Processing Speed and Working Memory Performance in Those with Both ADHD and a Reading Disorder Compared with Those with ADHD Alone

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Accepted 30 March 2011

Abstract

In previous studies, children with both Attention-Deficit Hyperactivity Disorder (ADHD) and a Reading Disorder were found to have more difficulties with processing speed, working memory, and timed as opposed to non-timed executive functioning (EF) measures when compared with those with either disorder alone. The current study found that older adolescents and adults with both disorders also had more difficulties on processing speed and working memory measures than individuals who only had ADHD. There were no differences among non-timed EF scores. These results add support to the premise that common underlying features may be contributing to the high co-morbidity between these disorders and associated cognitive weaknesses.

Keywords: Attention-deficit hyperactivity disorder; Reading disorder; Processing speed; Working memory; Neuropsychological assessment and cognition

Introduction

There is a high co-morbidity between attention-deficit hyperactivity disorder (ADHD) and reading disorders (RDs) with most estimates between 25% and 60% of individuals with ADHD meeting both criteria (McGillivray & Baker, 2009; Roy-Byrne et al., 1997). Possible hypotheses to explain this include cross-assortment in which individuals with one or both disorders are more likely to produce offspring together (Faraone et al., 1993); phenocopy in which those with RD are misdiagnosed as ADHD due to less work engagement (Pennington et al., 1993); cognitive subtypes in which those with both ADHD and RD have a distinct cognitive profile suggesting that there may either be a third disorder or a unique combination of the different disorders (Rucklidge & Tannock, 2002); or the high co-occurrence that arises from a common genetic etiology (Willcutt et al., 2003) that may result in an atypical brain development (Gilger & Kaplan, 2008). Though there was initial support in relatively small samples, follow-up studies generally did not substantiate cross-assortment, phenocopy, or separate disorder hypotheses (Seidman et al., 2001; Willcutt et al., 2003, 2005). On the other hand, there have been several studies suggesting that the high co-occurrence between these disorders may be due to an underlying common etiology (Willcutt et al., 2000, 2003, 2005).

From a cognitive perspective, there are a growing number of studies with children that suggest that both ADHD and RD are associated with processing speed and working memory weaknesses, with those who have both types of disorders having significantly greater problems on such measures than those with either disorder alone. For example, with respect to processing speed, all Stroop subtest scores were lower for children with both ADHD and RD compared with those with either disorder alone (Seidman et al., 2001). Furthermore, Stroop word reading and color naming speed scores were in some cases lower than inhibition scores among RD and ADHD groups (Seidman et al., 2001; van Mourik et al., 2005). Slower and more variable response
times have been found on continuous performance tests (CPTs) among those with both disorders when compared with healthy controls and other psychiatric patients, whereas there were no differences for omission or commission errors (Advokat et al., 2007). One of the largest studies to date examining both disorders (Willicutt et al., 2005) found that processing speed measures were consistently lower among those with combined ADHD and RD than those with either type of disorders alone. Though this would not explain the specific difficulty with reading, it does suggest an additive effect where some underlying difficulty may be more problematic in those with a combination of ADHD and RD than those with either disorder in isolation, at least when studied in children.

In addition to cognition studies, there are also some genetic studies that support a common underlying etiology contributing to the high co-occurrence between these disorders.

For example, chromosome 6p21 has been associated with both RDs and increased risk of ADHD (Willcutt et al., 2000). A rather large study of 233 affected siblings suggested overlapping regions (16p, 17q) for both ADHD and RD. On the other hand, areas 2p, 8p, and 15q were associated more specifically with RD; and 10q seemed specifically associated with ADHD (Loo et al., 2004), which may account for some unique features to each disorder. Twin studies have also found that processing speed and working memory both have high heritability estimates ranging from 70% to 98% (Luciano et al., 2001). Thus, genetic studies support the idea that difficulties with processing speed and working memory may be associated with underlying genetic abnormalities common to both ADHD and RD.

