THE INFLUENCE OF WORKING MEMORY LOAD ON RESPONSE INHIBITION IN CHILDREN WITH ADHD OR READING DISORDER

Séverine Van De Voorde[1]

Herbert Roeyers[1]

Sylvie Verté[1]

Jan Roelf Wiersema[1]

Running head and shortened title: Working memory and inhibition in ADHD or RD

Corresponding author

Herbert Roeyers PhD

Ghent University, Department of Experimental Clinical and Health Psychology

Henri Dunantlaan 2

B-9000 Ghent

Belgium

Tel: +32-9-2646462

Fax: +32-9-2646489

E-mail: Herbert.Roeyers@Ugent.be

---

[1] Department of Experimental Clinical and Health Psychology, Ghent University, Ghent, Belgium

Abstract

The aim of the present study was to examine the relationship between response inhibition and working memory in 8 to 12-year-old children with ADHD (n=19), reading disorder (RD; n=17), ADHD+RD (n=21), and control children (n=19). For the first time a within-task methodology was used to study the combined effect of both executive functions on a common measure of task performance in two often comorbid childhood disorders, ADHD and RD. We found evidence of an interaction between both domains, suggesting that they rely on a common pool of resources. In addition, we found that children with ADHD or RD were not more seriously affected by the combined load of both executive functions than children without ADHD or RD.

Executive Functions (EFs) can be defined as a collection of higher-order cognitive control processes that are necessary to guide goal-directed behaviour (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006). These functions are mediated by the prefrontal cortex and other cortical (e.g., anterior cingulate cortex; ACC) and subcortical (e.g., cerebellum, thalamus, basal ganglia) neural systems that are closely linked to the frontal lobe (Casey, 2005; Middleton & Strick, 2001, 2002; Nyberg, Brocki, Tillman, & Bohlin, 2009; Pennington & Ozonoff, 1996).

ADHD, one of the most prevalent developmental disorders found in child populations all over the world (Faraone, Sergeant, Gillberg, & Biederman, 2003), is characterized by symptoms of inattention and/or hyperactivity/impulsivity. As these behavioural symptoms are also observed in frontal lesion patients, it has been suggested that children with ADHD also suffer from frontal or executive weaknesses (e.g., Mattes, 1980; Pontius, 1973). It is therefore not surprising that one of the most dominant theoretical models of ADHD that has guided research over the past decade defines it as an EF deficit disorder (Barkley, 1997). Recent evidence for EF related problems stems from EEG and MRI studies that suggest that frontal-striatal substrates are implicated in the pathophysiology of ADHD (e.g., Willis & Weiler, 2005). When looking at the behavioural evidence, most studies find EF problems (see meta-analytic reviews by Pennington and Ozonoff, 1996, and by Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005) but results are very inconsistent across studies (Weyandt, 2005b). As impairments are found on some but not all EF tasks, some researchers argue that ADHD is associated with specific rather than with general EF impairments (e.g., Barkley, 1997; Pennington & Ozonoff, 1996; Sergeant, Geurts, & Oosterlaan, 2002; Shallice et al., 2002; Weyandt, 2005a; Wu, Anderson, & Castiello, 2002). Therefore, more knowledge into the subcomponents of the broad EF construct is needed (Nyberg et al., 2009).

Working memory (WM) and response inhibition, two core EF domains (Best & Miller, 2010; Miyake et al., 2000), have frequently been investigated separately as possible primary deficits in the pathophysiology of ADHD (Castellanos & Tannock, 2002; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Willcutt et al., 2005). Response inhibition refers to the ability to inhibit inappropriate action; WM is defined as the ability to temporarily maintain and manipulate information needed for generating upcoming action. According to Baddeley's multi-component model (1992), WM can be subdivided on the basis of two criteria: the modality of the stimulus (verbal-auditive versus visual-spatial) and the processing requirements (storage-only versus storage plus manipulation). Whereas inhibitory control deficits are often reported in ADHD (e.g., Castellanos et al., 2006; Willcutt et al., 2005; but see Alderson, Rapport, & Kofler, 2007 and Lijffijt, Kenemans, Verbaten, & van Engeland, 2005), empirical evidence for WM deficits is less unequivocal. Some studies find only visual-spatial WM deficits (see reviews by Martinussen et al., 2005, and by Willcutt et al., 2005), whereas others find both visual and verbal WM deficits (e.g., Brocki, Randall, Bohlin, & Kerns, 2008; Martinussen & Tannock, 2006). One possible explanation for this variability in findings is the existence of comorbidity. EF problems have also been found in other developmental disorders such as autism and Tourette's syndrome (Pennington & Ozonoff, 1996; Sergeant et al., 2002; Weyandt, 2005b). It is therefore possible that EF deficits reported in ADHD studies are actually due to a comorbid disorder that was not controlled for (Pennington & Ozonoff, 1996). One important comorbidity is that of ADHD with learning disorders, and more specifically reading disorder (RD). ADHD and RD co-occur much more often than can be expected by chance, with rates of overlap estimated between 15% and 40% (e.g., Del'Homme, Kim, Loo, Yang, & Smalley, 2007; Willcutt & Pennington, 2000). They also share some behavioural symptoms, like inattentive behaviour and poor academic performance (Hinshaw, 1992). These findings make differential diagnosis

difficult and urge research into cognitive and neurobiological variables that might better distinguish between both disorders (Rashid, Morris, & Morris, 2001). Although RD is primarily associated with linguistic problems, like impairments in phonological processing and slower serial naming speed (Pennington, Groisser, & Welsh, 1993; Purvis & Tannock, 2000; Rucklidge & Tannock, 2002; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000; Willcutt et al., 2001), EF deficits, like inhibition and WM problems have also been reported (e.g., Purvis & Tannock, 2000; Swanson, Mink, Bocian, 1999; van der Schoot, Licht, Horsley, & Sergeant, 2000; Van De Voorde, Roeyers, Verté, & Wiersema, 2010). In terms of Baddeley's WM model, results have been in favour of no problems, only verbal, or both verbal and visual-spatial WM problems (e.g., Kibby, Marks, Morgan, & Long, 2004; Savage, Lavers, & Pillay, 2007; Swanson, Ashbaker, & Lee, 1996).

Research on ADHD that has not taken into account the effect of RD, may have mistakenly attributed the deficit to ADHD (Lazar & Frank, 1998; Nigg, Hinshaw, Carte, & Treuting, 1998; Wu et al., 2002). Therefore, it will be important to control for this comorbidity when trying to find out which deficits are a unique feature of ADHD (Banaschewski et al., 2005; Lazar & Frank, 1998; Sergeant et al., 2002). It will also be important to try to identify EFs that can distinguish between these disorders (Beveridge, Jarrold, & Pettit, 2002). One of the major problems with EF is that it is a very complex and multi-faceted construct (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), which has given rise to different measurement problems (Weyandt, 2005b). Some classical frequently used EF tasks (like the Wisconsin Card Sorting Test) tap multiple EF components, which makes it difficult to find out which of those processes is impaired when performance on these tasks is low. Moreover, they lack both sensitivity and specificity when used to investigate EF deficits in clinical populations (Pennington & Ozonoff, 1996). Therefore, we need tasks that are better able to isolate specific EF components (Pennington & Ozonoff, 1996; Shallice et

