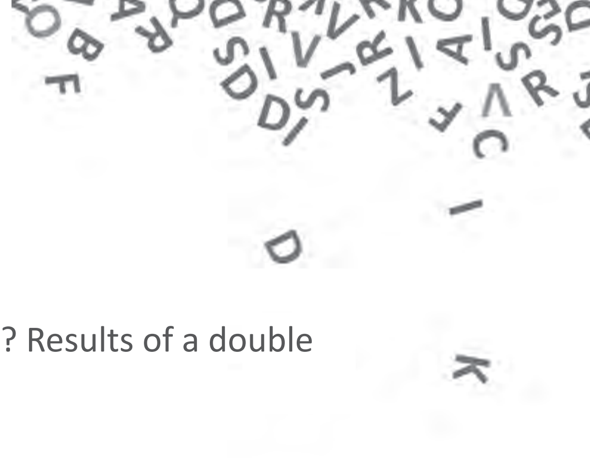

Chapter 3

How distinctive are ADHD and RD? Results of a double dissociation study.

Abstract

Background: The nature of the comorbidity between Attention-Deficit/Hyperactivity Disorder (ADHD) and Reading Disability (RD) was examined using a double dissociation design. **Method:** Children were between 8 and 12 years of age and entered into four groups: ADHD only (n = 24), ADHD+RD (n = 29), RD only (n = 41) and normal controls (n = 26). In total, 120 children participated in the study; 38 girls and 82 boys. **Results:** Both ADHD and RD were associated with impairments in inhibition and lexical processing, although inhibition and lexical processing were more severely impaired in RD than in ADHD. Visuospatial working memory deficits were specific to children with only ADHD. **Conclusions:** It is concluded that there was overlap on lexical processing and to a lesser extent on inhibition between ADHD and RD. In ADHD, impairments were dependent on IQ, which suggest that the overlap in lexical processing and inhibition is different in origin for ADHD and RD. The ADHD only group was specifically characterised by deficits in visuospatial working memory. Hence, no double dissociation between ADHD and RD was found on executive functioning and lexical processing. **Keywords:** ADHD, RD, comorbidity, executive functioning, lexical processing.

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INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) and Reading Disability (RD) are two common childhood disorders, which frequently co-occur. Research estimates the comorbidity of RD in children with ADHD between approximately 20-40% (Del'Homme, Kim, Loo, Yang & Smalley, 2007; Semrud-Clikeman et al., 1992). The comorbidity of ADHD in the RD population is estimated between 26-50 % (Holborow & Berry, 1986; Lambert & Sandoval, 1980).

The current study focuses on the nature of this comorbidity using neuropsychological measures. Neuropsychological functioning may be of particular importance in the context of the comorbidity of ADHD and RD, because it seems to be a translational domain between aetiological factors and observable symptoms (Doyle et al., 2005). Overlapping neuropsychological deficits may provide insight into the factors contributing to the frequent co-occurrence of both disorders, whereas the non-overlapping deficits may indicate why some patients develop the one, but not the other disorder.

The current study addresses this overlap and the specificity of neuropsychological deficits in ADHD and RD by using a double dissociation design, which compares four groups: ADHD only, RD only, ADHD+RD and normally developing controls. In double dissociation studies, processes are selected that are presumed to be primarily impaired in one, but not in the other disorder. In previous double dissociation studies of ADHD and RD, research was directed towards executive functioning (EF), especially for ADHD. Processes studied previously in RD were precursors of reading, such as, phonological or rapid naming skills (Bental & Tirosh, 2007; McGee, Williams, Moffitt & Anderson, 1989; Pennington, Groisser & Welsh, 1993; Purvis & Tannock, 1997; 2000; Willcutt et al., 2001). Deficits in EF have been suggested as the core deficits of ADHD (Barkley, 1997; Nigg, 1999; Quay, 1997). In contrast, phonological and rapid naming deficits have been found primarily in RD (Snowling, 2000; Stanovich, 1988; Stanovich & Siegel, 1994).

Earlier double dissociation studies in ADHD and RD have produced contradictory results, since EF deficits have been found in both ADHD and RD (Willcutt, Pennington, Olson, Chhabildas & Hulslander, 2005). Similarly, rapid naming deficits, thought specific for RD, have been found in ADHD (Pennington et al., 1993; Purvis & Tannock, 2000; Willcutt et al., 2005). Three factors may have contributed to these contradictory findings.

The first factor is that different EF domains have been employed in double dissociation studies. The EF inhibition is believed to be primarily impaired in ADHD (Barkley, 1997; Pennington et al., 1993; Robins, 1992; Willcutt et al., 2001). However, inhibitory deficits have been found in RD, although to a lesser extent than in ADHD (Närhi & Ahonen, 1995; Purvis & Tannock, 2000; Van Der Schoot et al., 2000; Willcutt et al., 2005). Likewise, deficits in working memory (WM) have been reported in both ADHD and RD (Barkley, 1997; Castellanos & Tannock, 2002; De Jong, 1998; Pennington & Ozonoff, 1996; Willcutt et al., 2001). However, if WM is divided into verbal and visuospatial components, verbal WM deficits are more often associated with RD than with ADHD (Martinussen & Tannock, 2006; Rucklidge & Tannock, 2002; Swanson, Mink & Bocian, 1999; Willcutt et al., 2001); whereas visuospatial WM deficits are more pronounced in ADHD than RD, although research concerning the specificity of visuospatial WM impairments in ADHD compared to RD is limited (Marzocchi et al., 2008).