Similar to the genetic studies, there is evidence to suggest that individuals with both ADHD and RD may have reduced connectivity in some of the same brain regions. When compared with controls, diffusion tensor imaging found that those with ADHD had more white matter abnormalities and fewer distinct frontal-striatal-cerebellar pathways (Silk et al., 2009) along the superior longitudinal fasciculus and other anterior regions of the corona radiata (Hamilton et al., 2008; Konrad et al., 2010). RDs have been found to be associated with many of the same tract abnormalities as ADHD, in addition to disturbances of specific temporal-parietal tracts associated with reading difficulties (Deutsch et al., 2005; Klingberg et al., 2000). Such white matter abnormalities have generally been associated with working memory weakness in other neuroimaging studies (Nagy et al., 2004; Niogi & McCandliss, 2006) and slower processing speed in some clinical populations with white matter abnormalities (Denney & Lynch, 2009; Forn et al., 2008; Genova et al., 2009). Thus, neuroimaging suggests that greater difficulties with processing speed and working memory may be associated with neuroanatomical abnormalities in both ADHD and RD.

Current study

Although the research discussed above suggests that children with both ADHD and RD have greater difficulties on measures of processing speed and working memory than individuals with either disorder alone, this has not been studied in older adolescents and adults. The purpose of the current study was to explore whether processing speed and working memory difficulties were found among those with both disorders (e.g., Willicutt et al., 2005) to a greater extent than those with ADHD alone. If this is the case, then the findings may further support a common underlying atypical brain development. We hypothesized that when compared with the ADHD alone group, those with both ADHD and RD would have: (H1) slower processing speed and working memory performance on relevant subtest scores from the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III); (H2) slower performance on the Symbol Digits Modalities Test (SDMT); (H3) lower T scores on all Stroop subtests instead of just the inhibition measures; and (H4) lower T scores on both Trail Making Tests A and B instead of just Trail B. We also predicted that the combined group would have more difficulties (H5) on timed variables on the CPT Second Edition (CPT-II) than the non-timed omission and commission variables. We did not predict differences on any of the Wisconsin Card Sorting Test (WCST) scores because they are not time-dependent measures (H6).

Methods

Participants

This study was a retrospective analysis of individuals who had a neuropsychological assessment for clinical purposes. This study was considered exempt from an institutional review for under section b of §46.101 of the Department of Health and Human Services Protection of Human Subjects since we only used archival test data that had all personally identifiable information removed.

All participants were enrolled in the last 2 years of high school, college, or graduate school and were initially recommended for an in-depth evaluation by multiple instructors and/or academic support staff due to ongoing academic difficulties. As part of
the clinical evaluation, they received an in-depth neuropsychological evaluation that included a semi-structured psychiatric interview that lasted at least 1 h by an experienced clinical neuropsychologist, completion of the Brown ADD Scale by the patient and a parent or other informant, and the Symptom Checklist 90 Revised (SCL-90R; Derogatis, 1993) to additionally screen for psychiatric difficulties, and neuropsychological tests discussed more below. Individuals were excluded who had a significant neurological history, such as epilepsy, traumatic brain injury with more than 5 min loss of consciousness, and other conditions that would impact cognition.

Diagnosis of ADHD was based on the DSM-IV (American Psychiatric Association, 2000) criteria provided by the patient during the psychiatric interview with additional information collected from a collateral informant (family member) with them during the interview or during a separate phone call from an academic-based informant (teacher, advisor, etc.). There also had to be objective evidence of academic failure and reports of impairment in other areas of life. Additional corroboration was provided by the Brown ADD Scale (Brown, 2001) from the informant and patient; with a T score of >65 on the attention deficit disorder scale (ADDS) Total Score required to meet inclusion for an ADHD diagnosis.

A diagnosis of a RD was made only after several criteria were met. First, the individuals had to have a history of significant academic difficulty (failing and repeating courses) related to reading difficulties. They had to score at least 1 SD below average (SS ≤ 85) when compared with the normative peer group, and significantly (p < .01) lower than expected academic performance when compared with their own intellectual functioning on the Woodcock Johnson Tests of Achievement, Third Edition WJ-III (Woodcock et al., 2001), including but not limited to Word Attack, Letter-Word Identification, Reading Fluency, Spelling of Sounds, as well as the Nelson Denny Reading Test (Brown et al., 1993). Finally, they had to meet the DSM-IV criteria for a RD. The diagnoses of Mathematics or Written Expression Disorders also required a history of significant academic difficulties in the relevant areas as indicated by both the patient and collateral informants (parents, guardians, etc.), academic instructors or support staff, and significantly lower than expected scores on the relevant WJ-III subtests when compared with both peers and relative to their own intellectual functioning.