al., 2002; Willcutt et al., 2005; Wu et al., 2002). This can be accomplished by designing experimental paradigms with a within-task manipulation of the EF in question (low vs. high EF load), so that an appropriate control condition is included (Pennington & Ozonoff, 1996; Willcutt et al., 2005). A significant group by condition interaction provides a better test for a specific executive deficit (Pennington & Ozonoff, 1996). In a study previously reported by our research group (Van De Voorde et al., 2010), children with ADHD and children with RD were compared to children without ADHD and children without RD, respectively, on separate measures of WM (n-back task) and inhibition (Go/no-go task) using this within-task methodology. With respect to ADHD, we found no deficit in inhibition or WM, as evidenced by the absence of an interaction between ADHD on the one hand and the within-subjects factors inhibition and memory load on the other. With respect to RD, we observed a deficit in WM but not in response inhibition. As the ADHD literature is full of reports that do find inhibition problems (e.g., Castellanos et al., 2006; Willcutt et al., 2005), whereas we did not when a baseline measure of functioning was taken into account, the question arose whether an inhibition deficit would surface when WM load was increased. This would be in line with several studies into the WM-inhibition interrelationship that found WM to be superordinate in relation to other EFs like response inhibition (e.g., Brocki et al., 2008; Nyberg et al., 2009). However, this would not be predicted based on Barkley's EF model of ADHD (Barkley, 1997) in which inhibition problems are thought to underlie other EF problems like WM problems. Several other theoretical models (e.g., Engle & Kane, 2004; Miyake et al., 2000; Roberts et al., 1994; Roberts & Pennington, 1996), supported by behavioural and neuroimaging data (McNab et al., 2008; Nyberg et al., 2009; Tsujimoto, Kuwajima, & Sawaguchi, 2007), also suggest a close interplay between WM and inhibition in healthy subjects. Although these models differ in the emphasis they place on both domains in this interaction, they all predict tradeoffs in the resources devoted to WM and inhibition under

high task demands (Nyberg et al., 2009). The best way to study their interrelationship, is to use a within-task methodology, in which *both* components are manipulated in the same task and the effect of combining these variables on a common dependent measure of task performance can be examined (Beveridge et al., 2002; Nyberg et al., 2009; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006). This kind of methodology of crossing two factors, allows the separation of additive and interactive effects (Beveridge et al., 2002; Nyberg et al., 2009). The interaction of these two factors, such that the effect of one factor is more pronounced under higher loadings of the other, would lend support to a unitary view of EF, and would imply that a common pool of executive resources is tapped by both domains (as hypothesized by the interactive framework of Roberts and colleagues, 1994, 1996). If independent effects of varying WM and inhibition loads are observed, this would be more consistent with the view that they are separable components of EF (Beveridge et al., 2002; Nyberg et al., 2009; Verté et al., 2006).

In the abovementioned study (Van De Voorde et al., 2010), we also included a memory load manipulation in the Go/no-go task, besides the inhibition manipulation, leading to two additional conditions. The latter were not analyzed in the previous report as the focus of this manuscript was on the question whether inhibition and WM problems would still be observed when a baseline measure of functioning was included. Therefore, we decided to use separate tasks that had been found to reliably measure the domains of interest (Go/no-go for inhibition and n-back for WM). In the present paper, further analyses will be conducted on the Go/no-go data collected in the same children (see Methods section for a detailed description of the task conditions). By adding the conditions in which WM was manipulated, it was possible to explicitly test the relationship between response inhibition and WM in children with ADHD and children with RD. More specifically, we were able to examine the possibility that an inhibition deficit in ADHD would only surface when both inhibition and WM are

forced up in the same inhibition task. With respect to RD, we previously found that they showed WM problems but no inhibition problems. As inhibition problems are sometimes, but not consistently, reported in RD (e.g., Purvis & Tannock, 2000; van der Schoot et al., 2000), it could be possible that they are the result of a deficit in WM. Therefore, we would expect that inhibition problems only surface when WM load is sufficiently high. We hypothesize that in both disorders WM and inhibition are not independent domains, and that the relationship between both EFs in the clinical groups will be different from that in the control group. Only 3 previous studies investigated the relationship between both domains in patients with ADHD (Brocki et al., 2008; Clark et al., 2006; Verté et al., 2006). Clark and colleagues (2006) found that in adults with ADHD inhibition and WM impairments may stem from a common pathologic mechanism rather than representing distinct deficits. With respect to school-age children with ADHD, Verté et al. (2006) and Brocki et al. (2008) suggested that they are distinct but related, semi-independent cognitive domains. However, it seems difficult to compare the results from these studies as they differed in a few aspects. Verté and colleagues and Brocki and colleagues used a child population, whereas Clark and colleagues studied adults. The study by Brocki included only boys from the ADHD-combined subtype, whereas the other two included both genders and all ADHD subtypes. Brocki and colleagues took a look at both visual-spatial and verbal WM, whereas the other studies included only a visual-spatial task. As there is still no agreement on the kind of WM problems children with ADHD show, it will be important to include both types of stimuli when investigating its relation to inhibition. As was mentioned above, it will also be important to control for comorbid RD, which none of the latter studies did. A last point of attention has to do with the methodology used to study the relation between inhibition and WM. The latter studies all used separate WM and inhibition tasks to identify possible deficits and there interrelation. However, in

order to show that both EFs are dissociable, it is necessary to use the within-task methodology.

The current study used this methodology of combining manipulations of both processes in the same task to meet the primary goal of this research: to examine the relationship between WM and inhibition in children with ADHD and in children with RD. We hypothesized that in both disorders WM and inhibition are not independent domains and that the relationship between both EFs in the clinical groups is different from that in the control group. In investigating this relationship we explicitly took some crucial aspects into account. First, we controlled for the comorbid disorder to isolate deficits that are unique to ADHD or RD. Second, we used a within-task methodology to study the interrelationship between WM and inhibition in both disorders. And lastly, different types of stimuli were used to investigate the modality-specificity of possible deficits (verbal-auditory versus visual).

Method

Participants

Four groups of children aged 8-12 years participated: 19 children with ADHD, 17 children with RD, 21 children with ADHD+RD, and 19 typically developing controls ('control group'). All children were recruited through newspaper advertisements, through referral by speech therapists or paediatric psychologists, and through letters to parents distributed in schools. Children were selected for the screening procedure if they had a diagnosis of ADHD and/or had a history of reading problems (diagnosis of RD or referral to a speech therapist). Parents and teachers completed the following questionnaires: the Disruptive Behaviour Disorder Rating Scale (DBDRS; Pelham, Gnagy, Greenslade, & Milich, 1992), the Child Behaviour Checklist/Teacher Report Form (CBCL/TRF; Achenbach, 1991), and the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999). Children were included in the control group if they had no history of learning or psychiatric problems and scored in the normal range on these questionnaires. The first two questionnaires were used as selection instruments in the control group only; in the clinical groups they were used to obtain a description of possible comorbid problems. Exclusion criteria for all groups were: (1) neurological problems, uncorrected hearing or vision, or speech problems, (2) native language different from Dutch, (3) a clinical score on the SCQ (symptoms of autism), (4) presence of other diagnoses (e.g. anxiety disorder), or (5) an estimated Full Scale IQ (FSIQ) below 80, based on the Vocabulary, Similarities, Picture Arrangement and Block Design subtests of the WISC-III (Wechsler, 1991). This short version of the WISC-III is the one recommended by Grégoire (2000) and has a high correlation ($r =$ .93) with FSIQ (Kaufman, Kaufman, Balgopal, & McLean, 1996). Sociodemographic information was obtained from the parents; The Hollingshead Index (Hollingshead & Redlich, 1958) with 5 classes of social status was used as a measure of socioeconomic status (SES).

