Contrasting deficits on executive functions between ADHD and reading disabled children

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Background: The object of this study was to analyze the executive functioning of children with attention deficit hyperactivity disorder (ADHD) or reading disability (RD) independent of their non-executive deficits. **Methods:** Three carefully diagnosed groups of children, aged between 7 and 12 years (35 ADHD, 22 RD and 30 typically developing children), were tested on a wide range of tasks related to five major domains of executive functioning (EF): inhibition, visual working memory, planning, cognitive flexibility, and verbal fluency. Additional tasks were selected for each domain to control for non-executive processing. **Results:** ADHD children were impaired on interference control, but not on prepotent and ongoing response suppression. ADHD showed deficits on visual working memory, planning, cognitive flexibility and phonetic fluency. RD children were impaired on phonetic fluency. The only EF measure that differentiated ADHD from RD was planning. **Conclusions:** The present sample of ADHD children showed several EF deficits, whereas RD children were almost spared executive dysfunction, but exhibited deficits in phonetic fluency. **Keywords:** ADHD, executive function, inhibition, reading disabilities, neuropsychology, phonemic fluency. **Abbreviations:** BVRT, Benton Visual Retention Test; ED, executive dysfunctioning; SON-R, Snijders–Oomen Non-Verbal Intelligence Test Revised; SSRT, Stop Signal Reaction Time; TEA-Ch, Test of Everyday Attention for Children; ToL, Tower of London; VMI, Visual Motor Integration test; WCST, Wisconsin Card Sorting Test.

There is a growing body of research demonstrating that children with attention deficit hyperactivity disorder (ADHD) present with both executive function (EF) and non-EF deficits (Sergeant, Geurts, & Oosterlaan, 2002; Sergeant, Willcutt, & Nigg, in press; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005a). One meta-analysis indicated that ADHD is associated with weaknesses in several EF domains: inhibition, planning and spatial working memory. Executive dysfunctioning (ED) cannot be fully explained by group differences in intelligence, or academic achievement (Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005b). The non-ED has been associated with processing speed and timing (Rommelse, Oosterlaan, Buitelaar, Faraone, & Sergeant, 2007; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003).

ADHD is associated with reading disability (RD) and RD shows ED (Pennington, Groisser, & Welsh, 1993). Two studies reported that ED in RD might be limited to verbal working memory and verbal fluency (Brosnam et al., 2002; Reiter, Tucha, & Lang, 2005). However, Purvis and Tannock (2000) demonstrated that RD children have ED in inhibitory processing, measured by the Stop Signal Reaction Time (SSRT) of the Change Task (Logan & Burkell, 1986). Nigg (1999) showed an association between RD and ADHD with SSRT. The association between ADHD and SSRT

remained in that study even following covariation for RD. Van der Schoot, Licht, Horsley, and Sergeant (2000) found that a subgroup of RD had poorer SSRT than typically developing children. In addition to ED, RD may be associated primarily with a phonological processing deficit in verbal working memory and the speed of processing (Willcutt et al., 2001, 2005b). A recent comparison between ADHD + RD, ADHD, RD and typically developing children reported no differences between these three clinical groups in inhibition and planning but did find poorer performance for working memory in the ADHD + RD group compared with the ADHD and control groups (Bental & Tirosh, 2007). Shanahan et al. (2006) have demonstrated that ADHD and RD are separable on both speed of word processing and motor processing. These findings suggest that both ADHD and RD have common ED but it is unclear if ED is entirely to be explained by EF or if it may be expressions of underlying non-EF malfunctioning. Further, the majority of studies reviewed above employed the English language, which has an irregular grapheme–phoneme relationship (Spencer, 2000). This led us to wonder whether the findings claimed for RD, in contrast to ADHD, would be replicated in a language (Italian) with a regular relationship between graphemes and phonemes.

A concern with previous reports claiming only ED in ADHD and/or RD is the failure to include non-EF tasks. We included several non-EF tasks that were

yoked to EF processes to measure EF as purely as possible: processing speed (i.e., mean reaction time and response variability), short-term memory, categorisation, and phonological awareness (Denckla, 1996; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Pennington & Ozonoff, 1996). Therefore, for each EF measure, a non-EF measure was derived and in the data analysis reported here we report findings using IQ as a covariate and without covariation, since there is discussion on the merits of this procedure (Miller & Chapman, 2001). Likewise, in order to strengthen our findings, we included multiple measures of EF domains (see Table 1), thereby increasing the reliability of our study.

The primary objectives of our study were:

1. Determine the ED of ADHD and RD participants in contrast to one another and typically developing children.
2. Assess the (in)dependence of the observed ED from/on non-EF processes.

Method

Participants

Eighty-seven children in the age range of 7 to 12 years were selected to participate in the study: 30 normal controls (6 females, 24 males), 35 with ADHD (only males and all Combined Subtype) and 22 with RD (6

females, 16 males). Table 2 presents the means and SDs for age, severity of disruptive symptoms according to parent and teacher ratings, IQ and reading performance. Reading performance is reported as a z-score of the average of the three reading measures (MT–Text, Words and Pseudo-words): a higher z-score indicates better performance.