Of the cases reviewed, a total of 109 participants (62 men and 47 women) met the diagnostic criteria for either ADHD alone (n = 44) or combined ADHD and RD (n = 65). We did not differentiate among types of ADHD since the available evidence does not strongly support group differences on neuropsychological measures (Geurts et al., 2005). Very few individuals (n = 8) met the criteria of a RD without ADHD. As a result, we could not include a group who had only a RD. Most (66%) of those with a RD also had a Disorder of Written Expression, and a much smaller proportion had an additional Mathematics Disorder (15%).

The sample consisted of older adolescents and adults ranging from 16 to 55 years old (M = 22.88 years old, SD = 8.68) most of whom were white (82.6%) with smaller numbers of individuals from other ethnic groups (4.6% African American, 7.3% Hispanic, and 5.5% Asian). The average estimated intelligence according to the General Ability Index (GAI) was in the high average range (M = 116.83, SD = 10.51). A small group (20.2%; n = 22) of individuals were taking medications for treatment of ADHD (e.g., Stimulants, Strattera, or Wellbutrin) at the time of testing. Most were seeking services for diagnostic clarification (82.6%), and the rest (17.4%) were already diagnosed with either an ADHD or a RD and seeking updated testing for academic accommodations because their prior assessments were more than 3 years old.

Measures

**WAIS-III** (Wechsler, 1997). Estimates of overall intellectual functioning were based on a GAI that was the average of the Verbal Comprehension and Perceptual Organization Indices. This was used rather than the Full-Scale IQ in order to remove the effects of processing speed and working memory subtests on the overall score. The use of a GAI would also reduce some confounding effects, since the subtests from both the Working Memory and Processing Speed indices were included as dependent variables. Additionally, we used the age-adjusted scale scores for Digit Symbol, Symbol Search, Digit Span, Arithmetic, and Letter-Number Sequencing as dependent variables.

**CPT-II** (Conners, 1995). This is a measure of sustained attention that lasts approximately 14 min. It requires the examinee to press the space bar or left mouse button for every letter that appears, except X. It results in multiple scores. However, this study used the T scores for Omission Errors, Commission Errors, Reaction Time, Reaction Time Standard Error, Variability of Responses, and Beta Response Style, which indicates the degree of caution. Higher T scores are suggestive of greater problems in the respective areas. The T scores are age-adjusted.

**The Stroop Test** (Golden & Freshwater, 1998). This test has three trials. The first requires individuals to rapidly read color words. The second asks examinees to rapidly name the color of ink for groups of Xs. The third requires the subject to inhibit their natural response to read a word and instead state the color of the ink in which the word was printed. The dependent variables were age- and education-adjusted T scores for each trial, based on how many items were completed within 45 s for each task. Lower scores indicate fewer items completed in the time limit.
SDMT, Written Form (Smith, 1982) is a test of information processing speed in which the participant is asked to write a number that is paired with a corresponding symbol. The dependent variable was an age- and education-adjusted \( z \)-score with negative scores indicating slower response times.

**Trail Making Test.** We used the Reitan administration method (Reitan, 1958) of the Trail Making Test. Trail A requires the participants to rapidly draw a continuous line connecting numbers in order and is primarily considered a processing speed task. Trail B requires the subjects rapidly draw a continuous line connecting alternating numbers and letters in order (e.g., 1-A, 2-B) and is considered to require processing speed, working memory, and cognitive flexibility. Dependent variables were \( T \) scores that were corrected for age, education, gender, and ethnicity using the Heaton Norms (Heaton et al., 2001). Lower \( T \) scores indicate a slower completion speed.

**WCST** (Heaton et al., 1993). This is a test of novel problem-solving and cognitive flexibility. The 128 card computerized version was used for this study. The demographically (age, education, gender, and ethnicity) adjusted \( T \) scores (Heaton et al., 2001) for Perseverative Errors, Non-Perseverative Errors, and Percent of Conceptual Level Responses were used as dependent variables.

**Results**

**Participant group differences**

\( \chi^2 \) analysis did not reveal any diagnostic group differences for gender, ethnicity, medication use, and reason for referral. One-way ANOVAs did not reveal any group differences on SCL-90R \( T \) scores, or Brown ADD Scale \( T \) scores. Further analysis of the SCL-90R is not included, since it was not the focus of this article and we only discuss it to ensure there were no objective group differences in reported psychopathology. More detailed analysis of the Brown ADDS scores are also not discussed because they were used to assist in diagnosis, and individuals were only included if their scores were considered clinically elevated \( (T \geq 65) \), thereby restricting the range.