Children's ADHD diagnosis was validated with the parent-administered Diagnostic Interview Schedule for Children for DSM-IV (DISC-IV; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Reading problems were evaluated with 2 standardized Dutch reading measures: the Dutch One-Minute-Test (Brus & Voeten, 1973) and the Klepel, a pseudoword reading task (van den Bos, lutje Spelberg, Scheepsma, & de Vries, 1994). The raw scores on these reading measures were converted into standard scores (SS) using grade related norms with a mean of 10 and a standard deviation (SD) of 3. Children in the control group had to obtain a SS of at least 8 on both reading measures. Assignment to one of the 3 clinical groups was based on the DISC-IV (diagnosis of ADHD) and the reading measures (SS ≤ 5 on at least 1 of the 2 reading tasks). Children with a clinical diagnosis but insufficient symptom levels to meet these criteria were excluded from the study to make groups as homogeneous as possible. The ODD (Oppositional Defiant Disorder) and CD (Conduct Disorder) modules of the DISC-IV were administered to evaluate the presence of comorbid behavioural disorders.

Sample Characteristics

As can be seen in Table 1, there were no significant differences between the groups with respect to age, gender, estimated FSIQ, or SES.

The mean score of ADHD symptoms on the DBDRS was significantly higher for the ADHD groups than for the non-ADHD groups, and the RD groups had a significantly lower reading score than the non-RD groups. However, children with ADHD had a significantly lower reading score compared to the control group, although they did not meet the cut-off for RD. The comorbid group did not significantly differ from the ADHD-only group on ADHD symptoms or from the RD-only group on the reading score. Based on the DISC-IV ADHD diagnoses, we found no differences between both ADHD groups in the proportion of ADHD subtypes ($\chi^2(2) = 1.46$, $p = .48$). In the ADHD-only group, 4 children (21%) met criteria for

the inattentive type, 3 children (15.8%) for the hyperactive-impulsive type, and 12 children (63.2%) for the combined type. In the ADHD+RD group, 6 children (28.6%) met criteria for the inattentive type, 1 child (4.8%) for the hyperactive-impulsive type, and 14 children (66.6%) for the combined type. Both ADHD groups had significantly more ODD symptoms on the DBDRS than both groups without ADHD. There were no differences between both ADHD groups in percentage of children meeting a DISC-IV ODD diagnosis ($\chi^2(1) = 0.35$, $p = .56$): 7 children (38.9%) in the ADHD-only and 5 children (29.4%) in the comorbid group. With regard to CD, all groups exhibited insufficient symptoms on the DBDRS to make a sound comparison, and none of the children had a DISC-IV CD diagnosis.

[Insert Table 1 about here]

Procedure

This study was part of a larger study on neuropsychological and linguistic deficits in the same children (see also Van De Voorde et al., 2010). The study was approved by the Ethical Committee of Ghent University and written consent was obtained from the parents. The different measures were spread over two testing days of approximately two hours. Children on psychostimulant medication discontinued it at least 24 hours before testing. No medication other than methylphenidate was used.

Neuropsychological Measure

Several Go/no-go tasks, programmed in Inquisit 2.0, were used to manipulate demands on response inhibition and WM. In the Go/no-go paradigm either a Go or a No-go stimulus is presented on the screen in each trial. Children have to make a response (e.g., push the spacebar) when they see a Go-stimulus but not when they see a No-go stimulus. This paradigm has been one of the most frequently used to investigate response inhibition

(Simmonds, Pekar, & Mostofsky, 2008) and has been shown to strongly implicate the prefrontal cortex among both children (Casey et al., 1997) and adults (Kiefer, Marzinzik, Weisbrod, Scherg, & Spitzer, 1998). Obviously, this task also requires WM because one has to keep in mind which items require a response (Beveridge et al., 2002).

We included three experimental manipulations: Inhibition load (2 levels), WM load (2 levels), and modality (3 levels). This resulted in 12 blocks of 100 trials, with stimulus duration (300 ms) and inter-trial interval (2000 ms) kept constant. Blocks were not counterbalanced across participants, but blocks were relatively short (maximum 5 minutes) and frequent breaks were provided to minimize the effects of fatigue and problems with sustaining attention.

Inhibition load. Inhibition difficulty can be manipulated by varying the No-go probability, that is, the frequency of items that do not need a response relative to items that do need a response (Beveridge et al., 2002; Bruin & Wijers, 2002; Dimoska & Johnstone, 2008; Ramautar, Kok, & Ridderinkhof, 2004). When Go stimuli are presented more often than No-go stimuli, a prepotent tendency to respond is created. The more prepotent a certain response, the higher the inhibition load or the inhibitory effort that is needed to successfully refrain from responding when a rare No-go stimulus is presented. We included a 'low inhibition condition' (50% Go trials and 50% No-go trials) and a 'high inhibition condition' (80% Go and 20% No-go trials). In the latter, the higher frequency of the ongoing response makes it more difficult to inhibit.

WM load. WM can be varied by increasing the number of Go targets that needs to be remembered (Beveridge et al., 2002). The 'low WM condition' included only one Go and one No-go stimulus, a format that is best suited to study response inhibition under minimal influence of other cognitive processes like WM or stimulus-response conflict (Simmonds et

al., 2008). We also included a 'high WM condition' in which more than one Go and No-go stimulus needed to be remembered.

Inhibition x WM conditions. Crossing both experimental factors resulted in four experimental conditions: (1) low inhibition low WM, (2) high inhibition low WM, (3) low inhibition high WM, and (4) high inhibition high WM.

Modality. The four conditions above were each presented in three different modalities to investigate the modality-specificity of possible deficits. In the visual modality, meaningless symbols were used; the verbal modality was represented by letters and digits. Meaningless symbols were symbol 1 (Go) versus symbol 4 (No-go) in the low WM condition and symbol 1, 2, 3 (Go) versus symbol 4, 5, 6 (No-go) in the high WM condition (see Figure 1). Letters were X (Go) versus O (No-go) in the low WM condition and X, D, F, K, S (consonants; Go) versus O, A, E, I, U (vowels; No-go) in the high WM condition. Digits were 1 (Go) versus 6 (No-go) in the low WM condition and 1, 3, 5, 7 (odd numbers; Go) versus 2, 4, 6, 8 (even numbers; No-go) in the high WM condition.

Dependent measures. Percentage of commission errors (i.e., pressed the button after a No-go signal) was used as the primary measure of task performance. Percentage of omission errors (i.e., nonresponse to a Go stimulus) and mean reaction time (RT) were also included to get a more complete picture of general performance. Mean RT was calculated for correct Go responses between 150 and 1500 ms.

Validity of the WM measure. In order to verify that it is the executive load and not the storage load of WM that was enlarged by the WM load manipulation, we correlated the data of the high WM condition with the data of the 1-back condition of the n-back task that was used on the same subjects in a previous study (Van De Voorde et al., 2010). In this way the n-back task was used as a reference task as it has been found to reliably measure WM (Parmenter, Shucard, Benedict, & Shucard, 2006). We found moderate, significant

correlations between the 1-back condition and the high WM condition of our experimental

Go/no-go task for all three modalities: symbols ($r = .35$, $p < .01$), letters ($r = .30$, $p < .01$) and

digits ($r = .32$, $p < .01$).

[Insert Figure 1 about here]

Results

Statistical Analyses

Prior to statistical testing, assumptions of normality and homogeneity of variances were tested in each group separately. Whenever assumptions were not met, a logarithmic transformation ($\log_{10}$) was performed and analyses were then conducted on these transformed data (Tabachnick & Fidell, 2007). This was the case for commission and omission errors.

