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The Double Deficit Hypothesis in a College-Level Sample: Sex Differences, Comorbid ADHD, and Academic/Neuropsychological Profiles

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THE DOUBLE DEFICIT HYPOTHESIS IN A COLLEGE-LEVEL SAMPLE:

SEX DIFFERENCES, COMORBID ADHD, AND

ACADEMIC/NEUROPSYCHOLOGICAL PROFILES

by

SUSAN KAY STERN

Under the Direction of Mary K. Morris, Ph.D.

ABSTRACT

The Double Deficit Hypothesis posits that four mutually exclusive subgroups can be identified in a reading disabled (RD) sample. These subgroups are predicted to differ on reading measures, and further evidence suggests they may differ on other academic achievement (AA) and neuropsychological (NP) measures, as well as sex ratios and rate of ADHD diagnosis. Two hundred twenty six college-level adults identified as RD were evaluated, and subgroup comparisons were analyzed. Significant subgroup differences were observed in each domain. No subgroup differences were observed for sex or ADHD diagnosis. Findings suggest that patterns of linguistic ability affect the profiles of reading, AA, and NP performance that characterize adults with RD. These findings have implications for evaluations and academic accommodations.

INDEX WORDS: Reading disability, Double deficit hypothesis

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DEDICATION

I would not be where I am today if it were not for my wonderfully supportive parents, Dr. Sam and Renee Stern, who provided me with everything I could ever need to succeed. I am forever grateful to them for their love, support and guidance. I would also like to thank my brothers, Steve and Matt, who have offered encouraging words to me whenever they could during my hardest times. I would also like to thank Kyle Weber, who provided me with a never ending supply of support, motivation, and love when I needed it most.

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INTRODUCTION

Much of the research on reading disabilities (RD) has investigated the etiology and predictors of the disorder and the remediation of resulting academic problems. As such, much of the research in the field of RD has been conducted on young children. Traditionally, RD was viewed as “unexpected” under-achievement and diagnosed based on a discrepancy between IQ and reading achievement (Fletcher, Morris & Lyon, 2003, p. 30; Swanson and Sáez, 2003, p. 183). Those that qualified based on this criteria received formal special education services; however, poor readers with no discrepancy, also known as “garden-variety” reading-impaired or “low achievers,” received less systemic assistance. Studies have since shown that there is no fundamental difference in phonological awareness between discrepancy-based and garden-variety dyslexic children (Fletcher et al., 1994; Stanovich & Siegel, 1994). Both groups experience impairments in phonological processing, regardless of aptitude-achievement discrepancies.

Considerable amounts of convergent data have been collected over the past 30 years on the phonological basis of reading disabilities (e.g., Brady & Shankweiler, 1991; Bruck, 1992; Catts, 1991; Goswami & Bryant, 1990; Olson, Wise, Conners, & Rack, 1989; Pennington, Van Orden, Smith, Green, & Haith, 1990; Perfetti, 1985; Snowling, 1991; Vellutino & Scanlon, 1987). Phonological awareness (PA) refers to one’s ability to recognize the component sounds that make up words, such as phonemes or syllables, and to manipulate them. Deficits in PA are strongly predictive of decoding difficulties for both words and nonwords (Rack, Snowling, & Olson, 1992). Poor PA may lead to secondary problems with vocabulary development and reading comprehension (Stanovich, Cunningham, & Feeman, 1984; Wagner & Torgesen, 1987).

Several studies have attempted to delineate the course of PA development over time. Bruck (1992) demonstrated that dyslexic readers improve in PA over time, but never advance to the level of PA skills comparable to normal readers, regardless of advances in age or reading level, while normal readers improve with age and reading level. Bruck's study included children diagnosed with RD, aged 8 to 16 years old, and adults, ranging in age from 19 to 27, who were diagnosed with RD in childhood. Both groups were compared to age- and reading level-matched normal readers. Children and adults with dyslexia performed below age-expected levels on most measures of PA. When adult dyslexics, who read above a 7th grade reading level, were compared to Grade 3 normal controls, who read at a 5th grade level, the adults still performed below expectation on measures of PA and demonstrated more errors than Grade 3 controls on measures of phoneme segmentation. Thus, Bruck demonstrated that young adults diagnosed with dyslexia as children do not seem to develop PA appropriate for their age or reading level. Pennington, Van Orden, Smith, Green, & Haith (1990) also observed persistent PA deficits in 30 adult dyslexics. These studies suggest that PA deficits persist in adults with dyslexia.

Denckla (1972) and Denckla and Rudel (1974, 1976) showed that the speed with which one can name visually presented serial or continuous stimuli, such as common objects, colors, letters, and digits, also was related to reading skill. This ability to rapidly and serially produce the correct label for a visual stimulus is known as *visual naming speed* (VNS; also commonly referred to as rapid naming). A common method for assessing VNS difficulties is via the Rapid Automatized Naming test (RAN; Denckla, 1976). RAN consists of 5 stimuli in a given category (letters, digits, colors, or objects) presented 10 times in a random order and requires rapid recognition and retrieval of the names of visually presented stimuli. Denckla and Rudel (1976) found that children with RD were significantly slower on all RAN subtests when compared to normal readers and non-dyslexic children with learning disorders. Furthermore, RAN was sensitive to the severity of RD, distinguishing mildly impaired readers from severely impaired readers. The decreased rate of naming was not due to generalized slow processing speed, as demonstrated by a greater mean performance IQ in the dyslexic group. This method of testing naming abilities is different from confrontation naming tasks that present discrete objects one at a time for a person to identify. Instead, it is a timed, serial, continuous task that requires rapid and fluent retrieval skills.

At about the same time as Denckla and Rudel’s findings, LaBerge and Samuels (1974) published a theory of automatic information processing. Their theory proposed that automaticity, in addition to accuracy, is essential for satisfactory reading skills; it allows one to allocate attention to the content and meaning of text. The latter theory, coupled with research findings from Denckla and Rudel, initiated preliminary investigations into the role of rapid naming in the reading disabled population.

An extensive amount of literature connects rapid naming to reading. Since Denckla and Rudel’s (1976) development and study of RAN, many others have investigated the relationship between rapid naming of letters, digits, objects, and/or colors and reading skills. Studies have demonstrated that rapid naming is significantly correlated with a broad range of reading skills, such as sight word identification (Ackerman & Dykman, 1993; Badian, 1993; Catts, 1991; Cornwall, 1992; McBride-Chang & Manis, 1996; Wolf, O’Rourke, Gidney, Lovett, Cirino, & Morris, 2002), nonword decoding (Bowers & Swanson, 1991; Chiappe, Stringer, Siegel, & Stanovich, 2002; Wolf et al., 2002), and untimed comprehension (Bowers & Swanson, 1991; Manis, Doi, & Bhadha, 2000; Spring & Davis, 1988; Wolf et al., 2002).

Other studies have found that rapid naming is predictive of later sight word identification (e.g., Cornwall, 1992; Meyer, Wood, Hart, & Felton, 1998b). Interestingly, Meyer et al. (1998b) found that rapid naming measures administered in the 3rd grade significantly predicted single word identification in 5th and 8th grade, but only for the poorest readers (the bottom 13% of the sample). When the authors looked at a separate sample of only poor readers, the predictive relationship was even stronger between rapid naming and word identification. After controlling for SES and IQ in the latter sample, Meyer and colleagues found that RAN measures still significantly predicted word identification in 5th and 8th grade. However, RAN measures did not predict timed or untimed reading comprehension in this sample.

The persistence of rapid naming deficits into adolescence and adulthood has been supported in the few studies available in older populations. Meyer, Wood, Hart, & Felton (1998a) investigated the evolution of VNS through the eighth grade. The study enrolled 160 children across reading levels in public schools from the first through eighth grades. Students were classified as in the lower, middle, or top group of readers according to their performance on two single-word reading measures. Meyer and colleagues reported a naming speed floor-effect as naming speeds approached an asymptote from the first to eighth grade across all reading levels. They also observed that the initial differences in RAN times between groups became smaller and smaller as they approached the eighth grade, however, the lower-level reading group reliably had slower naming times. This demonstrates that while poor readers may increase their naming speed skills, they do not improve to the point of parity with average readers.

Wolff, Michel, & Ovrut (1990) compared RAN performance in a sample of 50 adolescents and 41 young adults with documented RD to age-matched non-dyslexic controls. Repeated measures ANOVAs were conducted to determine differences in continuous RAN speeds between groups (RD vs. Non-RD) and conditions (colors vs. objects). Main effects were found in both the adolescent and adult samples for group (RD slower than Non-RD) and condition (RAN-objects slower than RAN-colors). Wolff et al. noted faster rapid naming scores in adults than adolescents, but the RD participants in both groups still performed significantly worse than a non-RD comparison group, consistent with Meyer et al.'s (1998a) results. Wolff et al. further examined naming speed abilities in a separate sample of adults with well-documented histories of dyslexia who were "remediated," operationalized as reading at a twelfth-grade reading level or above on the Gray Oral Reading Test. When compared with unremediated readers, who read below a seventh grade level, and non-dyslexic adults, the remediated readers differed significantly from the non-dyslexic group and exhibited no differences in naming speed from the unremediated RD group, providing further support for the persistence of VNS deficits.