A MANOVA indicated overall significant differences were found among age, education, and GAI according to diagnostic group, Wilks’ \( \Lambda = 0.91, F(3,107) = 3.48, p = .019, \eta^2 = .09 \). Follow-up ANOVAs revealed that GAI scores were significantly—\( F(1,107) = 8.28, p = .005, \eta^2 = .07 \)—higher for the ADHD alone group \((M = 119.93, SD = 9.76) \) than those with both ADHD and RD \((M = 114.29, SD = 10.50) \). The average individual from both groups had completed at least 1 year of college \((M = 13.64, SD = 2.92) \) with significantly—\( F(1,107) = 4.31, p = .040, \eta^2 = .04 \)—more education for those with ADHD \((M = 14.28, SD = 3.40) \) than both ADHD and RD \((M = 13.12, SD = 2.42) \). However, since all participants were actively enrolled in college the meaning of this difference is less relevant than for those populations who have completed their education. Though the individuals in the ADHD only group \((M = 24.39, SD = 9.78) \) were generally older than those in the ADHD/RD group \((M = 21.57, SD = 7.54) \), this difference was not significant.

Since there were significant group differences for GAI, we examined the relationship between the GAI and dependent variables using the Pearson correlation coefficients. Most dependent variables were significantly associated with GAI (Table 1). The only variables not correlated with GAI were the CPT-II scores of Omissions and Commissions and WCST-II scores of Perseverative Errors and Conceptual Level Responses.

**Group differences on cognitive measures**

A multivariate analysis of covariance (MANCOVA) was used to determine which dependent variables differed according to the diagnostic group (fixed factor) while controlling for the GAI. We used GAI as a co-variable due to diagnostic group

| Table 1. Significant correlations of dependent variables with GAI |
|-------------------|-------------------|-------------------|-------------------|
|                   | \( r \)            | \( p \)            | \( r \)            | \( p \)            |
| Digit Span        | .35               | <.001             | Trails A          | .26               | .006             |
| Arithmetic        | .55               | <.001             | Trails B          | .29               | .002             |
| Letter Number S   | .40               | <.001             | CPT-II Reaction Time | -.30          | .002             |
| Symbol Search     | .41               | <.001             | CPT-II Hit RT SE | -.30              | .002             |
| Coding            | .27               | .004              | CPT-II Variability | -.25            | .008             |
| Stroop Words      | .21               | .032              | CPT-II Beta Response S | -.27           | .004             |
| Stroop Color      | .22               | .022              | SDMT Written     | .30               | .002             |
| Stroop Color-Word | .33               | .001              | WCST Non-Pers. Errors | .25            | .023             |

*Notes:* GAI = General Ability Index; CPT = continuous performance test; SDMT = Symbol Digits Modalities Test; WCST = Wisconsin Card Sorting Test.
differences and significant correlations with the dependent variables. Though the groups differed for education, we did not use it as a co-variable because it was significantly correlated with GAI ($r = .40$, $p < .001$), had weaker significance and effect size than GAI, did not really differentiate demographic variables since all participants were actively pursuing their education, and most dependent variables (except CPT-II and WAIS-III subtests) were corrected for age and education.

A preliminary analysis supported the homogeneity of slopes assumption indicating that there was not an interaction between the dependent and covariate variables. The MANCOVA indicated that significant differences were found among the dependent variables according to the diagnostic group, Wilks’ $\Lambda = 0.69$, $F(20,87) = 2.39$, $p = .004$, $\eta^2 = .31$, and the covariate of GAI Wilks’ $\Lambda = 0.59$, $F(20,87) = 3.76$, $p < .001$, $\eta^2 = .42$. All the significant results are shown for each dependent variable on Table 2, which indicates that individuals with both RD and ADHD had significantly lower scores on the processing speed and working memory subtests from the WAIS-III, all the Stroop subtests, Trail A and B subtests, SDMT, and the timed variables of the CPT-II. There were no significant group differences for WCST variables or the non-timed omission and commission CPT-II variables. Post hoc tests were not required since there were only two levels of the independent variable.