A mixed design ANOVA was performed, with ADHD (2 levels) and RD (2 levels) as between-subjects factors, and Inhibition (2 levels), Memory (2 levels) and Modality (2 levels) as within-subjects factors. As interactions emerged between the within-subjects factor Modality and the other factors, ANOVAs were then performed for all modalities separately. The results of the latter analyses are reported below. As results of the inhibition manipulation were already described elsewhere (Van De Voorde et al., 2010), the focus of the current analyses is not on the main effects of the factors but on the interaction between the factors WM and inhibition and on their relationship to the diagnostic factors ADHD and RD. The number of ODD symptoms was not significantly related to any of the dependent variables and was therefore not included in the analyses.

Comparison of the Means

Unadjusted means for the four groups on each dependent measure in each condition are presented in Table 2.

Commission errors. A significant main effect of Inhibition emerged in all modalities, due to more errors in the high than in the low inhibition load conditions: $F(1,72) = 83.37$, $p < .001$, $\eta^2_p = .54$ (symbols); $F(1,72) = 185.85$, $p < .001$, $\eta^2_p = .72$ (letters); $F(1,72) = 239.57$, $p < .001$, $\eta^2_p = .77$ (digits). The main effect of Memory was also significant in all modalities, due to more errors in the high than in the low memory load conditions: $F(1,72) = 16.27$, $p <$

.001, η^2_p = .18 (symbols); $F(1,72)$ = 42.57, $p < .001$, η^2_p = .37 (letters); $F(1,72)$ = 38.89, $p <$ .001, η^2_p = .35 (digits). Both main effects clearly indicate that our manipulations had the desired effect of increasing the executive load. With respect to the diagnostic factors, we found a significant main effect of ADHD in all modalities: $F(1,72)$ = 22.96, $p < .001$, η^2_p = .24 (symbols); $F(1,72)$ = 12.93, $p < .001$, η^2_p = .15 (letters); $F(1,72)$ = 27.70, $p < .001$, η^2_p = .28 (digits). The main effect of RD was also significant in all modalities: $F(1,72)$ = 17.32, $p <$ .001, η^2_p = .19 (symbols); $F(1,72)$ = 18.03, $p < .001$, η^2_p = .20 (letters); $F(1,72)$ = 8.95, $p <$ .01, η^2_p = .11 (digits). There were no significant interactions between the diagnostic factors on the one hand and the within-subjects factors Inhibition and Memory on the other hand. This means that both disorders were associated with making more errors overall, independent of the level of inhibition or WM. A significant interaction emerged between Inhibition and Memory, but only in the conditions with letters, $F(1,72)$ = 11.60, $p < .001$, η^2_p = .14. The effects of Inhibition and Memory where greater under high than under low demands of the other factor. There were no significant three-way interactions between the factor ADHD or RD on the one hand and both within-subjects factors Inhibition and Memory on the other hand.

Omission errors. A significant main effect of Memory emerged in all modalities, due to more omission errors in the high than in the low memory load conditions: $F(1,72)$ = 9.75, $p < .01$, η^2_p = .12 (symbols); $F(1,72)$ = 31.70, $p < .001$, η^2_p = .31 (letters); $F(1,72)$ = 8.66, $p < .01$, η^2_p = .11 (digits). The main effect of Inhibition was not significant in any of the modalities ($ps > .29$). With respect to the diagnostic factors, we found a significant main effect of ADHD in all modalities: $F(1,72)$ = 4.34, $p < .05$, η^2_p = .06 (symbols); $F(1,72)$ = 6.32, $p < .05$, η^2_p = .08 (letters); $F(1,72)$ = 11.68, $p < .01$, η^2_p = .14 (digits). The main effect of RD was also significant in all modalities: $F(1,72)$ = 9.77, $p < .01$, η^2_p = .12 (symbols); $F(1,72)$ = 4.68, $p < .05$, η^2_p = .06 (letters); $F(1,72)$ = 6.31, $p < .05$, η^2_p = .08 (digits). There were no

significant interactions between the diagnostic factors on the one hand and the within-subjects factors Inhibition and Memory on the other hand. This means that both disorders were associated with making more omission errors overall, independent of the level of inhibition or WM. When post hoc Bonferroni comparisons were made between the four clinical groups, it appeared that it was only the comorbid group that differed significantly from the normal control group in the task with letters and the task with symbols. In the task with digits, both ADHD groups differed significantly from the normal control group, but the comorbid group made most errors. A significant interaction emerged between Inhibition and Memory in all modalities: $F(1,72) = 7.07$, $p < .05$, $\eta^2_p = .09$ (symbols); $F(1,72) = 4.93$, $p < .05$, $\eta^2_p = .06$ (letters); $F(1,72) = 5.55$, $p < .05$, $\eta^2_p = .07$ (digits). This was due to a greater effect of memory load under *low* than under high inhibition demands. There were no significant three-way interactions between both within-subjects factors and each of the diagnostic factors.

Mean reaction time. A significant main effect of Inhibition emerged in all modalities, due to *faster* responses in the high than in the low inhibition load conditions: $F(1,72) = 89.62$, $p < .001$, $\eta^2_p = .56$ (symbols); $F(1,72) = 38.97$, $p < .001$, $\eta^2_p = .35$ (letters); $F(1,72) = 66.90$, $p < .001$, $\eta^2_p = .48$ (digits). The main effect of Memory was also significant in all modalities, due to *slower* responses in the high than in the low memory load conditions: $F(1,72) = 122.27$, $p < .001$, $\eta^2_p = .63$ (symbols); $F(1,72) = 207.52$, $p < .001$, $\eta^2_p = .74$ (letters); $F(1,72) = 223.71$, $p < .001$, $\eta^2_p = .76$ (digits). With respect to the diagnostic factors, we only found a significant main effect of RD in the visual modality, indicating that children with RD were faster than children without RD: $F(1,72) = 4.75$, $p < .05$, $\eta^2_p = .06$. However, a significant interaction between RD and Inhibition ($F(1,72) = 6.47$, $p < .05$, $\eta^2_p = .08$) showed that this was only the case when inhibition load was high ($p < .01$) and not when it was low ($p = .11$). We found no other main effects of the diagnostic factors, indicating that, in general, there were no differences between the groups in response speed. In the task with letters, a

significant interaction was found between ADHD and Memory, $F(1,72) = 6.15$, $p < .05$, $\eta^2_p =$ .08, which suggests that the Memory effect (i.e., slowing down when memory load increases) was less pronounced in children with ADHD than in children without ADHD. In the task with digits, a significant interaction emerged between ADHD and Inhibition, $F(1,72) = 6.39$, $p <$ .05, $\eta^2_p = .08$, which suggests that the Inhibition effect (i.e., speeding up when the frequency of targets increases) was more pronounced in children with ADHD than in children without ADHD. A significant interaction emerged between Inhibition and Memory in all modalities: $F(1,72) = 3.54$, $p = .06$, $\eta^2_p = .05$ (symbols); $F(1,72) = 14.20$, $p < .001$, $\eta^2_p = .17$ (letters); $F(1,72) = 14.52$, $p < .001$, $\eta^2_p = .17$ (digits). This was due to a greater effect of memory load under *low* than under high inhibition demands. This interaction did not differ depending on the presence of ADHD or RD.

[Insert Table 2 about here]

Discussion

To the best of our knowledge, this is the first study that used a within-task methodology to examine the relationship between two dominant EF components, response inhibition and WM, in two often comorbid childhood disorders, ADHD and RD.

Adaptations were made to the Go/no-go paradigm such that both inhibition and WM load were experimentally manipulated in the same task. This kind of methodology of crossing two factors makes it possible to study the combined effects of inhibition and WM demands on a common measure of task performance, and allows the separation of additive and interactive effects (Beveridge et al., 2002; Nyberg et al., 2009). An interaction of both factors, such that the effect of one factor is more pronounced under higher loadings of the other, would lend support to a unitary view of EF, and would imply that a common pool of executive resources is tapped by both domains (as hypothesized by the interactive framework of Roberts and colleagues, 1994, 1996). If independent effects of varying WM and inhibition loads are observed, this would be more consistent with the view that they are separable components of EF (Beveridge et al., 2002; Nyberg et al., 2009; Verté et al., 2006).