Support for the persistence of VNS deficits has been reported in older adult populations, as well. Felton, Naylor, & Wood (1990) found that adults (mean age of 33.1 years), who were identified in childhood as RD, exhibited significantly slower times on measures of rapid naming when compared to adults identified in childhood as normal readers or borderline poor readers. They also observed that a childhood reading history successfully predicted performance on rapid naming as an adult, independent of childhood and adult intelligence, educational level, and socioeconomic status.

Other studies have directly investigated the relationship between VNS and reading skills in adults. Miller and colleagues (2006) found that rapid naming was a statistically significant predictor of reading achievement (i.e., word identification, word attack, and oral reading skills) in parents of children referred for dyslexia.Vukovic, Wilson & Nash (2004) investigated rapid naming in a group of 25 college-age adults recently diagnosed with RD who scored below the

27th percentile on a timed measure of reading comprehension (Nelson-Denny Reading Test). They concluded that rapid naming added no significant variance to reading comprehension after controlling for reading rate. However, these results may be misleading. The study systematically excluded any participants with moderate comprehension skills or better resulting in a restricted range. No correlations were reported to determine the extent to which rapid naming is associated with reading rate or reading comprehension. For example, if rapid naming and reading rate are highly intercorrelated, any significant contribution of VNS to reading comprehension may be statistically removed when reading rate is controlled, due to the shared variance.

Some reading researchers have argued that VNS is merely a facet of PA, sometimes called “phonological code retrieval” (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). However, more recent evidence has supported the proposal that naming speed may be a separate source of disability (e.g., Bowers & Wolf, 1993; Meyer et al., 1998a, 1998b; Wolf, 1991, 1997). A recurrent finding in the literature is the lack of a strong correlation between PA and VNS measures. In fact, most studies report only modest relationships (e.g., ranging from $r = .10$ to $r = .40$) (Blachman, 1984; Compton, DeFries, & Olson, 2001; Swanson, Trainin, Necoechea, & Hammill, 2003; Wolf & Bowers, 1999). Cornwall (1992) reported a modest correlation ($r = .35$, $p < .05$) between rapid letter naming and phoneme deletion in a sample of 7-12 year olds. She argued that “these abilities may represent unique aspects of the reading process, as opposed to an overall phonological ability” (p. 537). Felton and Brown (1990) found no significant correlation between rapid naming and phonological processing measures in a sample of at-risk kindergarteners and first-graders. Similarly, Goldberg, Wolf, Cirino, Morris and Lovett (as cited in Wolf & Bowers, 1999) found no significant relationship between phoneme elision and blending tasks and rapid naming ($r =$

.12) in a selected sample of severely impaired readers. However, in a larger sample, Wolf et al. (2002) found significant, but modest, correlations between phonological tasks (phoneme elision and blending) and naming speed (r = .28, p < .001 and r = .25, p < .001, respectively). These authors conclude that while "phonological processes occupy a critical, limited role in the ensemble of multiple lower-level perceptual, lexical, and motoric processes that make up naming," their findings do not "support a view in which naming speed, as measured by RAN tasks, is subsumed under the rubric of a phonological process" (p. 61).

Similar results were found in studies of adults. Miller et al. (2006) investigated PA and VNS in an adult sample of parents of children referred for reading difficulties. They found modest, but significant, correlations between rapid naming and PA measures (ranging from r = -.21 to r = -.43). In a college-level sample, Cirino, Israelian, Morris, & Morris (2005) reported a correlation of r = .13 (p > .05) between PA composite and VNS composite scores.

Additional support for the independence of VNS and PA is offered through the use of regression methods. Regression analyses have been utilized to demonstrate the unique input contributed by PA and VNS in the prediction of reading skills (e.g., Compton et al., 2001; Cornwall, 1992; Felton & Brown, 1990; Wolf et al., 2002). Wolf et al. (2002) found that VNS accounted for more variance in word identification, while PA contributed more variance when predicting nonword reading. These findings raise the possibility that VNS may account for more variance than PA in select reading measures.

Compton and colleagues (2001) utilized hierarchical regression analyses to investigate PA and VNS and their relationships with decoding skills. They utilized archival data from a large-scale twin study of children ranging in age from 8 to 18. Only the 476 children who met study criteria for RD (1.5 SD below age-matched peers on a composite measure of word recognition skill) were included in their analyses. They found that PA accounted for the largest proportion of variance in measures of nonword reading, while VNS accounted for the most additional variance (above and beyond the variance accounted for by PA) on a timed word reading measure. Compton and colleagues did not find support for an interactive effect on PA and VNS on reading and spelling measures and concluded that the deficits associated with PA and VNS deficits are additive.

While studies of decoding suggest that the contributions of PA and VNS may vary based on the type of decoding task being predicted (i.e., PA may be more strongly associated with nonword decoding while VNS may be more strongly associated with word decoding), studies including reading comprehension as a reading outcome are inconsistent. Cornwall (1992) observed only a PA contribution to reading comprehension, while Compton et al. (2001) and Wolf et al. (2002) found unique contributions of PA and VNS. No studies utilizing timed reading comprehension are available in children.

Allor (2002) reviewed 16 studies that utilized multivariate statistics to investigate the predictive ability of PA and VNS measures for reading in children, both normal and poor readers. She found that, while not as consistent as PA, rapid naming significantly and uniquely contributed to reading skills in the majority of studies. A significant contribution for visual naming speed was most consistent for word identification. She also noted that rapid naming may be most important in the early stages of reading development. For example, Wagner and colleagues (1997) observed that unique contributions of rapid naming were significant in predicting word identification from kindergarten to second grade and from first to third grade, but not from second to fourth grade.

Cirino et al. (2005) investigated the relative contribution of PA and VNS on timed and untimed decoding and comprehension measures in a college-level sample of adults referred for evaluation of academic difficulties. They found that PA accounted for a significant portion of the variance for every measure. VNS also accounted for significant additional variance on all measures except for untimed reading comprehension. The strength of contribution depended on the nature of the stimulus (word vs. nonword), the nature of the task (timed or untimed), and the type of reading skill (single word identification vs. comprehension). PA contributed more variance than VNS to untimed decoding, while PA and VNS contributed similarly for timed nonword decoding. However, VNS contributed more variance than PA for timed word decoding, with effect sizes of more than half of a standard deviation. With regard to comprehension, only PA predicted untimed reading comprehension but both PA and VNS significantly contributed unique variance to a timed comprehension measure.

Classification

Based on previous findings that suggested PA and VNS serve as separate and additive sources of impairment in children with RD, Wolf and Bowers (1999) proposed the double-deficit hypothesis (DDH). It posits that VNS represents a second core deficit of dyslexia, relatively independent of PA. The underlying assumption is that four unique groups would emerge from a sample of readers: those with no deficits in PA or VNS (ND), those with PA deficits only, those with VNS deficits only, and those with both PA and VNS deficits (double deficit; DD). The theory hypothesizes that those with combined deficits would have the most severe reading impairment, and those with a single deficit would have more impairment than those with none.

In an attempt to provide support for the DDH, Wolf (1997) and Bowers (1995, as reported in Wolf & Bowers, 1999) each reanalyzed previously obtained and published data to determine if the four hypothesized subgroups could be identified. Wolf's study re-examined cross-sectional data in a sample of school-aged children between kindergarten and fourth grade. The study used a cut-off of one standard deviation below the mean for PA (nonword decoding) and VNS (letter or digit naming) measures to divide the sample into four subgroups: PA only deficit, VNS only deficit, double deficit (DD), and no language-based deficit (ND). Bowers' study re-examined data from a previously reported longitudinal sample of similarly characterized children in Canadian schools. They identified the same four subgroups using the 35th percentile as a cut-off on measures of PA (Auditory Analysis Test) and VNS (digit naming). Despite utilizing different measures of PA and cut-offs, both investigators identified four subtypes within their samples of average and poor readers. They then compared subgroups on reading measures.

The results of these studies yielded similar findings with regard to the subgroups. The ND group performed in the normal range on both PA and VNS measures and had average reading skills. The two single-deficit groups (PA and VNS) were comprised of modestly impaired readers that differed in performance on the criterion-variables. There were no significant differences between these two groups on any reading measure although the PA-deficit group had lower scores than the VNS-deficit group on all reading measures except latency-based ones. Finally, the DD group had both impaired rapid naming and phonological skills. This group was most impaired on all phonological, naming speed, and reading measures.