Children with ADHD or RD. Children with ADHD were diagnosed using the Italian version of the PICS-IV (Parent Interview for Child Symptoms; Ickowicz et al., 2006; Zuddas, Anciletta, DeMuro, Marongiu, & Cianchetti, 1999) using DSM-IV criteria (APA, 1994). All patients were recruited from 'Child NeuroPsychiatry Units' in Venice and Cagliari (Sardinia). The presence of conduct disorder (CD), mood or anxiety disorders was an exclusion criterion. The inter-rater agreement on the PICS-IV was k = .78. In order to confirm impairment in several contexts, the Disruptive Behavior Disorder (DBD) Rating Scales for Parents and Teachers were completed (Pelham, Gangy, Greenslade, & Milich, 1992; Pillow, Pelham, Hoza, Molina, & Stultz, 1998; Marzocchi et al., 2001, 2003; Zuddas et al., 2006). Children with ADHD were required to obtain a score above the 90th percentile on both the Inattention and Hyperactivity-Impulsivity scales of both parents and teachers. All children were drug-naïve.

RD was diagnosed by two Italian standardised tests, namely, the *Test of Text Reading* (MT; Cornoldi, Colpo, & Gruppo, 1998), and three lists of Words and Pseudo-words (Sartori, Job, & Tressoldi, 1995). Inclusion

Table 1 Overview of tasks and their dependent variables

EF concept	Tasks	Dependent measures	Non-EF concept	Tasks	Dependent measures
Inhibition of a prepotent response	Change Task (Oosterlaan & Sergeant, 1998)	SSRT	Response execution	Change Task	Go MRT
Inhibition of an ongoing response	Circle Drawing Task (Bachorowski & Newman, 1990)	Circle time difference	Motor control	Visual Motor Integration (Beery & Buktenica, 2000)	Number of correct designs
Interference control	Opposite Worlds of the TEA-Ch (Manly et al., 1998)	TEA-Ch time difference	Rapid naming	Opposite Worlds of the TEA-Ch	TEA-Ch Same world condition
Working memory	Self-Ordered Pointing Task (Petrides & Milner, 1982)	SoP errors	Visual short-term memory	Benton Visual Retention Test (Sivan, 1992)	Number of correct designs
Planning	Tower of London (Krikorian, Bartok, & Gay, 1994)	ToL score ToL decision time ToL execution time	Spatial span memory	Corsi Block Tapping Test (Schellig, 1997)	Span level
Flexibility	Wisconsin Card Sorting Test (Grant & Berg, 1948)	WCST % perseverative responses	Semantic categorisation	Wisconsin Card Sorting Test	WCST non-perseverative responses
	Change Task	Change MRT Change number of errors Words produced	Response execution	Change Task	Go MRT Go number of errors
Fluency	Semantic Fluency (Benton & Hamsher, 1978		Semantic categorisation	Son-R (Snijders, Tellegen, & Laros, 1989; Tellegen & Laros, 1993)	Number of correct items
	Letter Fluency (Benton & Hamsher, 1978)	Words produced	Phonological awareness	Letter Fluency	Letter rule–breaks

Table 2 Clinical characteristics of the sample, IQ and reading scores

Variables	NC = 30		ADHD = 35		RD = 22		One-way ANOVA	
	M	SD	M	SD	M	SD	F (df = 2,84)	Tukey post-hoc (p < .017)
Age	9.28	1.19	9.21	1.57	9.38	1.34	.103	ns
Disruptive symptoms: parents								
Inattention	3.23	2.50	15.71	5.91	4.07	3.86	62.34***	NC,RD < ADHD
Hyperactivity	3.51	3.11	14.93	5.72	3.40	2.50	59.44***	NC,RD < ADHD
ODD	2.50	2.75	7.93	5.14	1.73	1.39	19.47***	NC,RD < ADHD
CD	.38	.70	3.46	3.86	1.87	1.64	9.28***	NC < ADHD
Disruptive symptoms: teachers								
Inattention	1.99	2.19	15.77	6.37	5.53	6.07	45.60***	NC,RD < ADHD
Hyperactivity	2.47	3.31	13.89	7.04	2.73	3.13	36.99***	NC,RD < ADHD
ODD	1.30	1.97	9.47	6.54	1.93	2.71	23.43***	NC,RD < ADHD
CD	.30	.76	3.72	3.84	1.93	1.49	10.55***	NC < ADHD
Full Scale IQ	116.43	10.18	106.74	14.44	100.05	10.17	12.21***	NC > ADHD,RD
Reading: accuracy (z)	.45	.38	−.30	.88	−2.71	2.29	37.19***	NC,ADHD > RD
Reading: speed (z)	.11	.69	.63	1.11	−3.09	1.89	42.69***	NC,ADHD > RD

Note: Inattention, Hyperactivity, ODD and CD are raw values obtained from the DBD Rating Scales. Reading performance values are the average, expressed in *z*-scores of three tests: MT Test (Cornoldi, Colpo, & Gruppo, 1998); Read Word and Pseudo-words (Sartori, Job, & Tressoldi, 1995); Reading performance values are presented in *z*-scores (Speed and Accuracy). IQ values are obtained from the WISC-R (Wechsler, 1994). Contrasts are significant at Alpha = .017 (Tukey Post-hoc). *p < .017, **p < .01, ***p < .001.

criteria required performing at least 1.5 SDs below the mean of the children of the same age on the MT Test (both Speed and Accuracy). Moreover, to be classified as RD, children had to obtain a score of at least 2 SDs below the mean on the three lists of Words and Pseudo-words (Speed and Accuracy).