A second factor that may have contributed to the contradictory results is a failure to take into account other co-occurring deficits in both ADHD and RD, which may be associated with EF, such as, pragmatic and arithmetic skills. Pragmatic deficits in both children with ADHD and RD may obscure the uniqueness of EF impairments in ADHD in double dissociation studies, since pragmatic deficits co-occur with EF impairments (Geurts, Verté, Oosterlaan, Roeyers & Sergeant, 2003; Griffiths, 2007). Similarly, arithmetic deficits have been reported in both children with ADHD and RD and are associated with poor EF, such as, visuospatial WM (Van der Sluis, Van der Leij & De Jong, 2005).

A third complicating factor is the heterogeneity of the ADHD groups employed in some double dissociation studies, encompassing children either with the predominantly inattentive, predominantly hyperactive-impulsive, and combined ADHD subtypes (Klorman et al., 1999).

The current study sought to improve upon previous double dissociation studies in ADHD and RD by using both inhibition and visuospatial WM tasks. Additionally, a lexical decision task was used to measure reading skills. This task is more closely related to reading than the more frequently used measures of single phonological skills or rapid naming (Gijsel, Van Bon & Bosman, 2004). Considerable effort was made to collect homogeneous groups. Children were carefully screened for pragmatic and arithmetic deficits and were excluded, when they had severe impairments in arithmetics and/or pragmatics. Only the combined subtype of ADHD entered into the study in order to provide more homogeneous ADHD groups.

METHOD

Participants

Children with ADHD and children with ADHD+RD were recruited in six paediatric outpatient clinics in The Netherlands and one outpatient clinic in Belgium. Children with RD were recruited by advertisements in Belgium, since they are not regularly seen by paediatricians. Normal controls were recruited in regular primary schools in the Netherlands. For the clinical groups, 155 children were screened out; 60 children did not meet criteria for the study; 8 children did not meet the pre-screening criteria, 3 children did not meet RD criteria, 34 children did not meet criteria for ADHD-Combined subtype (ADHD-C), 7 children had severely impaired pragmatic skills, 2 children showed arithmetic deficits, 2 children showed conduct disorder, 1 child had severe symptoms of depression and 1 child had a very low IQ and 2 children did not give consent to participate in the study. A total of 24 children with ADHD, 41 children with RD, and 29 children with ADHD+RD were enrolled in the study.

Table 3.1. Means, standard deviations, and pairwise group comparisons for age, IQ and selection measures for the ADHD, ADHD+RD, RD and normal control groups

		ADHD+RD n=29 (♂=23)		RD n=41 (♂=23)		NC n=26 (♂=16)		Pairwise Comparisons *p*<.05
Measure	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Age in Years	(1.31)	9.83	(1.33)	10.10	(1.04)	9.31	(0.92)	NC,A<R
IQ	(15.02)	95.34	(8.64)	104.85	(9.18)	107.32	(9.40)	A+R<R,NC
Picture Arrangement	(3.30)	10.21	(1.95)	11.61	(2.51)	10.38	(1.96)	ns
Arithmetic	(3.62)	8.89	(2.58)	10.28	(2.99)	12.38	(2.81)	A+R,R,A<NC
Block Patterns	(2.76)	8.82	(2.73)	11.56	(2.46)	11.00	(2.46)	A+R<R,NC
Vocabulary	(2.87)	8.86	(2.62)	9.95	(2.65)	12.08	(2.22)	A+R,R<A,NC
DBD Parents								
Inattention	(4.50)	17.59	(3.63)	7.22	(4.60)	1.88	(2.12)	A+R,A>R>NC
H/I	(4.60)	18.31	(3.49)	4.22	(3.73)	2.58	(2.08)	A+R,A>R,NC
ODD	(4.67)	8.55	(4.05)	2.83	(2.55)	1.85	(2.24)	A+R,A>R,NC
CD	(2.68)	1.70	(1.79)	0.67	(0.06)	0.10	(0.30)	A>NC,A+R>R,NC
DBD Teacher								
Inattention	(4.91)	17.14	(3.68)	5.43	(4.67)	1.54	(1.90)	A+R,A>R>NC
H/I	(4.99)	17.17	(4.70)	2.80	(3.54)	1.31	(2.31)	A+R,A>R,NC
ODD	(5.11)	7.00	(4.56)	1.42	(2.43)	0.92	(1.69)	A+R,A>R,NC
CD	(2.69)	2.08	(1.88)	0.26	(0.59)	0.04	(0.20)	A+R,A>R,NC
CCC Pragmatic Score								
Parents	(10.40)	138.72	(10.03)	151.61	(7.35)	154.92	(6.20)	A+R,A<R,NC
Teacher	(10.22)	138.11	(12.20)	150.77	(7.04)	152.96	(8.45)	A+R,A<R,NC
PDISC-IV								
OCD	(2.01)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)	A>A+R,R,NC
Tic Disorder	(2.87)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)	A>A+R,R,NC
MD	(3.00)	0.14	(0.51)	0.00	(0.00)	0.00	(0.00)	A>A+R,R,NC
Inattention	(2.16)	16.00	(2.44)	5.02	(3.29)	1.00	(2.20)	A,A+R>R>NC
H/I	(1.92)	15.72	(2.25)	2.24	(2.93)	1.00	(1.98)	A,A+R>R,NC
ODD	(4.96)	4.83	(4.52)	0.49	(1.71)	0.38	(0.98)	A,A+R>R,NC
CDRS								
Raw Score	(4.28)	20.76	(2.29)	20.34	(5.14)	18.24	(1.71)	A>A+R,R,NC
Reading								
OMT[a]	(10.36)	23.14	(8.95)	25.90	(9.09)	-8.12	(15.09)	R,A+R>A,NC
TRT[a]	(6.50)	22.97	(9.54)	25.51	(9.86)	-1.12	(5.92)	R,A+R>A,NC
PRT[a]	(13.93)	23.97	(11.41)	26.54	(12.00)	-8.62	(18.33)	R,A+R>A,NC
Arithmetic								
SAT[a]	(14.13)	11.41	(13.62)	10.02	(8.34)	-4.92	(11.95)	A+R,R>NC
CSA	(32.22)	33.38	(20.46)	55.85	(31.56)	52.88	(23.54)	A+R<R