The classification system proposed by Wolf and Bowers was similar to a typology previously proposed by Lovett (Lovett, 1984, 1986, 1987; Lovett, Ransby, & Roderick, 1988). The subtypes outlined by Lovett were based on developmental impairments in accuracy and automaticity, the first and later phases of reading skill acquisition as delineated by LaBerge & Samuels (1974); thus, she identified these RD subtypes as accuracy-disabled and rate-disabled.

LaBerge & Samuels' theory was later refined and augmented by Ehri & Wilce (1983) to include speed as the final phase, which most accurately characterizes Lovett's rate-disabled subtype. According to Lovett, rate-disabled readers exhibit poor VNS, accurate but slow word recognition, good spelling-to dictation and phoneme-analysis skills, and problems in reading comprehension. Accuracy-disabled readers exhibit impairments associated with failures to acquire early phase reading skills; therefore, accuracy-disabled readers exhibit poor decoding, spelling, and understanding of oral language structures (PA). Because accuracy-disabled readers have limitations in the basic skills necessary for reading, a failure to acquire later, more advanced reading skills is also observed. Thus, accuracy-disabled readers demonstrate slow reading rates in addition to the deficits already described (Lovett, 1984, 1987).

Other researchers have provided further support for the existence of these DDH subgroups in impaired readers (Compton et al., 2001; Goldberg, Wolf, Cirino, Morris, & Lovett, 1998, as cited in Wolf & Bowers, 1999; Lovett, Steinbach, & Frijters, 2000; Manis, Doi, & Bhadha, 2000; Sunseth, & Bowers, 2002; Wolf et al., 2002). Goldberg, Wolf, Cirino, Morris, & Lovett (as cited in Wolf & Bowers, 1999) identified four mutually exclusive subgroups in a sample of 83 severely disabled readers using phoneme elision and phoneme blending as measures of PA and rapid letter-naming as a measure of VNS. Those classified as having a DD comprised 49% of the sample, while 29% had a VNS deficit, 14% had a PA deficit, and 8% had no deficit. No data was reported on reading outcomes. Similarly, Wolf et al. (2002) classified their severely reading disabled sample of second and third graders into DDH subgroups. They classified 60% of the sample as DD, 19% as having a VNS deficit, 15% as having a PA deficit, and 6% as having ND. Again, no data was reported on reading outcomes.

Compton et al. (2001) identified DDH subgroups in a sample of 476 8-18 year-old poor readers. Utilizing a 1 SD cutoff on criterion measures of PA and VNS, 78% of their sample could be classified into DDH subgroups with 45% identified as having a DD, 43% with a PA deficit only, and 12% with a VNS deficit only. Participants were assessed on measures of word and nonword decoding, reading comprehension, and spelling. The DD group performed significantly below the PA and VNS subgroups on all reading and spelling measures. The PA subgroup performed significantly below the VNS subgroup on a measure of nonword reading. No other differences were observed between the PA and VNS subgroups.

Manis et al. (2000) classified their sample of second-graders, who were representative of the reading abilities of the two schools from which students were recruited, into four mutually exclusive groups based on performances on RAN-digits and Sound Deletion. A 25th percentile cutoff was utilized to identify the four DDH subgroups. Out of 85 students, 58.8% were classified as ND, 9.4% as having a VNS deficit, 15.3% as having a PA deficit, and 9.4% as having a DD. The DD subgroup did not differ significantly from the VNS or PA deficit subgroups on any reading measure (i.e., word and nonword reading, reading comprehension), but did differ significantly from the ND group. The PA group also significantly differed from the ND group on all reading measures, except for the Exception Word reading task. The VNS deficit group did not differ significantly from any other subgroup. Overall, the sample did not comprise many poor readers, but of the few included in the study (those scoring below the 25th percentile on Word Identification), most were in the DD subgroup. The specific number and distribution of poor readers within the DDH subgroups was not reported.

Sunseth & Bowers (2002) recruited 201 third graders for their study, irrespective of reading abilities. Participants were classified into DDH subgroups based on their performance on a modified 29-item version of the Auditory Analysis Test (AAT) and RAN-digits. Those included in the ND group scored above the 50th percentile for the sample on both tasks, the VNS group scored below the 30th percentile for the sample on RAN and above the 50th percentile on the AAT, the PA group showed the opposite pattern of performance on the criterion measures, and the DD group scored below the 30th percentile on both tasks. Of the 201 participants, 66.2% were able to be classified: 34.3% in the ND group, 9% in the VNS group, 8.5% in the PA group, and 14.4% in the DD group. The authors randomly selected 17 and 16 participants from the initial ND and DD groups, respectively, to create approximately equal cell sizes for ANOVA comparisons. Sunseth & Bowers utilized a 2 (PA or no PA deficit) x 2 (VNS or no VNS deficit) ANOVA to analyze their data. On all reading measures (i.e., word and nonword reading, reading fluency), the ND group performed significantly better than the three deficit subgroups. The DD group demonstrated more deficient performance compared to the three other subgroups across reading measures. On a measure of individual word reading, the PA group did not differ significantly from the DD group or the VNS group, but the VNS group performed significantly better than the DD group. On nonword reading, the PA and DD groups did not differ, and the VNS group scored significantly above both former groups. The opposite was observed on a measure of reading fluency; the VNS and DD subgroups did not differ, and the PA subgroup was significantly faster than the other deficit subgroups.

Additionally, the authors examined the subgroups for those meeting a low achievement criterion for reading difficulties (below 90 on standardized tests of word and nonword reading). The ND group performed in the above average range and included no poor readers; the VNS group was 33% poor readers; the PA group was 24% poor readers; the DD group comprised 94%

poor readers, demonstrating that having a double deficit is most strongly associated with poor reading.

Lovett et al. (2000) provided further support for the DDH in a sample of children with severe reading impairment. One hundred sixty-six 7-13 year-olds were classified into three groups based on the presence or absence of the two core deficits. A PA deficit was determined if a child's average score on three phonological measures was at least 1 SD below age-norm expectations. A VNS deficit was determined if the child's times on the RAN letter and digit arrays were both more than 1 SD above age norms. Eighty-four percent of this sample could be classified with 54% demonstrating a double deficit, 22% a PA deficit, and 24% a VNS deficit.

These subgroups were compared on standardized measures of intellectual ability, language, and academic achievement, including measures of word and nonword reading, passage comprehension, oral passage reading, spelling, and arithmetic. All subgroups were impaired on the reading achievement measures but, as hypothesized, the DD group consistently performed more poorly than the other subgroups. The difference between PA and DD subgroups reached significance for measures of word reading and passage comprehension. The PA group performed below the VNS group on all measures, but this difference only reached significance for Word Attack. The VNS group was the least impaired of the three deficit groups, and performed significantly better than the DD group on every reading achievement measure. Despite the VNS deficit subgroup's advantage over the other two groups, they were still significantly impaired compared to age norms.

Lovett and colleagues (2000) also noted significant differences among the subgroups on other non-reading measures. No differences were observed in nonverbal IQ, but the VNS group demonstrated a significantly higher verbal IQ compared to the PA and DD subgroups on the

WISC-R or WISC-3. The VNS verbal advantage also emerged on a measure of receptive vocabulary. The VNS subgroup performed significantly better (although still severely impaired compared to age norms) than the DD subgroup on a spelling measure. No significant between-group differences were observed in arithmetic achievement, but as observed for reading and spelling measures, all three subgroups were impaired compared to age norms.

Lovett's findings raise the possibility that DDH subgroups may differ on other cognitive and academic measures beyond reading. Waber, Forbes, Wolff, & Weiler (2004) investigated the neurodevelopmental characteristics of the DDH subgroups in a sample of 188 children between the ages of 7 and 11, recruited from hospital outpatient programs for the evaluation of children with learning problems. Waber et al. used a nonword decoding task as a measure of phonological processing and the average of the letter and digit subtests from the RAN as a measure of VNS. A score of 1 SD or less than the age-normed mean represented a deficit. Surprisingly, Waber and colleagues found that in their sample, PA deficits (2%) almost never occured in isolation but the other three subgroups were clearly represented with 30% in the ND group, 53% in the VNS group, and 15% in the DD group.

Waber and colleagues compared these three DDH subgroups on five cognitive domains: written language, oral language, visuospatial processing, motor speed, and processing speed. Between-group analyses revealed significant differences among all three groups (ND, VNS, and DD) in the written language domain, with the ND group performing best and the DD group performing the worst. The ND and VNS groups did not differ significantly in any other domain. The DD group performed significantly worse than the ND group and VNS group on processing speed measures and visuospatial measures, respectively. No significant between-group differences were observed for the oral language and motor speed factors. It was intriguing that there were no group differences on the oral language factor because the DD subtype is defined by deficits in two language processes. The authors suggested that this may be because the measures utilized as oral language measures assessed semantic knowledge and verbal reasoning, rather than language processes affected by the criterion variables (PA and VNS).