All children underwent a comprehensive neurological and medical examination. No child had a history of brain damage, epilepsy, psychosis or frank language disorder.

In order to ensure that there was no comorbidity of ADHD and RD in our groups, all ADHD children were required not to have to a score 1.5 SDs below the mean on the text reading test (Cornoldi et al., 1998) or to have a score 2 SDs below the mean on the lists of Words and Pseudo-words (Sartori et al., 1995). Moreover, RD children were required to obtain a score below the 70th percentile on the four sub-scales of the DBD (Inattention, Hyperactivity-Impulsivity, Oppositional Defiant Disorder, Conduct Disorder) in order to avoid a comorbid diagnosis of RD with ADHD.

Typically developing participants. Control children were recruited from primary schools in the same areas as ADHD children. The ADHD, RD and normal controls were matched for age. Typically developing children were excluded from the study if: (1) the parent or the teacher stated that the child had ever received a clinical diagnosis (e.g., a behavioural problem or a learning disability); or (2) their full scale IQ (FSIQ) estimate was below 80 as measured with the short version of the WISC-R; or (3) the score on one of the four DBD sub-scales (i.e., Attention, Hyperactivity/Impulsivity, Oppositional, Conduct) of the parent or the teacher exceeded the 75th percentile; or (4) they presented with RD and satisfied the inclusion criteria of the RD group.

Materials

WISC-R. Four subtests of the WISC-R (Arithmetic, Vocabulary, Picture Arrangement, Block Design)

(Wechsler, 1994) were administered to all children. Full scale IQ was used to match the three groups. These subtests correlate.93 to.95 with the full scale IQ (Groth-Marnat, 1997). Children with an IQ score below 80 were excluded from the study.

Reading tests. MT Test (Cornoldi et al., 1998). Children were presented with a text which normally takes a maximum of 4 minutes to read. The number of errors and the time to read were recorded. If a child was not able to read all of the text in 4 minutes, the task was interrupted and the total number of errors was pro-rated.

Lists of Words and Pseudo-words (Sartori et al., 1995). All children were presented with four lists of 16 words and three lists of 16 pseudo-words. The number of errors and the time to read were recorded.

Neuropsychological measures. Since neuropsychological tasks are never 'pure' measures of a single EF domain, more than one task was included to cover a particular domain. Several non-EF tasks were also included in order to control for the non-executive components of EF tasks (Geurts et al., 2004). Table 1 provides an overview of the EF domains, dependent measures, non-EF measure and tasks.

Procedure

All 87 children were tested individually, on three separate occasions: tests were administered in a fixed order by a trained psychologist. During the first session, the WISC-R and the reading tests were administered. At the second session, one to four days later, the Circle Drawing Task (Bachorowski & Newman, 1990), Self-Ordered Pointing Task–Abstract Designs (SoP; Petrides & Milner, 1982), Verbal Fluency (Benton & Hamsher, 1978), Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), and the Benton Visual Retention Test (BVRT; Sivan, 1992) were administered. One week later,

the Change Task (Oosterlaan & Sergeant, 1998), Corsi Block Tapping Test (Schellig, 1997), Categories of the Snijders–Oomen Non-Verbal Intelligence Test Revised (SON-R 51/2–17; Snijders, Tellegen, & Laros, 1989; Tellegen & Laros, 1993), Tower of London (ToL; Krikorian, Bartok, & Gay, 1994), the Test of Everyday Attention for Children–Opposite Worlds (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1998) and Visual Motor Integration test (VMI; Beery & Buktenica, 2000) were administered.

Data treatment and missing values

Owing to technical difficulties, data for the Change Task were available for 22 typically developing children, 35 children with ADHD and 21 with RD. Groups differed in terms of IQ. The possible confounding effect of IQ was controlled in analyses (see Table 2). Missing data from other tasks ranged between 0 and 3.

Statistical analysis

First, EF measures were analyzed using ANOVAs with group (3 levels) as the between-subject factor. ANOVAs were run separately for each of the 12 variables of the EF measures. Second, groups were compared on EF measures, after controlling for IQ. Third, groups were compared on EF measures, while controlling for specific and corresponding non-EF measures (see Table 1). Three group contrasts were performed: (1) NC versus ADHD, (2) NC versus RD, and (3) ADHD versus RD. These three contrast analyses were performed separately for each EF domain. Alpha level was adjusted to compensate for the number of comparisons; alpha was set at .017 (.05/3). Since the number of participants in each group was relatively small, partial eta squared ($_p\eta^2$) for each comparison is provided (Cohen, 1988). The group main effect, the group effect after covariations with IQ and with the specific non-EF tasks are presented in Table 3. In the text, the group main effect obtained by ANOVAs after covariation with non-EF tasks is reported.