Note. A=Attention Deficit Hyperactivity Disorder, ADHD= Attention Deficit Hyperactivity Disorder, CCC=Communication Checklist for Children, CD= Conduct Disorder, CDRS=Child Depression Rating Scale, CSA=Cognitive Subtests for Arithmetic, DBD=Disruptive Behaviour Disorders rating scale, H/I=Hyperactivity/Impulsivity, IQ=Intelligence Quotient, MD=Major Depression, NC=Normal Controls, OCD= Obsessive Compulsive Disorder, ODD=Oppositional Defiant Disorder, OMT=One Minute Test, PDISC=Parent Diagnostic Interview Scale for Children, PRT=Pseudoword Reading Test, R= Reading Disorder, RD=Reading Disorder, SAT=Speeded Arithmetic Test, TRT=Text Reading Test.

[a] Mean Delay in Schoolmonths (a negative value indicates advance).

Thirty children were screened for the normal control group. Four children met criteria for ADHD, thus 26 children were enrolled in the normal control group. The final sample consisted of 120 children aged 8 to 12 years. In total, 38 girls and 82 boys participated in the study. All children were of Caucasian origin, except two children in the ADHD only group; one child was of Asian origin and the other child was half-African. Subject characteristics for the ADHD, ADHD+RD, RD and normal control groups are presented in Table 3.1.

Measures to obtain a diagnosis of ADHD and RD

All participating children were screened for the presence of ADHD-C with the Disruptive Behaviour Rating Scale (DBD; Pelham, Gnagy, Greenslade & Milich, 1992; Dutch translation: Oosterlaan, Scheres, Antrop, Roeyers & Sergeant, 2000). The DBD is a reliable and valid instrument to screen for ADHD, ODD and CD (Oosterlaan et al., 2000). To meet the criterion of pervasiveness of ADHD, the DBD was completed by both the parent and the teacher. The parent version of the Diagnostic Interview for Children (PDISC-IV; National Institute of Mental Health (NIMH), Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000; Dutch translation; Ferdinand, Van der Ende, & Mesman, 1998) was administered. Adequate reliability and validity have been reported for earlier versions of the PDISC-IV (Schwab-Stone et al., 1996). The diagnosis of ADHD as assessed by the PDISC-IV was based on the DSM-IV and the ICD -10.

A diagnosis of ADHD-C was made if (a) scores on the DBD fell at least in the subclinical range (≥ 90th percentile) on both the Inattention and Hyperactivity/Impulsivity scales rated by both the parents and the teacher and (b) when the criteria for ADHD on the PDISC-IV were met.

All children were screened for RD using two Dutch technical word reading tests: the One Minute Test (OMT; Brus & Voeten, 1973), the Pseudoword Reading Test (PRT; Van den Bos, lutje Spelberg, Scheepsma & De Vries, 1999) and a text reading test; the Text Reading Test (TRT; Visser, Laarhoven & Ter Beek, 1998). All have adequate validity (Van der Sluis et al., 2005). A diagnosis of RD was made, if children had at least 15 months delay on at least two of the three reading tasks, as indicated by DSM-IV criteria for RD.