With percentage of commission errors as the primary measure, we were able to demonstrate that our manipulations had the desired effect of enlarging the executive load, as all groups made *more* errors in the high compared to the low load conditions. In addition, the Memory effect (i.e., the performance difference between the low and high memory conditions) was also visible in percentage of omission errors and mean RT: all the groups made *more* omission errors and were *slower* in the high as opposed to the low memory load conditions. The Inhibition manipulation had an additional effect only on mean RT, such that children were *faster* in the high than in the low inhibition load conditions (see also Beveridge et al., 2002; Nyberg et al., 2009).

Results regarding the main effects of the diagnostic factors and the absence of interactions with the factor Inhibition were already described and interpreted elsewhere (Van De Voorde et al., 2010). In short, we found that children with ADHD and children with RD made more errors than children without ADHD or RD, respectively, in all conditions of the Go/no-go task. In addition, although both our manipulations of executive load were successful, we did not find that children with ADHD or RD were more impaired by this manipulation than children without ADHD or RD. This suggests that there could be something else than only problems with EFs causing the higher error rate in children with ADHD and children with RD. Our results are for example more in line with the current belief that children with ADHD have problems with error monitoring (e.g., Wiersema, van der Meere, & Roeyers, 2005). However, the inaccurate response style could also be related to a problem with sustaining attention, as we found that both children with ADHD and children with RD also made more omission errors. However, as blocks were not that long (maximum 5 minutes) and as we did not find major differences in RT between groups, we believe that sustained attention problems cannot fully explain our findings. When we compared the performance profiles of the four individual groups, it appeared that it was only the comorbid group that made significantly more omission errors than the normal control group. The comorbid group also made significantly more commission errors than the single disorder groups and showed faster response times, although not significantly. This could not exclusively be due to higher impulsivity in the comorbid than in the ADHD-only group, as both groups did not differ in level of hyperactivity/impulsivity symptoms on the DBD rating scale. As the cognitive profile of the comorbid was somewhat different from that of the single disorder groups, it is possible that different factors underlie the inaccurate response style in the different clinical groups.

It must be noted that, although we found WM problems in the same children with RD in a previous study (Van De Voorde et al., 2010), we did not in the current one. This difference in results is probably related to task differences between both studies: in the current study, we used a manipulation of a Go/no-go task, which is essentially a response inhibition task, whereas the other study used the n-back task, a task specifically designed to measure WM. Although our memory manipulation was successful (as evidenced by a significant condition effect), it is possible that it did not tap WM as much as the n-back task, as it just required comparison of each stimulus with a fixed group of to be remembered stimuli, whereas in the n-back task, the to be remembered stimulus had to be updated continuously. It is likely that this method of increasing WM load in an inhibition task, in which inhibitory control remains the central ability measured, is not suited to measure WM in se but rather captures the influence of WM capacity on inhibition skill. However, we believe this was not problematic as the focus of the present study was not on WM alone but on the relationship with inhibition.

With respect to the relationship between response inhibition and WM, we found additive effects on the primary measure of task performance (commission errors) when digits or meaningless symbols had to be processed, and interactive effects in the task with letters. This could lead us to conclude that the relationship between these two EF components is dependent on the modality of the stimulus that has to be processed. However, the finding of an additive effect could also mean that the task did not impose enough load to exhaust children's executive system's capacity (Beveridge et al., 2002). The difference between the letter task and the other tasks could therefore rather be the result of task-specific differences than of modality-specific differences (see also Brocki et al., 2008). This could have been the case in our study as in the task with letters, five targets needed to be remembered, whereas in the task with symbols and digits, only three, respectively four, targets had to be remembered.

This could have differentially influenced task difficulty, leading to the discrepancy between the modalities. With caution, we could conclude that, when WM load is sufficiently high, both response inhibition and WM seem to rely on the same limited capacity resources. This was also found by Nyberg and colleagues (2009), and is in line with theoretical models that suggest a close interplay between both EFs (e.g., Engle & Kane, 2004; Miyake et al., 2000; Roberts & Pennington, 1996). With respect to the other dependent variables, we found greater effects of the memory manipulation under low than under high inhibition demands. This finding of the different task parameters influencing each other, is in line with our general finding that inhibition and WM are not independent domains. To support our conclusions, however, more research should be conducted using comparable tasks in different modalities but with higher executive demands on WM.

Of more importance was the question whether the relationship between inhibition and WM would be different in children with ADHD or RD compared to children without ADHD or RD, respectively. Based on the fact that results regarding inhibition problems in RD are inconsistent, and our finding of a WM deficit in the absence of an inhibition problem in RD in a previous report (Van De Voorde et al., 2010), we hypothesized that the emergence of inhibition problems would be dependent on the degree of WM load in the inhibition task that is used. However, the absence of a significant three-way interaction between RD, inhibition load and memory load did not support this hypothesis. There was also no significant three-way interaction between both within-subjects factors and the diagnostic factor ADHD. In our previous study, we did not find evidence of a response inhibition deficit when a baseline measure of functioning was taken into account. The current findings suggest that even under high memory load conditions, we find no evidence for a response inhibition deficit being the only explanation for the inaccurate response style in children with ADHD.

Although children with ADHD or RD were not more seriously affected by the combined load of both EFs than children without ADHD or RD, we found that, as in the control group, inhibition and WM were related to each other in the clinical groups. That the relationship between inhibition and WM is similar in children with ADHD and typically developing controls, was also found by Verté and colleagues (2006). However, as the current study was the first to investigate the relationship between inhibition and WM in children with ADHD using the within-task methodology, it is difficult to compare our results with those of previous studies. Using methods based on correlations between different EF tasks, Brocki and colleagues (2008) and Verté and colleagues (2006) found that both domains were distinct but related, semi-independent cognitive domains in children with ADHD. In the current study we did not find support for the view that they are distinct, neither in the control group nor in the clinical groups. Our results suggest that there is a close relationship between WM and response inhibition, as reflected in different ways in the behavioural performance (commission and omission errors, and RT) of children, independent of their diagnosis. It must be noted that these results apply only to elementary school-age children. It has been suggested that the relationship between inhibition and WM changes from childhood to adulthood, in that both processes become more fractionated, making it possible to complete complex tasks more efficiently. This fractionating of EFs could be the result of the fact that neural systems in the lateral prefrontal cortex become more finely tuned to more specific brain regions (Casey, Galvan, & Hare, 2005). Therefore, it is possible that differences between clinical groups and controls concerning the relationship between inhibition and WM do not emerge until some later point in development, for example when this fine-tuning to more specific brain regions is less pronounced in children with ADHD or RD.

Our results also suggest that varying the type and/or number of stimuli that has to be processed, has an influence on the results that are obtained. This could be one of the factors

responsible for the high variability in findings regarding EF problems in ADHD, RD, and other developmental disorders. Therefore, to clarify the relationship between these disorders and different EFs, it will be important to design tasks that are able to experimentally control for different task parameters.