Results

Gender was unevenly represented in the study groups: 6 females in the RD group and 6 females in the normal control group ($\chi^2(2) = 9.93$, $p < .01$). Preliminary analysis using gender as factor revealed that the difference between boys and girls (of the RD and control groups, only) was not significant on any neuropsychological variable.

Groups did not differ with respect to age ($F(2,84) = .103$, ns, $_p\eta^2 = .00$). They did differ with respect to IQ ($F(2,84) = 4.351$, $p < .05$, $_p\eta^2 = .05$). Pairwise group comparisons (Tukey; α set at .017) showed that the normal control group had a higher IQ than the ADHD and RD groups.

Table 3 Group means and standard deviations for executive function tasks and covariation with corresponding non-executive measures.

							Effect of group	Effect of IQ	Effect of non-EF measures	Contrasts between groups after covariation
	NC ($n = 30$)		ADHD ($n = 35$)		RD ($n = 22$)					
EF measure	M	SD	M	SD	M	SD	$F(1,84)$	$F(1,84)$	$F(1,84)$	Tukey
Prepotent inhibition										
SSRT	278.5	107	299	91.8	286.8	102.1	.296	.322	1.361	n.s.
Ongoing inhibition										
Circle time difference	86.4	50.7	42.3	42.8	70.2	109.5	3.649*	.049	3.005	n.s.
Interference control										
TEA-Ch time difference	5.3	4.0	9.1	7.8	7.9	4.7	3.509*	.983	1.811	ADHD < NC
Working memory										
SoP errors	16.5	6.9	23.6	7.3	21.3	6.8	8.062**	1.842	19.199***	ADHD < NC
Planning										
ToL total score*	28.6	2.7	24.7	5.2	29.1	2.9	12.105***	4.013*	4.761*	ADHD < RD,NC
ToL planning time/item*	5.1	1.8	3.5	1.5	4.9	1.9	7.067**	.023		ADHD < NC
ToL–total time/item)	9.0	1.7	9.7	4.1	9.9	3.2	.561	1.447		n.s.
Flexibility										
Change MRT	587	161	563	118	552	72	.464	.318	14.355***	n.s.
Change Errors	8.2	1.5	8.0	1.2	8.6	1.5	.115	.020	42.507***	n.s.
WCST % perseverative responses	13.5	8.7	26.9	14.5	21.7	12.8	10.017***	4.137*	.131	ADHD,RD < NC
Fluency										
Semantic number correct	26.2	4.9	25.4	7.8	24.6	10.3	.308	1.876	5.927*	n.s.
Letter number correct	16.4	6.0	10.4	5.1	11.0	4.6	11.688***		4.278*	ADHD,RD < NC

Note. ADHD = attention deficit hyperactivity disorder; RD = reading disorder; NC = normal controls; MRT = mean reaction time; SoP = Self Ordered Pointing Task; SSRT = Stop Signal Reaction Time; TEA-Ch = Test of Every Day Attention for Children; ToL = Tower of London; WCST = Wisconsin Card Sorting Test.
Note: TOL total score and TOL planning time discriminated children with ADHD and RD, both before and after covarying IQ (p < .01). Contrasts are significant at Alpha = .017 (Tukey post-hoc). *p < .017, **p < .01, ***p < .001

EF domains

Inhibition. Change Task. SSRT is a measure of the latency of the inhibitory process (Logan, 1994). The group main effect was not significant; pairwise comparison results were the following: ADHD vs. NC: ($F(1,55) = .578$, $p = .450$, $_p\eta^2 = .01$); RD vs. NC ($F(1,41) = .069$, $p = .795$, $_p\eta^2 = .00$); ADHD vs. RD ($F(1,54) = .203$, $p = .654$, $_p\eta^2 = .00$). After covariation with non-EF measures (MRT) the main group effect remained nonsignificant ($F(2,78) = .446$, $p = .642$, $_p\eta^2 = .01$).

Circle Drawing Task. The time used to trace the circle in the slow condition minus the tracing time in the neutral condition was used as the dependent variable. The main effect of group was significant; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 14.921$, $p < .001$, $_p\eta^2 = .19$); RD vs. NC ($F(1,50) = .530$, $p = .470$, $_p\eta^2 = .01$); ADHD vs. RD ($F(1,55) = 1.933$, $p = .170$, $_p\eta^2 = .03$). After covariation with Visual Motor Integration, the main group effect was no longer significant ($F(2,84) = 2.516$, $p = .807$, $_p\eta^2 = .06$).