Exclusion criteria for all groups

In order to study more homogeneous groups, children with former or current neurological disorders, such as epilepsy diagnosed by a clinician, were excluded. Likewise, patients were excluded with a former or current diagnosis by a clinician of depression, PDD, anxiety disorder, post-traumatic stress disorder, tic disorder (including Tourette syndrome), obsessive-compulsive disorder or conduct disorder. The PDISC was included to assess current undiagnosed psychiatric comorbidities in the child. The PDISC screened for major depression disorder, obsessive-compulsive disorder, tic disorder, ADHD, oppositional defiant disorder and conduct disorder. Children were excluded if they had a raw score of 40 or greater on the Children Depression Rating Scale (CDRS; Poznanski & Mokros, 1996).

Severe pragmatic deficits were assessed by the Communication Checklist for Children (CCC; Bishop, 1998; Dutch translation: Hartman et al., 1998). If children obtained a pragmatic score of 132 points or lower on either the parent or the teacher version of the CCC, they were excluded (Geurts et al., 2004).

Children with severe arithmetic deficits were excluded. Severe arithmetic deficits were defined as a delay greater than 20 school months on the Speeded Arithmetic Test (SAT; De Vos, 1992) and a score below the 3rd percentile on the Cognitive Subscales for Arithmetic (CSA; De Clerq, Desoete & Roeyers, 2002).

Children with an estimated IQ below 80 were excluded, as assessed by four subtests of the Wechsler Intelligence Scale for Children, Third edition (WISC-III): Picture Arrangement, Arithmetic, Block Design and Vocabulary (Wechsler, 1992; Dutch translation: Kort et al. 2002). These four subtests correlate between r = .93 to r = .95 with Full Scale IQ (Groth-Marnat, 1997).

Medication

Children were off stimulant medication at least 48 hours before testing. In the ADHD only group, 13 children and 9 children in the ADHD+RD group were on stimulant medication. Children were not on other types of medication.

Neuropsychological measures

Inhibition. The Stop task was administered to measure response inhibition (Lijffijt, Kenemans, Verbaten & Van Engeland, 2005; Oosterlaan, Logan & Sergeant, 1998). The task consisted of two types of trials: go trials and stop trials. At the start of both trials, a fixation point was shown for 500 ms. Subsequently, the go stimulus (a cartoon plane) was presented for 1000 ms at the centre of a computer screen. Subjects were required to indicate the position of the plane by pressing one of two response buttons that corresponded to the direction in which the plane pointed (right or left). Maximum reaction time was 1500 ms. Stop trials were identical to go trials, but in addition a cross was superimposed on the plane, which remained on the screen for a maximum time of 1000 ms minus delay time. Children were instructed not to press either button, when they saw the cross. Inter-trial interval was 1000 ms. The delay between the onset of the go signal and stop signal was varied using a tracking algorithm. The initial delay between the go- and stop-signal was 175 ms (Osman, Kornblum & Meyer, 1990). If the child succeeded in inhibiting the response, the delay between the onset of a go trial and the next stop signal was increased by 50 ms. If the child failed to inhibit his response, the delay between the onset of a go trial and stop signal was decreased by 50 ms. Six blocks, each of 64 trials were administered. In the first block, only go-trials were presented to practice fast and accurate responding to go-stimuli. In the following five blocks, both go- and stop-trials (16 per block = 25% of the trials) were presented in pseudo-randomised order. The first block was used for practice only.

Using a tracking procedure, it was established that there was a 50% chance of response inhibition on stop trials. At this point, the go- and the stop-process were of equal duration (Logan & Cowan, 1984). In this way, the finishing time of the go-process becomes an estimate of the finishing time of the stop-process: the stop signal reaction time (SSRT) can be determined by subtracting the mean delay time from the mean go-signal reaction time (MRT). Three additional variables reflecting the response execution process were obtained: MRT measured the speed of response execution; number of omission errors (indicated lapses of attention during response execution) and the number of commission errors (reflected potential impulsivity in response execution) (Halperin, Matier, Bedi, Sharma & Newcorn, 1992).

Visuospatial working memory. The Corsi Block Tapping test was administered to examine visuospatial WM (Corsi, 1972; Schellig, 1997). Nine blocks were displayed on a computer touch screen. A small cursor on the screen tapped a span of blocks, starting with a two block span. After a tone, the child had to re-tap the demonstrated span by touching the screen. Depending on performance of the child, the span could be increased to nine blocks. For each span, two trials were presented, except if one of the trials was incorrectly tapped, then a third trial for that span followed. The task was discontinued, when two trials of a span were incorrectly tapped. The dependent variable was the maximum span number that the child was able to re-tap: WM maximum span.

Lexical processing. A lexical decision task was used to measure lexical access skills, which has been shown to be a reliable and valid measure of lexical processing (e.g. Meyer & Schvaneveldt, 1971; Milne, Nicholson & Corballis, 2003). The dual route model of reading aloud is used to explain the theoretical underpinnings of the lexical decision task (Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Briefly, this model contains two routes: the lexical and the sublexical route. The sublexical route uses rules of grapheme-to-phoneme conversion, thus words will be read letter by letter. The other, parallel route, the lexical route uses matching to whole word representations in the mental orthographical lexicon, the assumed mental dictionary. Since both the sublexical and the lexical routes are needed for reading, the lexical decision task is a potentially more ecologically valid measure of reading disorder than only phonological measures which tap only the sublexical procedure.