Studies have shown that impairments in PA and VNS persist into adulthood (Bruck, 1992; Meyer et al., 1998a; Wolff et al., 1990), and yet there is a dearth of literature investigating DDH subgroups in adult samples. Cirino and colleagues (2005) are the only study to date to explore the DDH in a clinical sample of one hundred forty-six college-level adults who were referred to an on-campus assessment center for academic difficulties. The language processing measure utilized in this study to classify participants into DD subtypes was the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). PA and VNS deficits were defined by performance at least 1 SD below the normative mean on the Phonological Awareness Composite or Rapid Naming Composite. These criteria resulted in 39.7% of the sample classified in the ND subgroup, 28.8% classified in the VNS subgroup, 15.8% in the PA subgroup, and 15.1% in the DD subgroup. Similar to child samples, the DD group performed significantly worse than the ND group on all measures of reading. The DD group also performed significantly below at least one of the single-deficit groups on most reading measures, with the exception of a timed measure of reading comprehension, on which the DD group did not significantly differ from either the PA or VNS subgroup. The single-deficit groups, in turn, performed significantly below the ND group, except for an untimed reading comprehension task on which the VNS and ND subgroups did not differ. Few differences were observed between the single deficit subgroups. However, the VNS group performed more poorly than the PA group on a timed measure of word decoding.

Differences among the DDH subgroups on reading achievement measures are not completely consistent across several child studies and the one available adult study (Bowers, 1995, as cited in Wolf & Bowers, 1999; Cirino et al., 2005; Lovett et al., 2000; Manis et al., 2000; Sunseth & Bowers, 2002; Wolf, 1997). The most consistent finding across studies is that those with a double deficit are significantly more impaired on reading measures than those with no deficits in PA and VNS. In the adult study (Cirino et al., 2005), the DD subgroup was significantly more impaired than the single-deficit groups on the majority of reading measures, but this has not always been supported in child studies. Often, the PA subgroup did not differ from the DD subgroup, especially on measures of word and nonword reading. The VNS subgroup typically performs above the DD subgroup, with the exception of timed measures. The relationship between PA and VNS subgroups is also inconsistent. In general, VNS subgroups tend to perform as well, if not better, than PA subgroups, except on timed tasks (Sunseth & Bowers, 2002). In children, PA subtypes tend to be more reading impaired than VNS subtypes, although these differences are not always statistically significant. In the single study of adults, this was not observed (Cirino et al., 2005). Several researchers have suggested that those with a PA deficit are more impaired in nonword decoding than those with only a VNS deficit (Lovett et al., 2000; Sunseth & Bowers, 2002), although in the studies reviewed, this does not always hold true (Cirino et al., 2005; Manis et al., 2000). More consistent, however, is the fact that those with a single deficit evidence lower performance than those with no deficit in PA or VNS.

Double Deficit Hypothesis and Attention Deficit/Hyperactivity Disorder

Previous studies have documented increased rates of comorbid ADHD (15-26%) in samples selected for RD (Gilger, Pennington, & Defries, 1992; B.A. Shaywitz et al., 1995; S.E. Shaywitz, Fletcher, & B.A. Shaywitz, 1994). This elevated rate of comorbidity complicates differential diagnoses and treatment plans. No study to our knowledge has investigated the relationship between DDH subgroup membership and ADHD diagnosis in individuals with RD.

Waber et al. (2004) did not identify participants with ADHD in their sample of referred children, but they did investigate the prevalence of attention problems among three DDH subgroups (ND, VNS, and DD). They found no significant differences among the groups in either inattentiveness or hyperactivity, as measured by the parent and teacher versions of the Diagnostic Rating Scale (DRS), which is based on the DSM-IV. However, children with a score of more than 6 on the Hyperactivity scale of either the parent or teacher form of the DRS were excluded from the study, so the chances of significant differences with regard to hyperactivity were greatly reduced as a result of the selection process.

Several earlier studies have explored the relation of ADHD to PA and VNS, which may help elucidate how the presence of ADHD may interact with RD within the DDH framework. Brock & Christo (2003) investigated VNS in 20 children with ADHD and compared them to 20 age-, grade-, and gender-matched controls with comparable word decoding skills but without ADHD. Participants' average age was 10 years old, and males outnumbered females by more than 5:1. The authors limited their sample to participants with ADHD, Inattentive type. Spring and Capps' Digit Naming Speed test (Spring & Capps, 1974), a measure similar in design to RAN digit naming, was administered to each participant. Brock & Christo found that the ADHD group performed significantly slower than the non-ADHD controls.

Tannock, Martinussen, & Frijters (2000) found similar results to Brock & Christo (2003) in their study of children 7-12 years old, which assessed rapid letter and color naming among three groups: ADHD, ADHD+RD, and normal controls. All participants in the ADHD groups were diagnosed according to the DSM-IV. All subtypes were included, but no data was provided regarding their representation in the sample. Participants were identified as having RD based on a low achievement criterion of 1.5 SD below the mean on a measure of word identification. The ADHD group did not differ significantly from the ADHD+RD group in rapid color naming, and both groups performed significantly worse than the control group. On rapid letter naming, the ADHD group was significantly slower than controls, but significantly faster than the ADHD+RD group. Covarying for vocabulary knowledge did not alter these results, but when both vocabulary and nonword decoding were included in analyses as covariates, the differences among the three groups were no longer significant for letter naming, suggesting that it may be the presence of RD that impairs rapid letter naming performance. A limitation to this study is the lack of an RD-only group in order to try to isolate which difficulties are due to the presence of RD and which may be due to the interaction of RD and ADHD.

Semrud-Clikeman, Guy, & Griffin (2000) also compared the rapid naming skills of children and adolescents with ADHD and with RD. Participants were classified as having ADHD if their parents endorsed at least 12 symptoms of ADHD, according to the DSM-IIIR. RD was determined based on the presence of a significant discrepancy (20 standard score points or more) between the WISC-R FSIQ and a reading composite score and a significant discrepancy between FSIQ and a measure of nonword reading. The authors did not report a significant difference between participants with ADHD and controls on measures of rapid letter or digit naming, with both groups significantly faster than participants with RD. They did, however, note that both the ADHD group and the RD group performed similarly and significantly worse than the control group on rapid color and object naming.

Poor VNS performance has not been consistently observed. Felton, Wood, Brown, Campbell, & Harter (1987) found that children between the ages of 8 and 12 with ADHD-only did not differ significantly from controls on measures of VNS. Participants with ADHD were identified based on the Diagnostic Interview for Children and Adolescents (DICA). The ADHD-only and control groups completed the RAN subtests significantly faster than both RD and RD+ADHD groups. The RD and RD+ADHD groups did not significantly differ from each other, and the ADHD-only and control groups did not differ significantly from each other, suggesting that deficits in VNS are associated with RD but not ADHD.

Deficits in PA have also been reported in children with ADHD. Pennington, Groisser, & Welsh (1993) investigated PA in a sample of seventy 8-year old boys recruited from both suburban schools and clinic settings. They identified four groups, those with no ADHD or RD (controls), those with ADHD-only, those with RD-only, and a comorbid RD+ADHD group. They administered two measures of PA, Word Attack and the Pig-Latin Test. Pennington and colleagues found that, as expected, the RD groups performed significantly more poorly on Word Attack, with no difference observed between the ADHD-only and control groups. On the Pig-Latin Test, the control group performed significantly better than the RD-only and ADHD+RD groups, and the ADHD-only group performed performed significantly better than the comorbid group. The ADHD-only group did not differ significantly from the RD-only group. These results suggest that the presence of ADHD may not contribute additional impairment in PA, above and beyond the impact of RD.

Palacios & Semrud-Clikeman (2005) also found no significant difference between children with ADHD and controls on measures of PA. The participants in this study ranged in age from 11 to 15 and were selected from public and alternative schools. Most children in the ADHD group were previously diagnosed, and confirmation was attained by the Behavior Assessment System for Children (BASC). Palacios & Semrud-Clikeman observed no significant difference between the ADHD, Combined type and control participants on a PA composite score. However, the authors found a significant negative correlation between PA composite scores and the ADHD Quotient of the ADHD Test (Gilliam, 1995), raising the possibility of a relationship between PA and the number and severity of ADHD symptoms.