The current study suffers from some limitations that need to be mentioned. In view of the relative small sample sizes in all groups, the reported results will need to be replicated by future studies with larger samples. Due to these small sample sizes, it was not possible to distinguish between ADHD subtypes. Future research should investigate whether the reported effects apply for each of the ADHD subtypes as it has been suggested that they may differ in the cognitive profile they exhibit (Castellanos & Tannock, 2002; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). It should also be mentioned that we only studied inhibition of prepotent responses, as measured by the Go/no-go paradigm, which is only one aspect of response inhibition (see Kipp, 2005). Therefore, our results only apply to the relationship between WM and this specific type of inhibition. In addition, our results only apply to elementary school-age children and do not allow any inference about the studied relationships in adults. It must also be acknowledged that two of the modality conditions (i.e., digits and letters) involve previous top-down knowledge and are most probably easier for the participants to memorize compared to the meaningless figures which could be described as involving more bottom-up processing. This may have confounded the results. Lastly, it is possible that our memory manipulation did not sufficiently trigger the executive component of WM. Therefore, to support our conclusions, more research should be conducted using the same design but with a more executive demanding manipulation of WM.

In conclusion, we found evidence of an interplay between inhibition and memory processes when demands on both are increased in the same task. In addition, we found that the relationship between inhibition and WM was similar in children with ADHD, children with RD, children with comorbid ADHD and RD, and typically developing control children.

As EF deficits and the relationship between different EF components are currently still the focus of theorizing about ADHD (e.g., Barkley, 1997), effort should be made to further clarify these relations. Future studies should continue using experimental paradigms to test for factorial main effects of EF manipulations and their interaction with diagnostic factors while controlling for differences in basic cognitive processes.

References

Achenbach, T.M. (1991). *Manual for the Child Behaviour Checklist: 4-18 and 1991 profile.* Burlington, VT: University of Vermont.

Alderson, R.M., Rapport, M.D., & Kofler, M.J. (2007). Attention-deficit/hyperactivity disorder and behavioral inhibition: A meta-analytic review of the stop-signal paradigm. *Journal of Abnormal Child Psychology, 35,* 745-758.

Baddeley, A. (1992). Working memory. *Science, 255*, 556-559.

Banaschewski, T., Hollis, C., Oosterlaan, J., Roeyers, H., Rubia, K., Willcutt, E., & Taylor, E. (2005). Towards an understanding of unique and shared pathways in the psychopathophysiology of AD/HD. *Developmental Science, 8,* 132-140.

Barkley, R.A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Berument, S.K., Rutter, M., Lord, C., Pickles, A., & Bailey, A. (1999). Autism screening questionnaire: Diagnostic validity. *British Journal of Psychiatry, 175*, 444-451.

Best, J. R. & Miller, P. H. (2010). A Developmental Perspective on Executive Function. *Child Development, 81*, 1641-1660.

Beveridge, M., Jarrold, C., & Pettit, E. (2002). An experimental approach to executive fingerprinting in young children. *Infant and Child Development, 11,* 107-123.

Brocki, K.C., Randall, K.D., Bohlin, G., & Kerns, K.A. (2008). Working memory in school-aged children with ADHD combined type: Are deficits modality specific and are they independent of impaired inhibitory control? *Journal of Clinical and Experimental Neuropsychology, 30*, 749-759.

Bruin, K.J., & Wijers, A.A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology, 113,* 1172-1182.

Brus, B.T., & Voeten, M.J.M. (1973). *Een-Minuut-Test* [One-Minute-Test]. Nijmegen, The Netherlands: Berkhout.

Casey, B.J. (2005). Frontostriatal and frontocerebellar circuitry underlying cognitive control. In U. Mayr, E. Awh, & S.W. Keele (Eds.), *Developing individuality in the human brain* (pp.141-166). Washington, DC: APA Books.

Casey, B.J., Galvan, A., & Hare, T.A. (2005). Changes in cerebral functional organization during cognitive development. *Current Opinion in Neurobiology, 15,* 239-244.

Casey, B.J., Trainor, R.J., Orendi, J.L., Schubert, A.B., Nystrom, L.E., Giedd, J.N., Castellanos, F.X., Haxby, J.V., Noll, D.C., Cohen, J.D., Forman, S.D., Dahl, R.E., & Rapoport, J.L. (1997). A developmental functional MRI study of prefrontal activation during performance of a go-no-go task. *Journal of Cognitive Neuroscience, 9,* 835-847.

Castellanos, F.X., Sonuga-Barke, E.J.S., Milham, M.P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences, 10,* 117-123.

Castellanos, F.X., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. *Nature Reviews Neuroscience, 3,* 617-628.

Clark, L., Blackwell, A.D., Aron, A.R., Turner, D.C., Dowson, J., Robbins, T.W., & Sahakian, B.J. (2006). Association between response inhibition and working memory in adult ADHD: A link to right frontal cortex pathology? *Biological Psychiatry, 61,* 1395-1401.

Del'Homme, M., Kim, T.S., Loo, S.K., Yang, M.H., & Smalley, S.L. (2007). Familial association and frequency of learning disabilities in ADHD sibling pair families. *Journal of Abnormal Child Psychology, 35,* 55-62.

Dimoska, A., & Johnstone, S.J. (2008). Effects of varying stop-signal probability on ERPs in the stop-signal task: Do they reflect variations in inhibitory processing or simply novelty effects? *Biological Psychology, 77,* 324-336.

Engle, R.W., & Kane, M.J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation: Vol.44. Advances in research and theory* (pp. 145-199). New York: Academic Press.

Faraone, S.V., Sergeant, J., Gillberg, C., & Biederman, J. (2003). The worldwide prevalence of ADHD: Is it an American condition? *World Psychiatry, 2,* 104-113.

Grégoire, J. (2000). *L'évaluation clinique de l'intelligence de l'enfant* [The clinical evaluation of the child's intelligence]. Liège, Belgium: Mardaga.

Hinshaw, S.P. (1992). Externalizing behaviour problems and academic underachievement in childhood and adolescence: Causal relationships and underlying mechanisms. *Psychological Bulletin, 111,* 127-155.

Hollingshead, A.B., & Redlich, F.C. (1958). *Social Class and Mental Illness*. New York: John Wiley & Sons.

Kaufman, A.S., Kaufman, J.C., Balgopal, R., & McLean, J.E. (1996). Comparison of three WISC-III short forms: Weighing psychometric, clinical, and practical factors. *Journal of Clinical Child Psychology, 25,* 97-105.

Kibby, M.Y., Marks, W., Morgan, S., & Long, C.J. (2004). Specific impairment in developmental reading disabilities: A working memory approach. *Journal of Learning Disabilities, 37,* 349-363.

Kiefer, M., Marzinzik, F., Weisbrod, M., Scherg, M., & Spitzer, M. (1998). The time course of brain activations during response inhibition: Evidence from event-related potentials in a go/no go task. *NeuroReport, 9*, 765-770.

Kipp, K. (2005). A developmental perspective on the measurement of cognitive deficits in ADHD. *Biological Psychiatry, 57,* 1256-1260.

Lazar, J.W., & Frank, Y. (1998). Frontal systems dysfunction in children with attention-deficit/hyperactivity disorder and learning disabilities. *The Journal of Neuropsychiatry and Clinical Neurosciences, 10,* 160-167.

Lijffijt, M., Kenemans, J.L., Verbaten, M.N., & van Engeland, H. (2005). A meta-analytic review of stopping performance in attention-deficit/hyperactivity disorder: Deficient inhibitory motor control? *Journal of Abnormal Psychology, 114,* 216-222.

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*, 377-384.

Martinussen, R., & Tannock, R. (2006). Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. *Journal of Clinical and Experimental Neuropsychology, 28, 1073-1094.*

Mattes, J.A. (1980). The role of frontal lobe dysfunction in childhood hyperkinesis. *Comprehensive Psychiatry, 21*, 358-369.

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: An fMRI, within-subjects investigation. *Neuropsychologia, 46,* 2668-2682.