In the lexical decision task, participants had to decide if words, presented one by one on a computer screen, were valid words or pseudowords. The words were preceded by a warning cross (1200 ms) that appeared at the centre of the computer screen. The child was guarded from impulsive responding, since responding could only commence 300 ms after onset of presentation of the word. The word stayed on the screen until the response was given within 2000 ms. The inter-trial interval was 3500 ms. Pseudowords were derived from Valid words by changing some of the letters with the restriction that the pseudowords were still pronounceable and were consistent with Dutch orthography. All words were monosyllabic.

Since the valid words and pseudowords were not very different, children had to read the words letter by letter (since the words did not obviously differ in orthography) thus they had to use knowledge of letter-sound (grapheme-phoneme relations), the sublexical route of reading. In addition, lexical decision is aided by matching the presented word with the stored word in the orthographical lexicon. Efficient access to the orthographical lexicon is facilitated by the word superiority effect, which refers to the notion that known words are read as "higher" cognitive units than individual letters or strings (Healy, 1976). Thus, the use of the orthographical lexicon refers to the lexical route.

There was one practice block of 25 words, which could be extended once by 25 words, if 40% or more were incorrect. If the child failed the next practice block, the test was started, since we assumed that the task procedure was clear. The practice block was followed by 5 blocks each of 25 valid words and 25 pseudowords presented pseudo-randomly.

The dependent variable was d', measuring the accuracy of lexical decision by which subjects correctly identified valid words and pseudowords, independent of response bias. The d' was computed as: probit (hit rate correct valid words) – probit (false positive rate incorrect pseudowords) (MacMillan & Creelman, 1991). In this formula, hit rate refers to the number of correctly identified valid words divided by the total valid words; false positive rate refers to the number of incorrectly identified pseudowords divided by the total number of pseudowords. The hit rate and the false positive rate for each child were normalised by a probit function because responses were binomial. Mean reaction time (MRT) of the responses of the correctly identified valid words was recorded which indicated the speed of lexical decision making. Since pseudowords are not stored in the orthographical lexicon, pseudowords have to be decoded. Processing speed of decoding was assessed by MRT on pseudowords.

Procedure

Data were obtained during three visits. During visit 1, informed consent was obtained and potential eligibility determined, following this visit the DBD and CCC were completed by parents and teachers. On visit 2, all other diagnostic and screening measures were obtained. During visit 3, the Stop task, Lexical Decision task and Corsi Block Tapping test were administered using standardised instructions. The study was approved by a medical ethical committee.

Data Analysis

For the visuospatial WM task (Corsi Block Tapping test), 2.5% of the data were missing. These missing data were replaced by regression analysis following Tabachnick and Fidell (2007). Data were missing for three children, who had just started reading, on the Lexical Decision task. All variables were normalised using a Van der Waerden transformation based on rankings (Lehmann, 1975).

In order to investigate the effects of ADHD, RD and the interactions between both, the dependent variables in the study were analysed and covaried for age using a between group factorial ANCOVA. The study had a 2x2 design with ADHD as one factor with two levels (present or absent) and a second factor RD with two levels (present or absent). An alpha level of 0.05 was employed. Post-hoc testing was performed with Bonferroni t-tests which were corrected for multiple comparisons.

RESULTS

Inhibition

The age adjusted means are displayed in Table 3.2 for each of the four groups. The results of the ANCOVA with age as covariate are presented in Table 3.3.

Table 3.2. Neuropsychological performance adjusted for age for the ADHD, ADHD+RD, RD and normal control groups.

	ADHD *n*=24		ADHD+RD *n*=29		RD *n*=41		NC *n*=26	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Stop Signal Paradigm								
SSRT	268.57	13.74	297.61	12.15	275.05	10.46	238.38	12.91
MRT	520.04	17.32	558.64	15.32	590.64	13.19	490.90	16.28
Omission Errors	2.22	.91	5.01	.81	3.23	.69	.31	.86
Commission Errors	6.74	1.20	6.98	1.06	4.14	.91	3.33	1.13
Corsi Block Tapping Test								
WM Maximum Span	4.46	.18	5.06	.16	5.00	.14	5.41	.17
Lexical Processing[a]								
d’	2.68	.17	1.99	.15	2.38	.13	3.16	.16
MRT Valid Words	1092.25	70.70	1333.65	61.36	1304.02	51.67	868.78	64.19
MRT Pseudowords	1249.25	84.25	1575.60	73.12	1572.39	61.58	951.62	76.50

Note. ADHD=Attention Deficit Hyperactivity Disorder; MRT=Mean Reaction Time; NC=Normal Controls; RD=Reading Disorder; SSRT=Stop Signal Reaction Time, WM=Working Memory.