Tea-Ch (Opposite Worlds). The difference between the mean time to complete the Opposite World condition and the mean time to complete the Same World condition (interference score) was used as dependent variable. The main effect of group was significant for the interference score; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 6.067$, $p = .017$, $_p\eta^2 = .09$); RD vs. NC ($F(1,50) = 4.760$, $p = .034$, $_p\eta^2 = .09$); ADHD vs. RD ($F(1,55) = .492$, $p = .486$, $_p\eta^2 = .01$). The main group effect remained significant ($F(2,84) = 3.671$, $p < .05$, $_p\eta^2 = .08$) after covariation with the baseline condition (Same World condition), indicating a greater interference control deficit in the ADHD children compared to controls ($F(1,62) = 6.269$, $p = .015$, $_p\eta^2 = .09$).

Working memory. Self Ordered Pointing Task (SoP). The number of errors increased linearly with difficulty level ($F(1,81) = 136.531$, $p < .001$, $_p\eta^2 = .63$). The main effect of group was significant; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 16.535$, $p < .001$, $_p\eta^2 = .21$); RD vs. NC ($F(1,50) = 6.462$, $p = .014$, $_p\eta^2 = .11$); ADHD vs. RD ($F(1,55) = 1.451$, $p = .234$, $_p\eta^2 = .03$). The interaction of group by level of difficulty was significant ($F(2,81) = 3.885$, $p < .05$, $\eta^2 = .09$). Children with ADHD committed more errors than controls at the three most difficult levels of the task: at level 6 ($F(1,63) = 2.039$, $p = .158$, $_p\eta^2 = .03$); at level 8 ($F(1,63) = 10.656$, $p = .002$, $_p\eta^2 = .14$); at level 10 ($F(1,63) = 14.124$, $p < .001$, $_p\eta^2 = .18$); at level 12 ($F(1,63) = 8.461$, $p = .005$, $_p\eta^2 = .12$). After covariation with the Benton Visual Retention Test the main group effect remained significant ($F(2,81) = 4.109$, $p < .05$, $_p\eta^2 = .09$): Tukey post-hoc analysis revealed that children with ADHD performed more poorly
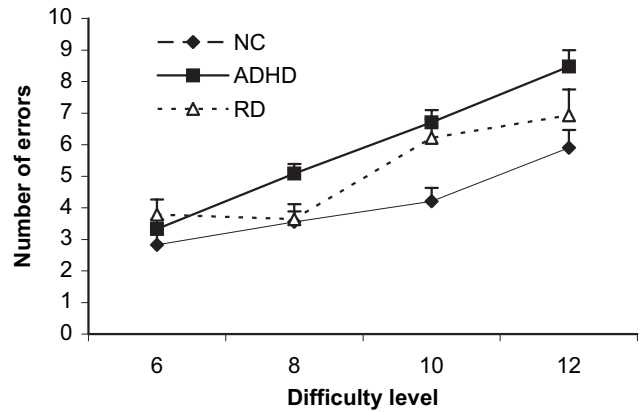

Figure 1 Effects of increasing difficulty in visuo-spatial working memory (SoP)

than controls ($F(1,63) = 7.956$, $p = .006$, $_p\eta^2 = .11$). Children with ADHD showed a visuo-spatial working memory deficit, not explained by passive storage of visual information, but also due to a deficit in the active control of the retention of visuo-spatial information. These results are depicted in Figure 1.

Planning. ToL. In order to evaluate 'planning skills', three variables were analyzed: the ToL score, the planning time and the execution time for each problem. The task included 12 problems encompassing four levels of difficulty. Individual data were averaged for difficulty level. Performance (ToL score) decreased linearly with difficulty level ($F(1,83) = 160.599$, $p < .001$, $_p\eta^2 = .66$). ToL Score is presented in Figure 2. The main group effect was significant with respect to the ToL score; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 15.789$, $p < .001$, $_p\eta^2 = .20$); RD vs. NC ($F(1,50) = .004$, $p = .951$, $_p\eta^2 = .00$); ADHD vs. RD ($F(1,55) = 11.687$, $p = .001$, $_p\eta^2 = .17$). After covariation with the Corsi task the group effect remained significant ($F(2,84) = 9.071$, $p < .01$, $_p\eta^2 = .18$). Post-hoc comparisons showed that children with ADHD were significantly poorer than normal controls ($F(1,62) = 9.623$, $p = .003$, $_p\eta^2 = .13$) and children with RD ($F(1,54) = 9.683$, $p = .003$, $_p\eta^2 = .15$). The cubic effect of the group by level interaction was significant ($F(1,83) = 3.870$, $p = .025$, $_p\eta^2 = .08$). This interaction was due to the significant differences between ADHD vs. RD and controls in the 3 and 5 moves problems ($p < .01$), but not in the 2 and 4 moves problems.