Tannock and colleagues (2000) also found evidence for weaknesses in PA in a sample of referred children ranging in age from 7-12 years. The authors identified three groups, an ADHD-only group, ADHD+RD group, and normal controls. Each group was administered the Word Attack subtest as a measure of PA. Tannock et al. observed significant differences among all three groups, with the ADHD+RD group performing more poorly than the ADHD-only group, which performed more poorly than the controls. As noted earlier, this study failed to include an RD-only group, so it is impossible to determine whether the poor performance by the ADHD+RD is due to the additive or interactive impact of ADHD and RD, or if it is due to the RD alone.

With so few studies exploring PA and VNS in individuals with ADHD and with comorbid RD and ADHD, and the inconsistent results obtained, it is difficult to predict how the addition of an ADHD diagnosis may influence poor readers and their cognitive presentation. Furthermore, the nature of this relationship has not been explored in an adult population. Studies to date provide stronger support for the presence of VNS deficits than for PA deficits in children with ADHD. However, there is also evidence that impairments may not be consistent across task stimuli, with deficits more likely for the rapid naming of colors and objects than for digits and letters.

Double Deficit Hypothesis and Sex

An overrepresentation of males has been noted in the literature, with 60-80% of those diagnosed with RD being boys (DSM-IV-TR, 2000; Rutter et al., 2004). Some have argued that this may be "partly an artifact of gender bias in the prediction of reading from IQ" (Share & Silva, 2003; Siegel & Smythe, 2005). Utilization of a single regression equation to identify "unexpected underachievement" would result systematic overestimation of reading scores for boys and underestimation for girls if boys have a lower mean reading performance. Siegel & Smythe present data that suggests this may be the case in young children. Others argue that the overrepresentation of males in clinic samples may be due to higher rates of comorbid ADHD of the hyperactive/impulsive subtype in boys, thus leading to more referrals due to disruptive behavior (Wilcutt & Pennington, 2000). In community and research-identified samples, the ratio of boys to girls meeting criteria for RD is approximately equal (1.2-1.5/1), compared to nearly four times that ratio in clinic samples (DeFries, 1989; Finucci & Childs, 1981; S.E. Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Wadsworth, DeFries, Stevenson, Gilger, & Pennington, 1992).

Some evidence suggests that there is a higher proportion of males in more severely reading-disabled groups. Feldman et al. (1995) studied a sample of adults with at least a three-generation family history of dyslexia and found that, while the proportion of male to female dyslexics was equivalent, the males exhibited a more severe reading impairment. This finding was supported in a recent genetic study, which demonstrated a larger ratio of males to females in individuals with more severe reading disabilities (Hawke, Wadsworth, Olson, & Defries, 2007). Feldman et al. contend that this more severe form of dyslexia may account for the higher reported incidence of referred male dyslexics. They also argue that females may develop more effective coping strategies. Support for this hypothesis is provided by their finding that 6 of 8 adults who reported a prominent history of RD in childhood but no longer met criteria for dyslexia in adulthood were females.

Sex ratios have yet to be directly addressed within a DDH framework, and few studies have reported distributions of males and females across the DDH subgroups. The Lovett et al. (2000) study is one of the few to have reported such distributions. Their sample of 166 severely reading impaired children, aged 7 to 13, comprised twice as many males (*n* = 113) as females (*n* = 53); however, the most severe subgroup (DD) had a 3:1 male to female ratio (57 males, 19 females). The VNS subgroup also had a larger male to female ratio of 2.7:1 (24 males, 9 females), while representation in the PA group was almost equal, with 16 males and 15 females.

Waber et al. (2004) also reported sex ratios within their three DDH subgroups (ND, VNS, and DD). Similar to Lovett et al. (2000), there were more than twice as many males (*n* = 128) as females (*n* = 57) in this sample of referred children with learning difficulties, aged 7 to 11. Unlike Lovett et al.'s (2000) sample, there did not appear to be significant differences in sex distribution among the three subgroups. The ND group consisted of 38 males (67%) and 19 females, the VNS group comprised 72 males (72%) and 28 females, and the DD group included 18 males (64%) and 10 females.

Little information is available on sex differences in PA and VNS abilities. Berninger, Nielsen, Abbott, Wijsman, & Raskind (2008) utilized data from a family genetics study to investigate this unexplored area. The study included dyslexic children and their parents. Children were recruited through school letters of opportunity, parent self-referrals, or referrals from professionals in the community. The average age of the children was 11 years old and grade levels ranged from first through ninth. Of the 122 children, 80 were boys and 42 were girls. All children included in the study performed below the population mean and at least one standard deviation below the Verbal Comprehension Index score from the WISC-3 on at least one achievement measure of reading rate, reading accuracy, or written spelling. Two hundred parents who met the same criteria as the children were also included. Of the 200 parents, 115 were males and 85 were females. Berninger and colleagues found no differences between RD boys and girls on RAN subtests, but found that the mothers performed significantly better than fathers on rapid color naming. Berninger and colleagues (2008) also administered three measures of PA (Elision, Phoneme Reversal, and the Nonword Memory from the CTOPP). No sex differences were observed in children for any of these measures. The parents, however, differed significantly on Elision and Nonword Memory, with females performing better than males. Thus, significant differences between males and females were only observed in adults and males tended to be more impaired than females.

Proposed Study

This study aims to support, refine, and expand current knowledge of the utility of the DDH in characterizing adults with reading disabilities. Previous research has identified four mutually exclusive subgroups based on the presence or absence of PA and VNS deficits across a variety of samples. Furthermore, evidence suggest that these subgroups exhibit distinct impairments in reading abilities based on subgroup membership. The first aim of this study is to seek support for the results reported by Cirino et al. (2005) in an independent sample of adults with reading disability drawn from the same clinical setting. DDH subgroups, based on the presence or absence of deficits in PA and VNS, will be identified and compared on multiple measures of reading skill.

Additionally, a small number of studies also have reported non-reading differences betweeen these subgroups (e.g., Lovett et al., 2000; Waber et al., 2004), in areas such as timed arithmetic and spelling achievement, visuospatial skills, processing speed, and verbal abilities. The proposed study will compare the DDH subgroups on a set of achievement and neuropsychological measures, selected based on the findings of Lovett et al. (2000) and Waber et al. (2004), to refine and improve our current understanding of the profile of academic and cognitive deficits or assets associated with each DDH subgroups in reading disabled adults.

Many limitations are present in the DDH literature to date, some of which will be improved upon in this proposed study. Previous studies generally had moderate to small sample sizes that were further reduced when subgroups were created. Most DDH studies have also focused on children. To expand the DDH literature on adults, the present study will include a larger, well-characterized sample of college-level adults. Moreover, while the concepts of fluency and automaticity are crucial to the DDH, few studies have included timed reading measures; thus, another advantage of the proposed study is the inclusion of multiple fluency measures. Furthermore, additional academic and neuropsychological measures will be included. As such, this study will extend findings of child studies by investigating DDH subgroup performance on non-reading measures in adults.

Classification of poor readers typically utilizes one definition consisting of either a low achievement cutoff or an ability-achievement discrepancy. This study will use multiple classification criteria to identify a heterogenous group of poor readers to enhance the likelihood of obtaining an adequate and more representative number of participants with each deficit subtype. Low achievement and discrepancy criteria will be utilized, with each criterion utilizing two different achievement measures (word decoding and reading fluency) in an attempt to identify readers with PA and/or VNS deficits. Reading fluency measures have not typically been utilized in prior studies, but may be a more sensitive marker of reading disability in an adult sample. Furthermore, two RAN composites will be employed when identifying the VNS deficit subgroup so as to identify all possible participants with VNS deficiencies. Finally, another advantage of this proposed study is the use of composite scores to identify PA and VNS impairment. Previous studies have frequently utilized individual scores from multiple tasks measuring similar constructs. The use of composite scores generally allows for more reliable data, thus strengthening confidence in our results.

Furthermore, there is a paucity of research addressing comorbidity with RD, such as attentional problems, within the DDH framework. Waber et al. (2004) touched on this issue. They reported no significant differences between DDH subgroups with regard to the level of attentional problems. However, children with clinical levels of hyperactive symptoms were excluded from their sample. No direct investigation of the relation between diagnosed ADHD and DDH subgroups has been conducted to date. Thus, this study will further elucidate the DDH by determining if a relation exists between ADHD diagnosis and the DDH subgroups. Specifically, if one has a diagnosis of ADHD, is there evidence to suggest that he or she is more likely to be represented in one of the DDH subgroups.

Waber and colleagues (2004) reported that males comprised the majority in each DDH subgroup. Lovett et al. (2000) also observed an overrepresentation of males in these subgroups, with the exception of the PA deficit subgroup (16 boys and 15 girls). These studies are starting points, but more evidence is needed to determine if there is a relation between sex and deficit subtype. Is there a difference between males and females in pattern or severity of deficits? Is a male more likely to have a double deficit than a female, as the literature suggests (Feldman et al., 1995; Hawke et al., 2007)?