[a] Two children in the ADHD only and one in the ADHD+RD group were missing because they had just started reading instruction and therefore the Lexical Decision task was too difficult.

No speed accuracy trade-off was present in any of the four groups, as indicated by the absence of a negative correlation between MRT and number of commission errors in the Stop task. As expected, children with ADHD (ADHD present) had slower SSRTs compared to children without ADHD (ADHD absent), but this was not significant at the .05 level, *F*(1, 115)=3.87, *p*=.052. This suggests that inhibition deficits were marginally present in children with ADHD. Inhibition deficits were clearly found in RD, see Table 3.3. Slower primary task processing as measured by MRT was observed in RD but not in ADHD. Both ADHD and RD were associated with lapses of attention during response execution as indicated by more omission errors. Children with ADHD were more impulsive in response execution than children without ADHD, since they committed more commission errors. No significant interaction occurred between ADHD and RD for any of the dependent measures of the Stop task.

This analysis indicates a clear inhibition deficit in RD with slower processing and impulsivity (commission errors) and marginal inhibition deficits in ADHD. Both ADHD and RD were associated with lapses of attention (omission errors).

Visuospatial WM

Working memory demands had no effect on RD (see Figure 3.1 and Table 3.3). Children with ADHD, as hypothesised, exhibited poorer visuospatial WM than children without ADHD as assessed by WM Maximum Span. A significant ADHD by RD interaction indicated that children with ADHD without RD had significantly poorer visuospatial WM compared to children with both ADHD and RD. The interaction was confirmed by post-hoc tests, ADHD only group versus ADHD+RD group, *t*(51)=2.36, *p*<.05 and RD only versus normal controls, *t*(65)=1.85, ns.

Table 3.3. Effects of ADHD and RD on neuropsychological performance covaried for age

	ADHD		RD		Interaction	
Measure	*F*(1, 115)	η_p^2	*F*(1, 115)	η_p^2	*F*(1, 115)	η_p^2
Stop Signal Paradigm						
SSRT	3.87[a]	.03	6.44**	.05	0.18	.002
MRT	0.06	.001	17.52**	.13	3.20	.02
Omission Errors	9.54**	.07	16.71**	.12	0.81	.007
Commission Errors	8.62**	.07	0.86	.007	0.24	.002
Corsi Block Tapping Test						
WM Maximum Span	7.07**	.05	0.23	.002	8.99**	.07
Lexical Processing[b]						
d’	8.74**	.07	19.85**	.15	0.12	.001
MRT Valid Words	4.68*	.04	29.70**	.21	2.37	.02
MRT Pseudowords	4.07*	.03	44.19**	.28	4.35*	.03

Note. ADHD=Attention Deficit Hyperactivity Disorder; MRT=Mean Reaction Time; SSRT=Stop Signal Reaction Time; RD=Reading Disorder, WM=Working Memory.

[a] *p*=.052. [b] Three children were missing.

* significant at *p*<.05. ** significant at *p*<.01.

These results demonstrate that children with ADHD had a clear deficit in visuospatial WM in contrast to children without ADHD. Adding ADHD to RD did not lead to a greater deficit in visuospatial WM than in only RD. Therefore, the ADHD main effect was carried by the ADHD only group which had the most pronounced deficits in visuospatial WM.

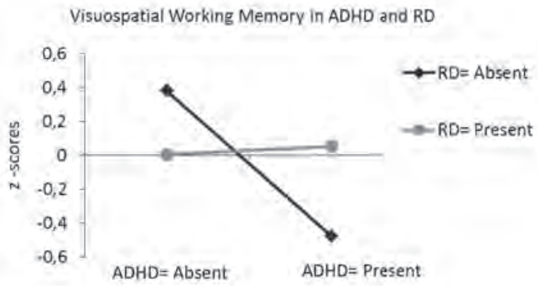

Figure 3.1. Visuospatial WM as assessed with Maximum Span in the ADHD, ADHD+RD, RD and normal control groups as indicated by the presence or absence of ADHD and RD. Means were adjusted for age and expressed in z-scores (higher scores indicating better performance). Note: post-hoc testing indicated that the ADHD only group (ADHD present, RD absent) had a significant poorer performance on visuospatial WM than the ADHD+RD group (both ADHD and RD present).

Lexical processing

As expected, RD was associated in the lexical decision task with lower d´ and slower MRTs for Valid Words, indicating respectively poorer accuracy in lexical decision and slower decision speed, see Table 3.3. Children with ADHD were less accurate and slower in lexical decision than children without ADHD. There was no significant ADHD by RD interaction for d' or MRT Valid Words. ADHD and RD were both associated with slower MRT to pseudowords, indicating a slower decoding process in both RD and ADHD. A significant ADHD by RD interaction indicated that the ADHD main effect was carried by the ADHD only group, since the ADHD only group was slower on MRT pseudowords than normal controls but faster than the two RD groups, see Figure 3.2. The interaction was confirmed by post-hoc tests. Children with ADHD only were slower than normal controls, $t(46)=2.69$, $p<.05$ but faster than children with ADHD+RD, $t(48)=3.28$, $p<.05$ and children with RD, $t(65)=3.58$, $p<.05$. Children with RD only were slower on pseudowords than normal controls, $t(65)=6.89$, $p<.05$. All effects of the lexical decision task were stronger in RD than in ADHD since the RD effect sizes fell in the large range whereas the ADHD effect size fell in the small or medium effect size range.