Planning time is presented in Figure 2. Across groups, planning time increased with level of difficulty ($F(2,84) = 17.306$, $p < .001$, $_p\eta^2 = .18$). The main effect of group was significant; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 15.386$, $p < .001$, $_p\eta^2 = .20$); RD vs. NC ($F(1,50) = .160$, $p = .691$, $_p\eta^2 = .00$); ADHD vs. RD ($F(1,55) = 9.120$, $p = .004$, $_p\eta^2 = .14$). Group by difficulty level interaction (quadratic effect) was significant ($F(2,84) = 3.791$, $p < .05$, $_p\eta^2 = .09$). Normal
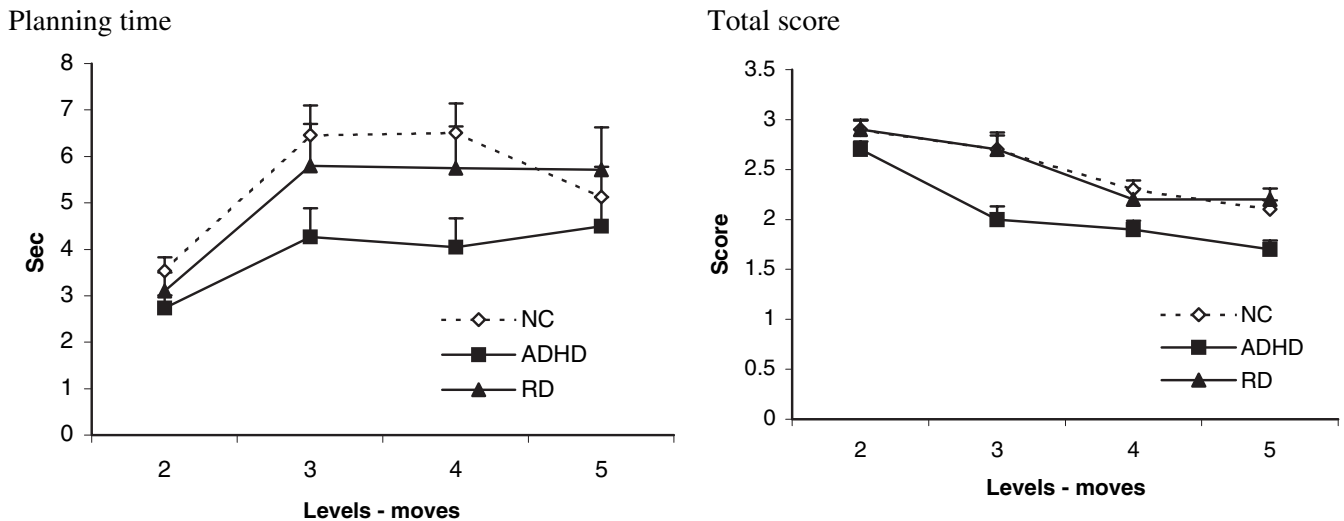
Planning time

Total score

Figure 2 Group performance on the Tower of London planning time and total score

controls and children with RD increased in planning time for executing 3 and 4 moves problems, compared to ADHD ($p < .01$). The difference between the three groups in planning time in the 5 moves problems was not significant.

Execution time increased with difficulty level and the linear trend was found to be significant ($F(2,84) = 165.923$, $p < .001$, $_p\eta^2 = .67$). The group effect of ToL execution time was not significant; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = .647$, $p = .424$, $_p\eta^2 = .01$); RD vs. NC ($F(1,50) = 1.695$, $p = .199$, $_p\eta^2 = .03$); ADHD vs. RD ($F(1,55) = .054$, $p = .817$, $_p\eta^2 = .00$).

Cognitive flexibility. Change Task (MRT and errors of the change responses of the Change Task). For the MRT of the Change condition the main effect of group was not significant; pairwise comparison results were the following: ADHD vs. NC ($F(1,55) = .399$, $p = .530$, $_p\eta^2 = .01$); RD vs. NC ($F(1,50) = .832$, $p = .367$, $_p\eta^2 = .02$); ADHD vs. RD ($F(1,55) = .164$, $p = .687$, $_p\eta^2 = .00$). The main group effect remained nonsignificant after covariation with the MRT of the Go-condition ($F(2,78) = .764$, $p = .469$, $_p\eta^2 = .02$).

The group effect was not significant for the number of errors in the change responses; pairwise comparison results were the following: ADHD vs. NC ($F(1,55) = .076$, $p = .784$, $_p\eta^2 = .00$); RD vs. NC ($F(1,50) = .034$, $p = .854$, $_p\eta^2 = .00$); ADHD vs. RD ($F(1,55) = .211$, $p = .648$, $_p\eta^2 = .00$). The main group effect remained non significant after covariation with the errors of the Go-condition ($F(2,78) = 1.071$, $p = .348$, $_p\eta^2 = .03$).

Wisconsin Card Sorting Test. The main effect of group was significant for perseverative responses; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 20.705$, $p < .001$, $_p\eta^2 = .25$); RD vs. NC ($F(1,50) = 7.591$, $p = .008$, $_p\eta^2 = .13$); ADHD vs. RD ($F(1,55) = 2.030$, $p = .160$, $_p\eta^2 = .04$). The group effect remained significant after

covariation with non-perseverative responses ($F(2,84) = 7.097$, $p < .001$, $_p\eta^2 = .15$). Post-hoc comparisons revealed that only ADHD children performed significantly worse than controls ($F(1,62) = 17.690$, $p < .001$, $_p\eta^2 = .22$). The performance of RD children was not significantly different from the performance of the controls ($F(1,54) = 1.317$, $p = .257$, $_p\eta^2 = .03$) or from the performance of the ADHD children ($F(1,54) = 2.302$, $p = .135$, $_p\eta^2 = .04$).