Middleton, F.A., & Strick, P.L. (2001). Cerebellar projections to the prefrontal cortex of the primate. *Journal of Neuroscience, 21*, 700-712.

Middleton, F.A., & Strick, P.L. (2002). Basal-ganglia 'projections' to the prefrontal cortex of the primate. *Cerebral Cortex, 12*, 926-935.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex frontal lobe tasks: A latent variable analysis. *Cognitive Psychology, 41,* 49-100.

Nigg, J.T., Blaskey, L.G., Huang-Pollock, C.L., & Rappley, M.D. (2002). Neuropsychological executive functions and DSM-IV ADHD subtypes. *Journal of the American Academy of Child and Adolescent Psychiatry, 41,* 59-66.

Nigg, J.T., Hinshaw, S.P., Carte, E.T., & Treuting, J.J. (1998). Neuropsychological correlates of childhood attention-deficit/hyperactivity disorder: Explainable by comorbid disruptive behavior or reading problems? *Journal of Abnormal Psychology, 107,* 468-480.

Nyberg, L., Brocki, K., Tillman, C., & Bohlin, G. (2009). The proposed interaction between working memory and inhibition. *European Journal of Cognitive Psychology, 21*, 84-111.

Parmenter, B.A., Shucard, J.L., Benedict, R.H.B., & Shucard, D.W. (2006). Working memory deficits in multiple sclerosis: Comparison between the n-back task and the paced auditory serial addition test. *Journal of the International Neuropsychological Society, 12,* 677-687.

Pelham, W., Gnagy, E.M., Greenslade, K.E., & Milich, R. (1992). Teacher ratings of DSM-III-R symptoms for the disruptive behaviour disorders. *Journal of the American Academy of Child and Adolescent Psychiatry, 31*, 210-218.

Pennington, B.F., Groisser, D., & Welsh, M.C. (1993). Contrasting cognitive deficits in attention deficit hyperactivity disorder versus reading disability. *Developmental Psychology, 29,* 511-523.

Pennington, B.F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37,* 51-87.

Pontius, A.A. (1973). Dysfunction patterns analogous to frontal lobe system and caudate nucleus syndromes in some groups of minimal brain dysfunction. *Journal of the American Medical Women's Association, 26,* 285-292.

Purvis, K.L., & Tannock, R. (2000). Phonological processing, not inhibitory control, differentiates ADHD and reading disability. *Journal of the American Academy of Child and Adolescent Psychiatry, 39,* 485-494.

Ramautar, J., Kok, A., & Ridderinkhof, K.R. (2004). Effects of stop-signal probability in the stop-signal paradigm: The N2/P3 complex further validated. *Brain and Cognition, 56,* 234-252.

Rashid, F.L., Morris, M.K., & Morris, R. (2001). Naming and verbal memory skills in adults with attention deficit hyperactivity disorder and reading disability. *Journal of Clinical Psychology, 57,* 829-838.

Roberts, R.J., Hager, L.D., & Heron, C. (1994). Prefrontal cognitive processes: Working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General, 123*, 374-393.

Roberts, R.J., & Pennington, B.F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology, 12,* 105-126.

Rucklidge, J.J., & Tannock, R. (2002). Neuropsychological profiles of adolescents with ADHD: Effects of reading difficulties and gender. *Journal of Child Psychology and Psychiatry, 43,* 988-1003.

Savage, R., Lavers, N., & Pillay, V. (2007). Working memory and reading difficulties: What we know and what we don't know about the relationship. *Educational Psychology Review, 19,* 185-221.

Semrud-Clikeman, M., Guy, K., Griffin, J.D., & Hynd, G.W. (2000). Rapid naming deficits in children and adolescents with reading disabilities and attention deficit hyperactivity disorder. *Brain and Language, 74,* 70-83.

Sergeant, J.A., Geurts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research, 130,* 3-28.

Shaffer, D., Fisher, P., Lucas, C., Dulcan, M., & Schwab-Stone, M.E. (2000). NIMH Diagnostic Interview for Children Version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnosis. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*, 28-38.

Shallice, T., Marzocchi, G.M., Coser, S., Del Savio, M., Meuter, R.F., & Rumiati, R.I. (2002). Executive function profile of children with ADHD. *Developmental Neuropsychology, 21*, 43-71.

Simmonds, D.J., Pekar, J.J., & Mostofsky, S.H. (2008). Meta-analysis of go/no-go tasks demonstrating that fMRI activation associated with response inhibition is task-dependent. *Neuropsychologia, 46,* 224-232.

Swanson, H.L., Ashbaker, M.H., & Lee C. (1996). Learning-disabled readers' working memory as a function of processing demands. *Journal of Experimental Child Psychology, 61,* 242-275.

Swanson, H.L., Mink, J., & Bocian, K.M. (1999). Cognitive processing deficits in poor

    readers with symptoms of reading disabilities and ADHD: More alike than different?

    Journal of Educational Psychology, 91, 321-333.

Tabachnick, B.G., & Fidell, L.S. (2007). *Using multivariate statistics* (5th ed.). Boston: Allyn

    and Bacon.

Tsujimoto, S., Kuwajima, M., & Sawaguchi, T. (2007). Developmental fractionation of

    working memory and response inhibition during childhood. *Experimental Psychology,*

    54, 30-37.

van den Bos, K.P., lutje Spelberg, H.C., Scheepsma, A.J.M., & de Vries, J.R. (1994).

    Handleiding de Klepel [Manual for the Klepel]. Nijmegen, The Netherlands:

    Berkhout.

van der Schoot, M., Licht, R., Horsley, T.M., & Sergeant, J.A. (2000). Inhibitory deficits in

    reading disability depend on subtype: Guessers but not spellers. *Child*

    Neuropsychology, 6, 297-312.

Van De Voorde, S., Roeyers, H., Verté, S., & Wiersema, J.R. (2010). Working memory,

    response inhibition, and within-subject variability in children with ADHD or reading

    disorder. *Journal of Clinical and Experimental Neuropsychology, 32,* 366-379.

Verté, S., Geurts, H.M., Roeyers, H., Oosterlaan, J., & Sergeant, J.A. (2006). The relationship

    between working memory, inhibition, and response variability in child

    psychopathology. *Journal of Neuroscience Methods, 151,* 5-14.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). San Antonio, TX:

    The psychological Corporation.

Weyandt, L.L. (2005a). Neuropsychological performance of adults with ADHD. In D. Gozal,

    & D. Molfese (Eds.), *ADHD: From genes to animal models to patients.* New York:

    Humana Press.

Weyandt, L.L. (2005b). Executive function in children, adolescents, and adults with attention deficit hyperactivity disorder: Introduction to the special issue. *Developmental Neuropsychology, 27,* 1-10.

Wiersema, J.R., van der Meere, J.J., & Roeyers, H. (2005). ERP correlates of impaired error monitoring in children with ADHD. *Journal of Neural Transmission, 112*, 1417-1430.

Willcutt, E.G., Doyle, A.E., Nigg, J.T., Faraone, S.V., & Pennington, B.F. (2005). Validity of the executive function theory of ADHD: A meta-analytic review. *Biological Psychiatry, 57,* 1336-1346.

Willcutt, E.G., & Pennington, B.F. (2000). Comorbidity of reading disability and attention-deficit/hyperactivity disorder: Differences by gender and subtype. *Journal of Learning Disabilities, 33,* 179-191.

Willcutt, E.G., Pennington, B.F., Boada, R., Ogline, J.S., Tunick, R.A., Chhabildas, N.A., & Olson, R.K. (2001). A comparison of the cognitive deficits in reading disability and attention-deficit/hyperactivity disorder. *Journal of Abnormal Psychology, 110,* 157-172.