These results indicate that both RD and ADHD are associated with less accuracy and slower processing in lexical decision making. Both RD and ADHD were associated with decoding processing deficits; RD was associated with slowest decoding processing regardless of comorbid ADHD. However, the ADHD only group showed slower decoding but not to a level of impaired performance as in the RD groups.

Controlling for age and IQ

We examined whether our findings for the EF tasks and the Lexical Decision task were independent of both age and IQ, see Table 3.4. Inspection of Table 3.4 indicates that all main effects for ADHD were lost after covarying for both age and IQ, with the exception of omission and commission errors. In contrast, the main effects for RD remained significant after covarying for both age and IQ. A significant ADHD by RD interaction emerged for MRT on the Stop task, indicating that the RD group was slower than the normal control group. This finding was confirmed by post-hoc tests, RD-normal controls, $t(64)=4.36$, $p<.05$. The other group comparisons were not significant, t-values between 1.02 and 1.91. The two previously observed interactions on visuospatial WM (Corsi Block Tapping test) and decoding processing (MRT on pseudowords) remained significant, after covarying for both age and IQ.

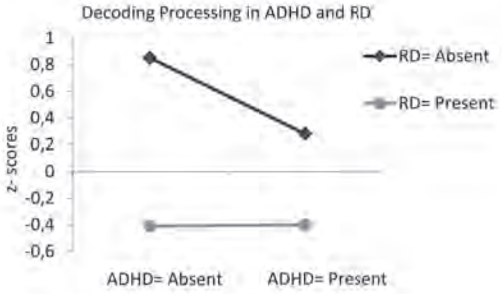

Figure 3.2. Decoding processing as assessed by MRT on pseudowords in the ADHD, ADHD+RD, RD and normal control groups. Means were adjusted for age and expressed in z-scores (higher scores indicate faster processing).

Table 3.4. Effects of ADHD and RD and their interaction on neuropsychological performance covaried for IQ and age

	ADHD		RD		Interaction	
Measure	*F*(1, 113)	η_p^2	*F*(1, 113)	η_p^2	*F*(1, 113)	η_p^2
Stop Signal Paradigm						
SSRT	2.03	.01	4.50*	.03	0.30	.003
MRT	0.21	.002	12.42**	.09	3.90*	.03
Omission Errors	4.49*	.03	11.22**	.09	1.16	.01
Commission Errors	7.55**	.06	0.75	.007	0.33	.003
Corsi Block Tapping Test						
WM Maximum Span	1.59	.01	2.65	.02	10.76**	.08
Lexical Processing[a]						
d’	2.88	.02	11.57**	.09	0.54	.005
MRT Valid Words	1.50	.01	20.72**	.15	2.93	.02
MRT Pseudowords	1.32	.01	33.15**	.23	5.05*	.04

Note. ADHD=Attention Deficit Hyperactivity Disorder; MRT=Mean Reaction Time; SSRT=Stop Signal Reaction Time; RD=Reading Disorder, WM=Working Memory.

[a] Data of three children were missing.

* significant at $p<.05$. ** significant at $p<.01$.

DISCUSSION

Results of this double dissociation study revealed that RD was associated with inhibitory deficits and slower processing. Unexpectedly, inhibition deficits were marginally demonstrated in children with ADHD. Impairments in lexical processing were present in both ADHD and RD. RD, regardless of ADHD, was invariably associated with slower decoding processing. The ADHD only group had slower decoding processing speed compared to the normal control group but better than the RD groups. The ADHD only group was characterised by visuospatial working memory deficits. Findings for the ADHD factor were related to IQ, whereas findings for the RD factor were independent of IQ. These results indicate that there was no double dissociation observed in this study using a primary measure of inhibition, visuospatial WM and lexical processing.

The first neuropsychological process in which we sought a double dissociation was inhibition. We observed here clear inhibition deficits in RD and modest inhibition difficulties in ADHD confirming previous reports (Närhi & Ahonen, 1995; Purvis & Tannock, 2000; Van der Schoot et al., 2000; Willcutt et al., 2005). One possible explanation for the inhibitory deficits in RD may be that they are secondary to processing speed deficits in RD. Purvis and Tannock (2000) found that RD was not associated with inhibition deficits, when processing speed was marginally demanded, e.g. when a single response was required (as in the Conners Continuous Performance test). However, when two choice responses were required, children with RD exhibited inhibition deficits (as in the Stop task). The findings here indicate that inhibition deficits in children with RD are *not* due to processing speed deficits; no significant correlation was found between inhibition (SSRT) and latency of response execution (MRT) in the Stop task. Thus, inhibition deficits in RD are, at least partly, genuine inhibition deficits.