Verbal Fluency. Semantic Fluency. The total number of words produced in the semantic fluency task showed no main effect of group before and after covariation with SON-R: ($F(2,84) = .373$, n.s., $_p\eta^2 = .01$). Pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = .259$, $p = .614$, $_p\eta^2 = .00$); RD vs. NC ($F(1,50) = .616$, $p = .436$, $_p\eta^2 = .01$); ADHD vs. RD ($F(1,55) = .127$, $p = .723$, $_p\eta^2 = .00$).

Letter Fluency. The main effect of group was significant for the number of correct words; pairwise comparison results were the following: ADHD vs. NC ($F(1,63) = 19.022$, $p < .001$, $_p\eta^2 = .23$); RD vs. NC ($F(1,50) = 12.578$, $p = .001$, $_p\eta^2 = .20$); ADHD vs. RD ($F(1,55) = .183$, $p = .670$, $_p\eta^2 = .00$). The covariation with the number of phonological errors did not reduce the significant group effect ($F(2,84) = 14.010$, $p < .001$, $_p\eta^2 = .25$). Again, post-hoc comparisons showed that both ADHD and RD children performed significantly worse than controls ($p < .001$).

Non-EF dependent variables

The group comparisons for the non-EF dependent variables are presented in Table 4.

As may be seen from Table 4, none of the processing speed measures differentiated between the groups. In contrast, the ADHD group differed from controls on spatial short-term memory, memory

Table 4 Group means and standard deviations for non-EF tasks

| Non-EF measure | Groups | | | | | | Effect of group | Group contrasts |
| | NC ($n = 30$) | | ADHD ($n = 35$) | | RD ($n = 22$) | | | |
	M	SD	M	SD	M	SD	$F(1,84)$	$p < .017$
Response execution								
Go-MRT	484.9	150.9	426.2	253.4	504.6	78.7	1.270	n.s.
Go-Errors	4.54	4.38	7.83	9.95	7.00	7.78	1.119	n.s.
Motor control VMI	19.07	3.38	17.02	3.36	18.00	4.21	2.595	n.s.
Rapid naming TEA-Ch baseline	26.07	4.11	26.49	7.34	29.52	8.07	1.984	n.s.
Visual short-term memory								
BVRT	6.13	1.89	4.69	1.95	5.19	1.79	4.797*	ADHD < NC
Spatial short-term memory								
Corsi Span Task	4.70	.75	4.09	.95	4.41	.73	4.406*	ADHD < NC
Semantic categorisation								
WCST % non-pers. responses	10.96	6.42	22.91	12.71	17.75	9.14	11.475***	ADHD < NC
SON-R	11.37	3.76	8.03	4.09	10.23	6.68	4.106*	ADHD < NC
Phonological awareness								
Letter–rule breaks	2.20	3.36	1.34	1.81	.14	.35	5.145**	NC < RD

Note: ADHD = attention deficit hyperactivity disorder; RD = reading disorder; NC = normal controls; BVRT = Benton Visual Retention Test; Corsi = Corsi Block Tapping Test; MRT = mean reaction time; SON-R = Snijders–Oomen Non-verbal Intelligence Test Revised. WCST = Wisconsin Card Sorting Test.
Legend: *$p < .05$; **$p < .01$; ***$p < .001$.

span, and non-perseverative errors in the WCST and SON-R categories. Thus, non-EF measures are important in the neuropsychological assessment of ADHD children. Controls performed better than RD children, as expected, on the phonological task.

Discussion

The major aim of the current study was to investigate if ADHD and RD could be discriminated by their EF profile, independent of their non-EF performance.

We first determined how children with ADHD would present in a variety of EF domains: inhibition, planning, working memory and set-shifting. This was partly supported: ADHD showed deficits in planning, working memory, set-shifting and letter fluency. However, they did not show a *generalised* inhibitory control deficit, thus replicating, among others, Scheres, Oosterlaan, and Sergeant (2001), nor were ADHD children differentiated in inhibitory processing from RD children. The only inhibitory measure to discriminate between ADHD and typically developing children was the time difference score on the TEA-CH. This measure did not discriminate between ADHD and RD participants. Initially, the time difference score on the Circle Drawing Task discriminated ADHD from controls, but when the non-EF measure (Visuo-Motor Integration) was entered as covariate, this difference was no longer significant. Hence, the hypothesised inhibition impairment in ADHD was not solely attributable to ED, but also involves visuo-motor coordination processing.

Children with RD performed more poorly than controls on both the letter fluency task and on the set-shift measures (perseverations on the WCST),

suggesting ED of a more limited nature in RD children than in ADHD children.