The proposed study addresses issues that have important implications for identification of and intervention in RD. Careful characterization of different RD subtypes and their associated academic and neuropsychological deficits can aid in diagnosis. Based on subgroup features, examiners can orient their attention to areas that should be assessed and are more likely to be impaired. Accurate identification of RD subtypes will aid in more effective remediation techniques and interventions for children, and appropriate accommodations for college-level adults.

Specific Hypotheses

1. Four mutually exclusive subgroups, based on patterns of performance on measures of PA and VNS, will be identified in a sample of college students with RD. Because this sample comprises only students meeting criteria for RD, the ND subgroup is expected to contain the fewest participants.

2. The prevalence of males will be greater in the DD subgroup compared to the other DDH subgroups.

3. A higher proportion of the VNS deficit subgroup will be diagnosed with ADHD compared to all other subgroups.

4. Subgroups will differ on measures of reading achievement. The DD subgroup will perform below the ND subgroup across all measures of reading decoding, fluency, and comprehension. The ND subgroup will achieve higher scores on all measures of reading achievement than both the VNS and PA subgroups. The VNS subgroup will perform better than the PA and DD subgroups on untimed measures of decoding and comprehension, while the PA

subgroup will perform better than the VNS and DD subgroups on timed measures of word decoding.

5. Subgroups will differ on non-reading measures of academic achievement. The VNS subgroup will perform better than the PA and DD subgroups on a measure of spelling. The PA subgroup will perform better than the VNS and DD subgroups on a measure of math fluency.

6. Subgroups will differ on neuropsychological measures. The VNS subgroup will perform better than the PA and DD subgroups on measures of verbal ability. The DD subgroup will be more impaired on measures of visuospatial processing than the VNS subgroup. Additionally, the DD subgroup will perform below the ND subgroup on measures of cognitive and motor processing speed.

STUDY DESIGN AND METHODS

Participants

This study used archival data from the Regents Center for Learning Disorders (RCLD) at Georgia State University. This site serves 14 state colleges and universities in the northern Georgia area. Students experiencing academic difficulties were referred to the center by their college or university's Disability Services Office for a comprehensive psychological evaluation. Standardized questionnaires and relevant historical information were submitted and reviewed prior to their scheduled visits. The evaluations were conducted over two or three sessions, typically lasting a total of 8-10 hours. A semistructured clinical interview and a standard battery of assessments were administered to all participants by a doctoral or post-doctoral trainee or a licensed psychologist. The battery included intellectual, academic, socioemotional, and neuropsychological measures. Any individuals who were taking prescribed medication at the time of testing were instructed to maintain their regular dosage during the testing period. The initial sample consisted of 673 students who completed all study measures.

Demographic information for the initial sample can be found in Table 1. The mean age was 23.9 (SD = 7.483) with 81.1% of European American descent and 50.1% female. Approximately 11.4% of the sample was diagnosed with an anxiety disorder, and 16.6% were diagnosed with a mood disorder. Diagnoses of mood or anxiety disorders were made by an assessment team led by a licensed psychologist on the basis of the Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition, Text Revision (DSM-IV-TR; American Psychiatric Association, 2000). Those with mood or anxiety disorders were not excluded from analyses, given their frequency in this clinical sample.

Within the initial sample, an RD group was identified based on either an ability-achievement regression-corrected discrepancy (DISCR) or low achievement (LA) criteria. Multiple criteria were used to identify poor readers in order to include both students that have poor reading abilities that are commensurate to their cognitive abilities, as well as those that have below-expected reading abilities for their intellectual level. The first set of criteria (DISCR) required one’s actual reading performance to be more than one standard error of prediction below the predicted standard score on either of two measures of reading achievement based on a regression equation. The formula used the correlation between the sample’s Full Scale IQ (FSIQ) and a specific achievement measure to determine an expected reading score, standard error of estimate, and standard error of prediction (the more conservative estimate). The criterion for LA was met if a participant performed at or below a certain cut-off score. For the purposes of this study, the cut-off score was equal to one standard deviation below the normative mean based on the standardization sample.

Table 1

Participant Characteristics

Characteristics	Initial Sample (%) N=673	Study Sample (%) n=226	χ^2	*P*
Age (mean)	24.1	21.6	4.527[a]	<.005
Female	50.1	43.4	3.051	0.081
Ethnicity[b]			0.849	0.357
European American	81.1	78.3		
African American	12.1	14.2		
Asian	2.4	1.8		
Latino	1.9	2.7		
Multiracial	1.9	3.1		
Other	0.3	0		
Dominant Hand (right)	88.7[c]	88.1[d]	0.075	0.785
Anxiety	11.4	7.5	2.776	0.096
Mood Disorder	16.6	9.3	7.250	0.007

Note: [a]t-values; [b]European American vs. Other Ethnic Backgrounds used for chi-square tests due to small *n*; [c]N = 70; [d]n = 225.

The two criterion measures of reading achievement utilized in this study to identify poor readers were the Basic Reading Skills standard score (a composite score based on measures of untimed word and nonword decoding) and the Reading Fluency standard score. The Reading Fluency subtest assesses the ability to rapidly read and correctly respond true or false to a simple sentence. Both measures are derived from the Woodcock-Johnson III Tests of Achievement (WJ-

3; Woodcock, McGrew, & Mather, 2001). These two measures are utilized to attempt to capture both decoding impaired and fluency-impaired participants. A reading comprehension measure was not included because it added very few (approximately 6) additional participants, and therefore, is believed to be redundant. The correlations between Full Scale IQ and Basic Reading Skills ($r = .46$) and Reading Fluency ($r = .43$) within the initial sample were utilized in the regression equation to determine expected achievement scores and standard errors of prediction.

Participants who met criteria for RD based on either DISCR or LA were included in the final study sample. Those with a history of a traumatic brain injury, seizure disorder, or other neurological conditions were excluded. In addition, those forty years of age or older, and those diagnosed with past or present psychotic disorders or pervasive developmental disorders were excluded.

The final sample comprised 226 adults (Table 1) ranging from 17 to 39 years of age ($M = 21.61$, $SD = 3.878$). The sample was 43.4% female. The majority of subjects were European American (78.3%), followed by African American (14.2%), Asian (1.8%), Latino (2.7%), and Multiracial (3.1%). The study sample was significantly younger than the initial sample ($p < .005$) but was comparable with regard to gender, ethnicity and handedness. There were no significant differences between the two groups with regard to anxiety disorders. There was, however, a higher prevalence of mood disorders in the initial sample compared to the study sample ($p < .05$).

Classification Procedures

Within the study sample, each participant was identified as having a deficit in phonological awareness (PA), visual naming speed (VNS), both PA and VNS (double deficit; DD), or neither of these areas (no deficit; ND). Groups were mutually exclusive, thus each participant could only be classified into one group. This method of grouping poor readers based on language measures is consistent with the Double Deficit Hypothesis proposed by Wolf and Bowers (1999).

Phonological awareness was assessed using the Phonological Awareness Composite of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). Visual naming speed was assessed using the Rapid Naming Composite and the Rapid Alternative Naming Composite of the CTOPP. Scores for the composites have a mean of 100 and a standard deviation of 15. If a participant had a score of one standard deviation or more below the mean on the PA Composite, but not either of the Rapid Naming Composites, then they were identified has having a PA deficit only. If they scored one standard deviation below the normative mean on either the Rapid Naming Composite or the Rapid Alternative Naming Composite, but not the PA Composite, then they were identified as having a VNS deficit only. Those scoring 85 or below on both the PA Composite and either the Rapid Naming Composite or the Rapid Alternative Naming Composite were identified as having a DD deficit. If all composite scores were above 85, then they were categorized in the ND subgroup.

Planned Subgroup Comparisons

Subgroups were compared on demographic variables. If differences were identified, these variables were considered for possible inclusion as covariates in subsequent analyses. In the present study, exclusionary criteria were selected to limit the impact of age on academic and cognitive outcome measures. Although subgroups were compared on IQ measures, Dennis, Francis, Cirino, Schachar, Barnes, & Fletcher (2009) argue that IQ should never be used as a covariate because, “When the covariate is an attribute of the disorder or of its treatment, or is intrinsic to the condition, it becomes meaningless to ‘adjust’ the treatment effects for differences in the covariate” (p. 3).

Once the entire sample of poor readers had been categorized into subgroups, multivariate analysis of variance (MANOVA) comparisons were used to compare subgroups on reading achievement measures to ascertain if specific language processes (PA and VNS) in adult poor readers are associated with differences in pattern and level of severity of one's reading abilities. Significant findings were further analyzed via individual univariate analyses. Bonferroni corrections were applied to correct for Type I error.

Similar MANOVA analyses were utilized for subgroup comparisons on non-reading measures. Other academic achievement skills and several neuropsychological domains were explored based on the results of previous studies with children (Lovett et al., 2000; Waber et al., 2004).