The second primary EF task used for a possible double dissociation was visuospatial WM. Visuospatial WM impairments were most pronounced in children with ADHD only, and concurs with earlier findings (Martinussen, Hayden, Hogg-Johnson, Tannock, 2005; Marzocchi et al., 2008). Both the ADHD+RD and the RD groups did not differ from each other in visuospatial WM. The most impaired group on visuospatial WM was the ADHD only group. Visuospatial abilities have been suggested as compensatory skills for the reading deficits in patients with RD (West, 1997). The evidence here indicates that visuospatial WM deficits are specifically related to ADHD only and not to RD. This finding suggests that the differentiation of ADHD from RD should be further sought in the area of visuospatial WM.

A clear RD effect was shown on all dependent measures of the lexical decision task, the third measure of interest. Results support the validity of the lexical decision task in children with RD. However, children with ADHD were impaired in lexical processing although to a lesser degree than children with RD. The findings in ADHD are in accordance with findings of Willcutt et al. (2005) who demonstrated that children with ADHD were slightly impaired in orthographical processing compared to normal controls. The orthographical processing deficits may have been caused by an impaired lexical route that taps orthographic codes.

RD was ubiquitously associated with slower processing in tasks used in the study. Our results contrast with those of Shanahan et al. (2006), who found that processing speed deficits were common in both ADHD and RD. However, our results are consistent with Wolf and Bowers (1999), who found that deficits in processing speed were related to reading difficulties.

A robust finding here was that children with ADHD, regardless of comorbid RD, had lower IQs compared to children with RD only and normal controls. After covarying for IQ, the majority of main effects for ADHD were lost, suggesting that IQ is essentially related to EF and lexical processing in children with ADHD. This finding is consistent with the meta-analysis of Frazier, Demaree and Youngstrom (2004), who showed that IQ effect sizes were larger than for EF when comparing ADHD to controls. Interestingly, RD effects are not modified by IQ. This suggests that there is a functional communality in ADHD for both EF and IQ in contrast to RD. Further work is needed to determine how to use this functional communality to differentiate ADHD from RD.

The failure to find a double dissociation on inhibition, visuospatial WM and lexical processing should be considered with some issues in mind. Firstly, the sample size was small. However, it should be noted that there were main effects reported here with large effect sizes even with a small sample size. Secondly, it could be argued that the ADHD group was poorly diagnosed. This seems unlikely, since we applied a rigorous inclusion and exclusion procedure both in terms of associated psychiatric and neuropsychological disorders. Thirdly, the overlap in lexical processing and the inhibition deficits of RD may have been due to sub-threshold findings of ADHD in RD and vice versa. Children with RD only had significant elevated ratings of inattention compared to normal controls. Hierarchical regression analyses (see Appendix C for results) revealed that following age and IQ, both inattention and technical reading contributed to inhibition deficits. These findings suggest that inattention and inhibition in the RD groups studied here may have a common functionality. Inattention and technical reading did not contribute to visuospatial WM, after IQ and age. Hence, results on visuospatial WM were independent of technical reading and inattention. Overlap in lexical processing was not due to ADHD symptoms but due to technical reading, which suggest that the overlap in lexical processing might be due to sub-threshold findings of RD in ADHD.

A fourth issue concerns the limited number of cognitive domains that were studied: inhibition, visuospatial WM and lexical processing. The specificity of the visuospatial WM findings would have been enhanced, if a verbal WM task had been administered. Work by others suggests that verbal WM deficits are not specific for either ADHD or RD (Willcutt et al., 2001; 2005) but that visuospatial WM deficits might be specific to ADHD (Martinussen et al., 2005). Our results suggest that visuospatial WM should be further explored for specific effects and that RD may be better differentiated from ADHD via early lexical decision encoding processes.

A fifth issue concerns the relationship between pragmatics and arithmetic performance. Both were related to the dependent variables (results available on request to the first author). Hence, could the overlap in lexical processing in ADHD and RD and to a lesser extent in inhibition deficits be due to confounding effects of arithmetic and pragmatics? Pragmatic deficits were only seen in children with ADHD regardless of comorbid RD, hence pragmatic effects could not account for the inhibition deficit in RD. Arithmetic deficits were seen only in children with RD which may have led to inhibition deficits in RD. In addition, the overlap in lexical processing cannot be explained by overlap in arithmetic or pragmatic deficits in ADHD and RD. Notwithstanding, it would be useful in future work to select groups varying along the two processes of arithmetic and pragmatic skills to determine the their role in key EF measures (Jonsdottir, Bouma, Sergeant, & Scherder; 2006).

In this study, we found no double dissociation on lexical processing and inhibition between ADHD and RD: the ADHD only group was characterised by visuospatial WM deficits, and children with RD regardless ADHD were slowest on decoding processing compared to ADHD only and normal controls. Visuospatial WM and decoding processing seem more useful candidates to demonstrate a double dissociation.