Willis, W.G., & Weiler, M.D. (2005). Neural substrates of childhood attention-deficit/hyperactivity disorder: Electroencephalographic and magnetic resonance imaging evidence. *Developmental Neuropsychology, 27,* 135-182.

Wu, K.K., Anderson, V., & Castiello, U. (2002). Neuropsychological evaluation of deficits in executive functioning for ADHD children with or without learning disabilities. *Developmental Neuropsychology, 22,* 501-531.

Table 1. Means of the Four Groups on Descriptive and Diagnostic Measures

Measure	Control (*N*=19) M (SD)	ADHD (*N*=19) M (SD)	RD (*N*=17) M (SD)	ADHD+RD (*N*=21) M (SD)	F (3, 72)
Age	120.5 (17.7)	127.2 (18.9)	127.1 (14.4)	122.7 (15.6)	.72
SES	4.4 (0.7)	4.2 (0.7)	4.0 (0.8)	3.8 (1.1)	1.73
Sex (M:F)	11:8	16:3	9:8	17:4	[a]
FSIQ	108.7 (12.9)	106.8 (15.9)	107.9 (10.1)	105.3 (12.2)	.25
ADHD symptoms[b]	1.7_a (1.4)	13.1_b (4.6)	4.0_a (3.0)	11.8_b (4.9)	41.31***
ODD symptoms[b]	0.9_a (1.2)	6.9_b (2.9)	1.4_a (1.6)	5.4_b (3.2)	28.50***
CD symptoms[b]	0.1 (0.2)	1.8 (1.5)	0.2 (0.3)	1.0 (1.1)	
Reading score[c]	11.4_a (2.5)	9.3_b (2.1)	4.3_c (1.9)	4.3_c (1.5)	61.06***

Note. ADHD = attention-deficit/hyperactivity disorder. RD = reading disorder. SES = socioeconomic status. FSIQ = full-scale intelligence quotient. ODD = oppositional defiant disorder. CD = conduct disorder. Means with different subscripts are significantly different by Bonferroni post hoc tests.

[a] $\chi^2(3) = 6.67$.

[b] Mean of teacher and parent Disruptive Behavior Disorder Rating Scale (DBDRS) raw score.

[c] Mean of Klepel and On-Minute-Test standard score.

*** $p < .001$

Table 2

Unadjusted Means of the Four Groups in the Different Conditions of the Go/no-go Tasks

Measure	Modality	Load Condition	Control (N=19) M (SD)	ADHD (N=19) M (SD)	RD (N=17) M (SD)	ADHD+RD (N=21) M (SD)
Commission Errors (%)	Symbols	LILM	7.7 (6.8)	16.2 (11.6)	14.6 (10.8)	29.5 (17.2)
		HILM	17.1 (13.4)	32.4 (16.3)	25.3 (11.9)	50.0 (19.4)
		LIHM	11.2 (11.3)	21.8 (17.9)	20.8 (13.7)	37.6 (19.9)
		HIHM	20.0 (15.9)	38.4 (21.8)	32.9 (20.2)	57.6 (19.6)
	Letters	LILM	7.3 (7.3)	12.4 (8.5)	10.1 (5.5)	20.5 (13.9)
		HILM	18.2 (10.2)	26.8 (14.5)	28.2 (10.0)	41.7 (16.4)
		LIHM	11.1 (8.3)	21.9 (16.1)	19.5 (10.4)	33.0 (16.7)
		HIHM	23.7 (15.5)	37.6 (24.2)	37.6 (15.8)	58.1 (17.3)
	Digits	LILM	6.7 (5.7)	14.5 (10.3)	9.2 (5.1)	26.0 (17.7)
		HILM	16.8 (14.2)	31.3 (19.1)	26.2 (12.1)	46.7 (23.3)
		LIHM	9.2 (8.3)	25.1 (17.6)	16.7 (10.5)	38.2 (21.8)

Measure	Modality	Load Condition	Control M (SD)	ADHD M (SD)	RD M (SD)	ADHD+RD M (SD)
Omission Errors (%)	Symbols	HIHM	22.9 (16.3)	46.6 (22.4)	35.9 (19.7)	52.1 (22.1)
		LILM	1.8 (2.6)	3.1 (4.4)	5.8 (8.8)	8.3 (8.2)
		HILM	2.0 (1.9)	3.8 (4.7)	5.9 (6.8)	6.3 (5.6)
		LIHM	2.9 (3.6)	4.9 (6.1)	10.7 (12.1)	12.8 (10.9)
	Letters	HIHM	2.9 (4.6)	6.2 (7.4)	4.9 (6.0)	7.4 (5.7)
		LILM	1.7 (2.8)	2.0 (2.8)	1.6 (2.4)	3.0 (3.6)
		HILM	2.4 (4.2)	7.9 (10.1)	6.0 (7.8)	9.1 (7.5)
		LIHM	1.1 (1.8)	3.2 (4.5)	2.9 (3.9)	5.2 (4.9)
	Digits	HIHM	2.4 (3.8)	3.8 (4.0)	4.6 (4.9)	7.4 (5.2)
		LILM	1.3 (1.9)	5.3 (6.7)	9.3 (13.5)	6.8 (5.2)
		HILM	2.3 (3.3)	5.9 (6.4)	7.7 (10.0)	7.5 (6.2)
		LIHM	3.2 (3.8)	9.9 (8.9)	7.3 (8.4)	11.9 (8.7)
		HIHM	2.6 (3.6)	8.9 (10.4)	7.5 (11.2)	10.7 (10.3)

Measure	Modality	Load Condition	Control M (SD)	ADHD M (SD)	RD M (SD)	ADHD+RD M (SD)
Mean Reaction Time (ms)	Symbols	LILM	578.7 (94.7)	594.7 (78.0)	595.3 (83.4)	542.1 (96.2)
		HILM	556.1 (109.8)	534.0 (85.9)	520.2 (95.9)	470.2 (80.9)
		LIHM	675.9 (102.8)	653.3 (96.1)	639.4 (84.5)	604.6 (110.0)
		HIHM	646.4 (125.7)	619.1 (91.5)	587.8 (77.0)	548.2 (108.0)
	Letters	LILM	481.0 (96.3)	524.1 (111.3)	504.2 (93.6)	485.9 (77.8)
		HILM	467.9 (105.4)	507.6 (136.0)	494.3 (97.1)	460.4 (92.1)
		LIHM	631.5 (116.4)	656.0 (109.7)	643.4 (74.5)	572.9 (121.0)
		HIHM	578.2 (115.0)	593.8 (124.4)	598.8 (81.9)	511.5 (108.0)
	Digits	LILM	523.0 (89.3)	561.5 (88.0)	524.7 (93.5)	525.4 (84.0)
		HILM	534.0 (108.3)	525.4 (87.0)	495.0 (75.5)	490.1 (81.4)
		LIHM	661.8 (101.6)	697.1 (112.9)	640.0 (66.4)	629.1 (119.6)
		HIHM	620.9 (118.7)	620.0 (126.1)	587.8 (72.5)	566.0 (95.5)

Note. ADHD = attention-deficit/hyperactivity disorder. RD = reading disorder. LILM = low inhibition low memory condition; HILM = high inhibition low memory condition; LIHM = low inhibition high memory condition; HIHM = high inhibition high memory condition.

亦 勳 佫 县 叁 式

1   2   3   4   5   6

Figure 1. Meaningless symbols used in the visual modality of the Go/no-go task. Symbols 1 to 3 represent the Go stimuli. Symbols 4 to 6 represent the No-go stimuli.