Additionally, the representation of comorbid ADHD diagnoses across subgroups was evaluated using a chi square procedure. It is well known that RD and ADHD frequently occur in conjunction in the population (Gilger et al., 1992; B.A Shaywitz et al., 1995; S.E. Shaywitz, Fletcher, & B.A. Shaywitz, 1994). However, the relation between comorbidity and DDH subgroup membership has received little attention. The possible relations between RD-ADHD comorbidity and language deficits are important to investigate so that at-risk groups may be identified and targeted for tailored interventions, if needed.

For the purposes of this study, participants were identified as having ADHD if they met two criteria: a licensed psychologist's diagnosis based on DSM-IV-TR criteria and a significant level of current symptoms on either subscale of the self-report version of the ADHD Behavior Checklist for Adults (Barkley & Murphy, 2006). The clinician's diagnosis integrates many sources of behavioral, neuropsychological, informant-report, and self-report data in order to expertly assign clinical diagnoses. It also requires that there be evidence for a developmental process, meaning that attentional and/or hyperactive/impulsive symptoms were present in childhood. In addition to the clinician's diagnosis, participants must obtain a summary score of at least 1.5 standard deviations above the age-based normative mean (Murphy & Barkley, 1995) for either the Inattentive or Hyperactive/Impulsive subscale. This quantitative measure used in conjunction with the clinician's comprehensive evaluation, resulted in conservative inclusion criteria for identifying ADHD in the study sample.

Finally, the representation of sex across the four subgroups was compared utilizing a chi square analysis. It is well-supported that more males are typically identified as reading disabled than females in clinical samples (Lovett, 1987; Lovett et al., 1988; Lovett et al., 2000; Siegel & Smythe, 2005). This study aimed to examine whether patterns of PA and VNS performance within a sample of poor readers are related to sex.

Measures

Measures are organized based on their purpose in the proposed study: identifying poor readers, classifying poor readers into subgroups, and comparing these subgroups on reading measures, other achievement and neuropsychological measures, and representation of ADHD diagnosis.

Identifying Poor Readers

The Woodcock-Johnson III Tests of Achievement (WJ-3; Woodcock, McGrew, & Mather, 2001) is a well-standardized and commonly used assessment instrument. Two measures from this battery were utilized in identifying the study sample of poor readers. The first was Basic Reading Skills, which is a composite score based on two subtests, Word Attack and Letter-Word Identification, that assesses word and nonword decoding abilities. Utilization of this composite score identified poor readers who may have difficulties in reading accuracy. The second component was the Reading Fluency subtest. This measure requires participants to respond “yes” or “no” to a series of simple sentences as fast as they can in a 3-minute time period. For example, an examinee would respond “no” to the sentence “an apple is blue.” It identifies poor readers who may have difficulties in reading fluency.

The Wechsler Adult Intelligence Scale, 3rd edition (WAIS-III; Wechsler, 1997) is an individually administered standardized test of general intellectual functioning. Several domains are evaluated, including verbal comprehension, perceptual organization, working memory, and processing speed. The FSIQ score reflects performance across all of these domains and is a representation of one’s global intelligence. The FSIQ was utilized in determining whether a participant meets the criterion for the DISCR group.

Classifying Poor Readers into Subgroups

Three composite scores from the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999) were used to assess PA and VNS. The Elision and Blending tasks constitute the Phonological Awareness Composite. Elision requires participants to listen to and repeat a real word, then repeat the word with a phoneme deleted from the beginning, middle or end. Blending requires a participant to listen to individual phonemes and blend them together to make a real word. The items increase in difficulty from two to eight phonemes. The Rapid Naming Speed Composite is based on the Rapid Letter Naming and Rapid Digit Naming tasks. Participants must read out loud, as fast as they can, six individual letters (*s*, *t*, *a*, *n*, *c*, *k*) that are repeated randomly in a 9x4 format. This process is repeated with identical letters in a different order. The total time taken to read all 72 stimuli results in a standard score. Rapid Digit Naming is methodologically identical, but with six numbers (2, 3, 4, 5, 7, 8). The Rapid Alternative Naming Speed Composite comprises the Rapid

Object Naming and Rapid Color Naming tasks. These are methodologically identical to the other Rapid Naming tasks, but with six objects (pencil, boat, star, key, chair, fish) presented in the Rapid Object Naming task and six colors (red, yellow, green, blue, black, brown) presented in the Rapid Color Naming task.

Reading Measures for Group Comparisons

Four subtests from the WJ-3 were used as measures of untimed word (Letter-Word Identification; LWID) and nonword (Word Attack; WA) decoding, comprehension (Passage Comprehension; PC), and fluency (Reading Fluency; RF). The LWID subtest requires participants to decode real words with increasing difficulty. The WA subtest is similar, however, one must decode nonwords. The PC subtest is a cloze test requiring participants to supply a missing word from a sentence in a brief passage. The RF subtest is the same measure used to identify poor readers. It requires participants to respond “yes” or “no” to simple sentences within a 3-minute time limit.

The Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999) provides a timed measurement of word and nonword decoding. Participants must read increasingly difficult real and nonwords within a 45-second time limit. The TOWRE will provide a measure of decoding fluency.

The Nelson Denny Reading Aptitude Test (Brown, Fishco, & Hanna, 1993) is a measure of silent reading comprehension under timed conditions. Participants have 20 minutes to read seven passages and answer 38 questions, with no penalty for guessing. This measure was utilized as an estimate of reading comprehension under time restrictions. It challenges one’s ability to decode and comprehend words, attend to concepts, make inferences, and do so rapidly. The

Nelson Denny Rate also served as a dependent variable. This measure is based on the examinee's self-report of how many lines of text he or she can read in 60 seconds.

Other Achievement and Neuropsychological Domains

Achievement Measures

Three subtests from the WJ-3 were included to assess non-reading achievement abilities. The Spelling subtest requires one to listen to orally presented words of increasing difficulty and correctly spell the word. The Calculation subtest assesses one's ability to compute arithmetic problems of increasing difficulty, presented in a worksheet format. Math Fluency requires participants to rapidly solve simple calculations in a 3-minute time limit.

Verbal Abilities

The Verbal Comprehension Index (VCI) of the WAIS-III is a composite score that measures general verbal skills, such as verbal fluency, the ability to understand and use verbal reasoning, and verbal knowledge. The VCI is comprised of three subtests. The Vocabulary subtest from the WAIS-III assesses vocabulary knowledge and expressive verbal abilities. The Similarities subtest assesses conceptual reasoning and requires one to identify increasingly abstract relations between a pair of words. The Information subtest consists of a series of questions assessing factual knowledge, such as common events, objects, places, and people.

The Logical Memory I subtest of the Wechsler Memory Scale, 3rd edition (WMS-III; Wechsler, 1997) assesses memory for details and themes of narrative stories that are delivered orally. The Logical Memory I Recall Total (age-adjusted) Scaled Score represents the examinee's ability to recall, without cues, as many details (verbatim) of two different stories, the latter of which is given twice. The Letter Fluency task from the Verbal Fluency subtest of the

Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) assesses the ability to retrieve as many words as possible beginning with a specific letter in 60 seconds.

Visuospatial Processing

The Block Design subtest of the WAIS-III requires the examinee to reproduce abstract patterns using blocks and measures spatial perception and visual abstract reasoning.

The Rey Complex Figure Test (RCFT; Meyer & Meyer, 1995) assesses several complex functions, such as executive functioning, visuospatial processing, and visual memory. The subject is required to copy a complex figure, recall it approximately 3 minutes later (Immediate), and then again approximately 20 to 25 minutes later (Delayed). Copy and delayed scores were utilized in exploratory analyses.

Processing Speed

The Processing Speed Index (PSI) of the WAIS-III assesses motor speed, visual attention, quick scanning, and discrimination between visual information. The PSI comprises two subtests. The Digit Symbol Coding subtest measures visual-motor speed and short-term visual memory. The examinee is given 120 seconds to match symbols to numbers according to a key. Finally, the Symbol Search subtest assesses visual perception and speed. This timed task requires examinees to discriminate between target symbols and distractors.

Motor Speed

The Grooved Pegboard (Bornstein, 1985) assesses visual-motor coordination. Examinees are required to rapidly rotate and fit 25 grooved pegs into holes with randomly positioned slots.