**Discussion**

Prior research has suggested that the high co-morbidity among children for ADHD and RD may be due to underlying features that are common to both disorders (Willcutt et al., 2000, 2003, 2005). This appears to support an additive effect where those with both RD and ADHD had greater processing speed and working memory difficulties than those with either disorder alone (Willcutt et al., 2005). The current study was consistent with prior research and the current hypotheses.

Specifically, we found that all the processing speed and working memory scores from the WAIS-III and CPT-II were significantly lower for those with both disorders than ADHD alone which was consistent with the first hypothesis. Similarly, SDMT scores were significantly lower for the combined than the ADHD alone group which supported the second hypothesis. Though the $T$ scores were rather close for all three subtests for those with both ADHD and RD, those with only ADHD had their lowest Stroop score on Color Naming, whereas the highest mean $T$ score was for the Color-Word Naming subtest which is supposed to measure inhibition. This was consistent with prior research indicating that the inhibition score was less sensitive to ADHD than the color naming and word reading scores (van Mourik et al., 2005).

Interestingly for the fourth hypothesis, the Trail Making Test had a similar tendency as the Stroop. Specifically, both Trails A and B were significantly lower for the ADHD/RD combined group when compared with the ADHD only group. However, the actual mean scores for Trail B were higher than Trail A for both diagnostic groups. Though some may find this surprising,

| Table 2. Dependent variables marginal means and MANCOVA* |
|---------------------------------|-----------------|-----------------|------|------|-----------------|
| **Dependent variable**          | **ADHD ($n = 44$)** | **ADHD + RD ($n = 65$)** | **MANCOVA results** |
|                                 | $M$ | $SE$ | $M$ | $SE$ | $F(2,105)$ | $p$-value | $\eta^2$ |
| WAIS-III                        |     |      |     |      |            |           |        |
| Arithmetic                      | 11.53 | 0.34 | 10.54 | 0.31 | 25.67 | <.001 | .33 |
| Symbol Search                   | 10.96 | 0.32 | 9.50 | 0.29 | 17.35 | <.001 | .25 |
| Digit Span                      | 10.57 | 0.37 | 9.27 | 0.33 | 11.22 | <.001 | .18 |
| Letter Number Seq               | 10.09 | 0.41 | 9.33 | 0.48 | 10.84 | <.001 | .17 |
| Digit Symbol Code               | 10.00 | 0.35 | 8.42 | 0.32 | 10.04 | <.001 | .16 |
| CPT-II Reaction Time            | 42.82 | 1.65 | 46.90 | 1.49 | 7.03 | .001 | .12 |
| Hit RT Standard Error           | 55.37 | 2.03 | 54.67 | 1.82 | 5.28 | .007 | .09 |
| CPT Variability                 | 54.44 | 1.75 | 53.59 | 1.58 | 3.66 | .029 | .07 |
| CPT $\beta$ Response Style     | 50.61 | 1.62 | 51.71 | 1.46 | 4.41 | .015 | .08 |
| Stroop Words                    | 45.82 | 1.14 | 41.31 | 1.03 | 6.67 | .002 | .11 |
| Stroop Colors                   | 43.49 | 1.23 | 40.02 | 1.11 | 4.88 | .009 | .08 |
| Stroop Color Word               | 48.00 | 1.48 | 41.62 | 1.33 | 11.86 | <.001 | .18 |
| Trail A                         | 44.40 | 1.24 | 41.97 | 1.12 | 4.92 | .009 | .09 |
| Trail B                         | 49.18 | 1.38 | 44.78 | 1.24 | 7.82 | .001 | .13 |
| SDMT $Z$ score                  | $-0.52$ | 0.146 | $-0.92$ | 0.131 | 7.26 | .001 | .12 |

Notes: MANCOVA = multivariate analysis of covariance; ADHD = Attention-Deficit Hyperactivity Disorder; SDMT = Symbol Digits Modalities Test; RD = reading disorder; GAI = General Ability Index; CPT = continuous performance test.

*Covariate value is based on GAI = 116.83.
the empirical literature has not consistently found Trail B to be better than Trail A in differentiating these groups. Specifically, while some meta-analyses have at most, found a minimally larger effect size for Trail B than Trial A (Boonstra et al., 2005; Hervey et al., 2004), this difference is negligible. Furthermore, some of the individual empirical articles within these meta-analyses found larger difference for Trails A than B (e.g., Holdnack et al., 1995), and other articles have found no difference when comparing healthy controls with those with ADHD on any Trail Making Subtest (Riccio et al., 2005). Regardless, the theoretically less complex processing speed measure was relatively lower than the task with higher executive functioning (EF) demands for both groups; implying that at least in this group, with higher than typical intelligence and education, that processing speed variables may be more sensitive to ADHD alone or in combination with a RD than more complex EF tests.