ADHD participants were differentiated from RD participants in planning (total score and the decision time) on the ToL. This indicates that both ADHD and RD children have a common ED. In contrast, ADHD and RD participants had virtually equal scores in visuo-spatial working memory but significantly differed from one another on the Benton retention span, a non-EF measure.

Several measures of processing speed (see Table 4) revealed no significant difference between groups. Hence, we failed to replicate the processing speed findings of Shanahan et al. (2006), but this may depend on the tasks used here.

In order to provide a comprehensive test of the inhibition model (Barkley, 1997), we used three measures of inhibitory control: inhibition of prepotent responses, ongoing responses and the capacity to control interferences. Following covariation with non-EF measures, children with ADHD were not significantly different from controls on two measures: SSRT and Circle Drawing Task. This suggests that claims of deficits in inhibition in ADHD may reflect a more generalised deficit in attention/cognitive control as suggested by a recent meta-analysis (Alderson, Rapport, & Kofler, 2007). Further research with larger samples and a combined group of ADHD + RD children needs to be conducted before definitive conclusions can be drawn.

The third measure of inhibition was derived from the Opposite Worlds Task of the TEA-Ch (Manly et al., 1998). This task discriminated children with ADHD from controls: ADHD children spent more time in naming the opposite digits compared to the baseline naming measure, replicating Shanahan et al. (2006). This finding contrasts with the Change task results

and poses the question of how far claims of poor inhibition in ADHD may be task specific. The SSRT measure does not require a switch mechanism as in the TEA-CH. However, the Change MRT and errors were also nonsignificant, suggesting that the switch from automatic to controlled processing is better measured in the TEA-CH than in the Change Task.

Visual Working Memory (SoP) differentiated children with ADHD from controls, and did so robustly, since after partialling out for Visual Short Term Memory (Benton task), the effect, albeit smaller, remained significant. The RD group was nearly equal to the ADHD group in their impairment in visual working memory, suggesting that a common process deficit is present in both ADHD and RD. This is an important finding, since it demonstrates that the visuo-spatial working memory deficit in ADHD children can be separated from the capacity to retain visuo-spatial information.

Interestingly, the ToL discriminated children with ADHD from both controls and the RD group, substantially replicating three earlier reports (Brosnam et al., 2002; Reiter et al., 2005; Oosterlaan, Scheres, & Sergeant, 2005). The poor performance of children with ADHD on the ToL was characterised by a shorter delay in response initiation following instructions at the beginning of task execution and a larger number of rule violations. ADHD showed a trade-off: as the task became more difficult, they maintained a constant speed of processing at the cost of a higher error rate. This suggests that performance in the ToL reflects more an impulsive strategy than a true planning problem, although highly impulsive individuals are unlikely to be optimal planners. An alternative explanation is the delay aversion hypothesis that ADHD children started to perform the task immediately due to their aversion to delay (Sonuga-Barke, Taylor, Sembi, & Smith, 1992). In order to disentangle these two different accounts, future neurospychological studies should include a condition in which children have to wait before starting to perform the task or receive a concrete reinforcement (Luman, Oosterlaan, Hyde, van Meel, & Sergeant, 2007).

Total Score and Decision Time of the ToL differentiated children with ADHD from children with RD. This is the only EF task here that discriminated ADHD from RD participants. This finding, if replicated, would suggest that functional magnetic resonance imaging (fMRI) studies of these two groups would gain in specificity by pitting working memory tasks against planning tasks.

We note that the poor performance of the ADHD children was restricted here to EF tasks that, potentially, activate the dorsolateral prefrontal cortex bilaterally (Tower of London, Self Ordered Pointing Task, and Wisconsin Card Sorting Task). The inhibition tasks activate a more extended network involving the inferior frontal gyrus and fronto-striatal system and the basal ganglia (Aron & Poldrack, 2006; Sergeant et al., 2002). The letter fluency task involves the left inferior frontal gyrus (Gaillard et al., 2003). In view of these results, we suggest that neuropsychological studies of ADHD should determine the association of the dorsolateral and inferior frontal more thoroughly (Shanahan et al., 2006).

Limitations and future directions

Some limitations should be noted: first of all, the control group was composed of children recruited from schools, whereas children with ADHD or RD were recruited from clinics. This different sampling procedure may have emphasised the differences between the disordered and the control children. Secondly, in future studies it would be very useful to contrast ADHD and RD on a variety of working memory tasks, because it is possible that children with ADHD would be more impaired in *visuo*-spatial working memory, whereas children with RD would be more impaired in *verbal* working memory. Thirdly, a group with comorbidity (ADHD + RD) was absent in this study; therefore, it was not possible to test competing hypotheses on the specific neuropsychological profile of ADHD, RD and their comorbidity. Clearly, before conclusions on ED are drawn, their independence from non-EF processes needs to be demonstrated.

Supplementary material

The following supplementary material is available for this article:

Appendix S1. EF tasks and dependent measures as part of the online article from: http://www.blackwell-synergy.com/doi/abs/10.1111/j.1469-7610.2007.01859.x (This link will take you to the article abstract).

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