sufficient power (.78) to detect large effect sizes (see Aron & Aron, 1999). Hence, only on measures on which we found large effect sizes is it likely to discriminate between the different groups with the current group sizes (see also Cohen, 1977). Milich et al. (2001) argued that the inconsistent results in ADHD subtype reports might largely be due to lack of power. However, even Murphy et al. (2001) could not distinguish the two subtypes of ADHD from each other, although that study had satisfactorily large groups. Moreover, in the studies by Klorman et al. (1999) and Nigg et al. (2002), both with sufficiently large samples with ADHD subtypes, only some of the EF tasks differentiated between the ADHD subtypes. Note that these studies did not replicate one another with respect to the *kind* of deficits that the ADHD subtypes exhibited. The small to medium effect sizes found in the current study indicate that there are few robust differences, but that there might be subtle differences between the ADHD subtypes. Enhanced power levels could make such differences between the subtypes statistically significant, but one may question the clinical significance of such statistical findings. Individual diagnostic assessment of EF does not seem to contribute to the differentiation between the two ADHD subtypes.

However, some might argue that, although the controls were carefully matched, the age range from 6 to 13 years would produce inflated standard deviations that would lead to the reported non-significant findings of the current study. Age-appropriate standard scores might solve this problem, partially. Unfortunately, most of the tests have no proper norm scores. We re-analyzed the data with age-corrected standard scores (*z*-scores). This re-analysis hardly altered the findings reported for the raw scores. Two differences emerged. First, the *z*-score transformation re-analysis indicated that children with ADHD-C show less interference control compared to the ADHD-I group. The ADHD-C group did not differ from normal control children. This might imply that ADHD-C is associated with a general inhibition deficit because they show difficulties in all three domains of inhibition as postulated by Barkley (1997a, 1997b). Second, children with ADHD-C exhibited greater difficulty with cognitive flexibility measures (as measured with the WCST) than normal controls. This finding contrasts with a previous report from our group (Scheres et al., 2004). The current study was substantially larger here and the difference between the two studies may be due to a power issue. In general, the reported findings using raw data hold up after using age-correct standard scores. This might imply that the lack of significant subtype differences is not due to the broad age range of the groups employed in the current study.

Another possible limitation could be that children with ADHD-I were selected using *DSM-IV-TR* (APA, 2000) criteria for this subtype. Other studies have shown that there are possibly two types of attention problems (Carlson & Mann, 2002; McBurnett, Pfiffner, & Frick, 2001): symptoms associated with a sluggish cognitive tempo (inconsistent alertness and orientation, e.g., daydreaming) and symptoms related to distraction. Symptoms of a sluggish cognitive tempo are not included in the *DSM-IV-TR* symptoms of inattention. Owens and Hoza (2003) showed that, for example, “shifts from one activity to another” has a high positive predictive power (e.g., predicting the presence of a disorder) for the inattentive subtype. Although this was an item in former editions of the DSM, it is not in the *DSM-IV-TR*. Therefore, it may be that there exists a group of children with inattention symptoms, which is distinguishable from children with ADHD-C on EF tasks, but that these children were not included in our sample. Hinshaw (2001) pointed out that by using the *DSM-IV-TR* criteria, one might underestimate the true magnitude of differences between ADHD-I and ADHD-C (see also Lahey, 2001). Future research should include children with a broader range of inattention symptoms than the symptoms included in the *DSM-IV-TR* (APA, 2000).

The present study challenges Barkley's (1997a, 1997b) EF-hypothesis of ADHD by showing that (1) ADHD-C boys do not encounter pervasive EF deficits, (2) EF deficits are not only related to ADHD-C but also to ADHD-I, and (3) boys with ADHD-C show deficits in non-EF domains. We did find an inhibition deficit in children with ADHD (in both subtypes). This study is the first study with stringent methodological controls for IQ, age, ODD/CD, ASD, OCD, and TS in the search for ADHD subtype differences in neuropsychological functioning. Despite this exclusion of possible confounders, the current findings did not yield evidence for the distinctiveness of ADHD-C and ADHD-I. This is in contrast to the argument by Milich et al. (2001) that ADHD-C and ADHD-I are separate disorders. However, this does not imply that the ADHD-C and ADHD-I subtypes cannot be differentiated from each other on other cognitive measures. Furthermore, the present study shows that most of the neuropsychological measures applied are not suitable for use in daily clinical practice, where they are intended to be used as an aid to differential diagnosis of ADHD-C and ADHD-I.

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