The CPT-II results supported the fifth hypothesis with significantly lower scores among all the timed variables; whereas there were no differences on the non-timed omission and commission scores. This was consistent with a prior study that found both ADHD and RD were associated with greater difficulties on timed CPT-II variables (Advokat et al., 2007). Finally, there were no differences between groups on the WCST variables which supported the sixth hypothesis. These results lend credence to the idea that non-timed measures of EF are less sensitive to the type of difficulties associated with ADHD or ADHD and RD combined. This may help explain the reason for inconsistent findings in the ADHD literature where differences between the WCST and healthy controls is not consistently found (Geurts et al., 2005; Roth & Saykin, 2004).

Beyond simply examining significance and effect sizes, these results raise some practical clinical concerns. First, it is important to note that none of the marginal means subtest scores for those with only ADHD actually went below the average range, though they were all at least 1 SD below the estimated intellectual functioning according to the GAI. This is despite the fact that all participants scored within the clinical range on the Brown ADD Scale on self and informant reports and clinical interview information. This is consistent with research (Barkley & Murphy, 2010; Riccio et al., 2005) that suggests that self-reported measures of EF are typically more consistent with an ADHD diagnosis than performance-based measures of EF which may not differ than healthy controls among young adults.

Though not significantly below average, it is worth noting that the lowest scores for individuals within the ADHD only group for both the Stroop and Trail Making Tests were on the more basic processing speed measures (Trail A and Color Naming), whereas they performed about a half a standard deviation higher on the subtests considered to tap more complex working memory (Trail B) and inhibition (Stroop Color-Word). Furthermore, the scores in the “low-average” range for the combined ADHD/RD group were only on timed measures (all three Stroop subtest, Trail A, and SDMT), whereas measures that were primarily working memory and all the non-timed EF measures were solidly in the average and higher ranges. These findings might suggest that processing speed and timing difficulties may underlie many of the problems found in both ADHD and RDs, more than EF components. Though not entirely consistent with the ADHD theories that focus on difficulties with inhibition (Barkley, 1997a, 1997b), working memory (Pennington & Ozonoff, 1996), delaying gratification (Sonuga-Barke et al., 1992), or a more general EF (Brown, 2002); the empirical literature does suggest that timed cognitive tests tend to be more sensitive and specific to ADHD (Hervey et al., 2004; Holdnack et al., 1995; Roth & Saykin, 2004) and RD (Advokat et al., 2007; Seidman et al., 2001; Willicutt et al., 2005) than non-timed measures of impulse, sustained attention, and other EF.

While individuals with ADHD and RD may certainly be observed to have prominent EF difficulties, the available genetic (Loo et al., 2004; Luciano et al., 2001; Willicutt et al., 2000, 2003) and diffuse tensor neuroimaging research (Klingberg et al., 2000; Silk et al., 2009), along with the relationships these have with processing speed and working memory difficulties, suggest that at least some of these symptoms may arise from white matter abnormalities. This hypothesis receives additional support from studies in which individuals with multiple sclerosis (MS) have remarkably similar profiles on the Stroop and Trail subtests as those with ADHD and RD (Denney & Lynch, 2009; Krupp et al., 1994), with executive dysfunctions attributed more to asynchronous communication due to white matter abnormalities than specific frontal-subcortical abnormalities (Arrondo et al., 2009; Forn et al., 2008; Sepulcre et al., 2006). Furthermore, similar frontal-subcortical abnormalities found on functional neuroimaging for ADHD (Filipek et al., 1997; Roth & Saykin, 2004) are also present among those with MS (Genova et al., 2009), even though the latter disorder clearly arises from white matter abnormalities rather than prefrontal lobe dysfunction. These results in conjunction with the aforementioned studies support the premise that weaknesses in processing speed and working memory found in those with both ADHD and RD may arise from underlying common white matter and genetic abnormalities.

Limitations

Although these results generally support the hypotheses, there are some limits to this current study and how the results may be generalized. First, all of these individuals were clinically referred and not part of a random sample. They were not representative of the “typical” individual with ADHD or RD in that they were well-educated and had above average intellectual...
functioning. Most were either currently enrolled or were considering enrollment in college or graduate school. Thus, these findings should be investigated further with a wider variety of young adults, including those who did not attend college and/or of more average intelligence.

Furthermore, the fact that most of these individuals were attending college would suggest that their degree of EF, in general, would be less problematic than those who have difficulty holding a job (Barkley & Murphy, 2010). Though there are numerous findings within the literature for individuals with more variable background to suggest that processing speed is a consistent problem in those with ADHD (Hervey et al., 2004; Holdnack et al., 1995), more research needs to be done in diverse populations. Thus, future studies designed to examine the additive effects of ADHD and RD on processing speed and other cognitive functions should seek more diverse populations, randomized samples, and include a wider variety of cognitive measures.

Another weakness was that we did not include a group of individuals with a RD alone. This was due to a practical limitation whereby few of those tested were found to have a RD and not ADHD. Though not formally analyzed in the current study, a large percentage of those who met the criteria for both groups had previously been identified with only a RD. The reason for the diagnosis of ADHD not previously being given, might be because prior assessments were educational in focus using primarily achievement tests within the school district with less focus on EF or non-learning disorder psychological factors. These and other factors may imply that the co-morbidity of those with a RD and ADHD may be even higher than available published studies suggest. Thus, while future studies should strive to include a RD alone group; additional research examining the prevalence of missed diagnoses of ADHD among those previously identified with a Reading or other Learning disorder would also be important.

Another potential limitation is that we did not use formal measures of malingering. At the time, these data were collected such formal measures were less commonly used; however, a few recent studies (Booksh et al., 2010; Sollman et al., 2010) have suggested that college students are able to malinger ADHD symptoms, with self-report measures of ADHD being the easiest to simulate followed by some performance measures. Despite this, the sensitivity of formal malingering measures was modest, at best, in identifying malingering students. Interestingly, CPT-II performance was found to be more related to motivation than ADHD symptoms (Sollman et al., 2010). The fact that most our participants performed relatively within normal limits on the CPT-II may add actually support to the validity of their diagnoses of ADHD. In addition, we used multiple sources of information for diagnoses which has been recommended (Booksh et al., 2010) to reduce the success of malingering symptoms of ADHD in college students. Thus, while formal measures were not used, we are reasonably confident that those diagnosed with ADHD truly had the disorder. Regardless, the use of malingering measures in future studies would help to improve confidence of valid diagnoses in ADHD samples.

A final limitation worth noting is that this study did not include a healthy control group. Instead, we used demographically adjusted scores that were based on healthy controls. Some of the healthy control normative data sets used different samples. Specifically, the Heaton normative data (Trails, WCST) were based on age-, gender-, education-, and demographically adjusted scores; the Stroop and SDMT were based on age- and education-adjusted scores; and the CPT-II and WAIS-III were based on age-adjusted scores. This may contribute to some normative score differences. On the other hand, this limitation also has the strength of making these results more relevant to clinical practice since we employed the same normative data used by many clinicians. Furthermore, even if one were to argue that some of the differences may be due to normative groups, it is worth noting that the same normative sample was used for some non-timed EF measures (WCST) and timed measures (Trails) with greater differences found on the timed measures. Furthermore, Trail A was still relatively lower than Trail B for both the groups, which not only used the same normative data, but has similar task demands though with less working memory requirements. Thus, while the lack of a local group of healthy controls was a limiting factor, these findings still support the hypotheses.

Conclusions

These results support the hypothesis that those with both ADHD and RD will have more difficulties with processing speed and working memory than those who have only ADHD. Although this study did not include any neuroimaging, the findings have some similarities to clinical populations with known white matter abnormalities. Furthermore, other studies have shown an association between atypical white matter and cognitive difficulties associated with ADHD (Konrad et al., 2010) and learning disorders (Keller & Just, 2009; Klingberg et al., 2000). The possibility that white matter abnormalities may be associated with both ADHD and RD has some practical implications. For example, abnormalities of white matter pathways may be amenable to improvement in response to cognitive remediation programs (Keller & Just, 2009) and medications (Castellanos et al., 2002). Further study should include healthy controls, more diverse populations, and seek to correlate processing speed difficulties with the degree of white matter abnormalities with diffusion tensor imaging among those with RD and ADHD.
Conflict of Interest

None declared.

References