ADHD Diagnostic Criteria

This ADHD Behavior Checklist for Adults (Barkley & Murphy, 2006) is a symptom checklist containing 18 questions derived from the DSM-IV-TR criteria for ADHD, with nine items addressing inattention and nine addressing hyperactive/impulsive symptoms. With regard to the proposed study, only the current (referring to the past 6 months) self-report form of the checklist was used. Responses range from 0 to 3 (Rarely or Never, Sometimes, Often, or Very Often). Thus, summary scores for inattentive and hyperactive/impulsive symptoms range from 0-27. Summary scores, rather than symptom counts, will be utilized in the proposed study. One argument for use of the summary score, rather than the symptom count, is based on the nature of the DSM-IV criteria. The DSM-IV-TR criteria for the diagnosis of ADHD were developed primarily for use with children; therefore, it may be more difficult for an adult to exhibit similar behaviors outlined in the DSM-IV-TR, but still suffer from impairment of daily activities. As a result, adults are less likely to meet the DSM-IV-TR criteria for ADHD which requires the presence of 6 or more symptoms in one or both domains. Utilization of the summary score allows use of age-based normative data to determine if the overall severity of symptoms is significantly more than the average adult may report.

RESULTS

Data Screening

The data was examined for univariate and multivariate outliers, skewness, linearity, multicollinearity, and singularity. Univariate outliers were identified primarily by extreme *z*-scores. Extreme scores were considered those 3.29 standard deviations ($p < .001$, two-tailed test) from the mean (Tabachnick and Fidell, 2007). These extreme data points were recoded and given a value one integer above or below the next closest non-extreme value. Statistical analyses were conducted with and without modified outliers. No significant differences were observed, so data points were returned to their original values.

The criterion for multivariate outliers was Mahalanobis distance at $p < .001$. One case was identified to meet this criterion, however analyses conducted with and without the individual case resulted in no significant changes in results; therefore it was not deleted from the sample.

Skewness and kurtosis were explored utilizing statistical and graphical (histograms and P-P plots) inspection techniques. Several variables were transformed due to skewness. Statistical analyses were conducted with and without transformed variables. The results did not significantly differ; thus, only untransformed variables were used in the final analyses.

Finally, two variables proved to be unusable in their current form, and two others did not have enough cases to justify inclusion in the final analyses. The RCFT Delayed Recall standard score was incorrigibly negatively skewed and demonstrated minimal variability; thus, the variable was retained, but raw scores were utilized instead of standard scores, which provided more variability with a normal distribution. Furthermore, the RCFT Copy scores exhibited similar problems; therefore it was recoded as a categorical variable and analyzed separately in a chi-square analysis. This modified variable had three levels: intact performance (>16^{th} percentile), mildly-moderately impaired (2^{nd}-16^{th} percentile), and significantly impaired (<1^{st} percentile).

The WAIS-III PSI and the D-KEFS Letter Fluency task did not include a sufficient number of cases to be included in the analyses. There were, however, enough cases of the Digit Symbol subtest of the WAIS-III, which is one component of the PSI, to substitute in the final analysis in place of the PSI variable.

Bivariate scatterplots were utilized to assess linearity, which was determined to be adequate for analyses. Correlation matrices were explored to rule out multicollinearity and singularity issues (Tables 2, 3, and 4). There was one instance of multicollinearity. As would be expected, the two untimed decoding tasks (Letter-Word Identification and Word Attack) were highly correlated ($r = .811$, $p < .01$). Both variables were theoretically pertinent, however, because each task requires a different form of decoding (i.e., words vs. novel nonwords) that are important to assess. Thus, it was determined that both would be kept in the analyses despite the possible negative effect on our analyses due to inflated error terms (Tabachnick and Fidell, 2007).

Study Sample and Subgroup Profiles

The study sample was compared to the initial sample on those reading achievement measures used to identify the study sample to ensure that they did, in fact, have significantly lower scores (Table 5). Independent samples *t*-tests demonstrated significant differences between the two samples, with the study sample scoring approximately one standard deviation below the initial sample on Basic Reading and Reading Fluency tasks. Overall, the study sample also performed significantly below ($p \leq .001$) the initial sample on all measures used to classify the DDH subgroups.

Demographic information for the subgroups is provided in Table 6. The subgroups did not differ in age, handedness, or diagnosis of anxiety or mood disorder. The subgroups did differ, however, on ethnicity. Specifically, a significantly higher proportion of ethnic minorities met criteria for the DD subgroup compared to the other subgroups. Ethnic minorities as a whole comprised over a third of the DD subgroup.

Table 2

Intercorrelations for Reading Achievement Measures

	LWID	WA	PC	RF	NDComp	NDRate	TOWRE-s	TOWRE-p
LWID								
WA	.811*							
PC	.581**	.448**						
RF	.246**	.112	.395**					
NDComp	.350**	.195**	.439**	.568**				
NDRate	.177**	.063	.175**	.525**	.595**			
TOWRE-s	.567**	.502**	.321**	.440**	.427**	.467**		
TOWRE-p	.699**	.722**	.411**	.287**	.397**	.355**	.725**	

**$p \leq .01$. Note. LWID = Letter-Word Identification; WA = Word Attack; PC = Passage Comprehension; RF = Reading Fluency; NDComp = Nelson-Denny Reading Test, Comprehension; NDRate = Nelson-Denny Reading Test, Reading Rate; TOWRE-s = Test of Word Reading Efficiency, Sight Word Efficiency; TOWRE-p = Test of Word Reading Efficiency, Phonemic Decoding Efficiency.

Table 3

Intercorrelations for Other Academic Achievement Measures

	Spelling	Calculation	Math Fluency
Spelling			
Calculation	.537**		
Math Fluency	.388**	.559**	

**$p \leq .01$

Table 4

Intercorrelations for Neuropsychological Measures

	VCI	DigSym	BD	LogMem Recall	RCFT Delay	GPDom	GPNondom
VCI							
DigSym	.028						
BD	.391**	.317**					
LogMem Recall	.408**	.106	.194**				
RCFT Delay	.279**	.194**	.539**	.334**			
GPDom	.306**	.345**	.407**	.095	.277**		
GPNondom	.330**	.254**	.475**	.161*	.319**	.734**	

*$p \leq .05$. **$p \leq .01$. Note. VCI = Verbal Comprehension Index; DigSym = Digit Symbol Coding; BD = Block Design; LogMem Recall = Logical Memory I Recall Total; RCFT Delay = Rey Complex Figure Test; GPDom = Grooved Pegboard, dominant hand trial; GPNondom = Grooved Pegboard, nondominant hand trial.

As expected, subgroups differed in a predictable pattern on the classification measures (Table 7). On both measures of phonological awareness (Elision and Blending), the PA and DD subgroups performed significantly below ($p < .001$) the VNS and ND subgroups. Similarly, on all measures of rapid naming (Digits, Letters, Colors, and Objects), the VNS and DD subgroups performed significantly below ($p < .001$) the PA and ND subgroups.

Chi-square Analyses

Subgroup Differences in Gender

The ratio of males to females in the DD subgroups was assessed utilizing chi-square analyses. No significant differences were observed among the subgroups ($x^2 = .833$, $p = .842$). Sex ratios ranged from approximately 1:1 to 1.4:1. Interestingly, in accordance with the proposed hypothesis (although not a significant finding), the subgroup with the largest sex ratio was the DD subgroup, which had a greater proportion of males than females.

Subgroup Differences in Prevalence of ADHD

No significant differences were observed among the subgroups in the proportion of participants identified as having ADHD ($x^2 = 1.23$, $p = .747$). However, in accordance with the proposed hypothesis (although not a significant finding), the subgroup with the largest representation of ADHD-identified participants was the VNS subgroup. Within the VNS subgroup, 17.4% were identified as having ADHD, compared to 13.2% in the ND subgroup, 12.9% in the PA subgroup, and 11.4% in the DD subgroup. The analysis was repeated with a modified and less stringent criterion for ADHD (i.e., clinician's diagnosis alone). The relation among DD subgroups and clinician diagnosis of ADHD remained non-significant ($x^2 = 6.75$, $p = .08$).

Table 5

Means and Standard Deviations on Measures Used to Identify and Classify the Study Sample

	Study Sample n = 226	Initial Sample n = 192
Basic Reading*	87.52 (11.40)	100.46 (8.27)
Reading Fluency*	84.15 (9.71)	101.26 (10.10)
Rapid Digit Naming*	7.96 (2.58)	9.70 (2.89)
Rapid Letter Naming*	7.21 (2.63)	9.23 (2.94)
Rapid Naming Composite*	85.33 (14.94)	96.53 (16.69)
Rapid Color Naming*	8.49 (2.63)	10.18 (6.07)
Rapid Object Naming*	7.23 (2.72)	8.46 (2.97)
Alternative Rapid Naming Composite*	87.06 (14.89)	94.12 (15.94)
Elision*	7.64 (5.96)	9.18 (2.48)
Blending Words*	8.12 (5.55)	9.60 (2.73)
Phonological Awareness Composite*	85.30 (15.49)	96.37 (13.48)

*$p < .005$

Table 6

Subgroup Demographics

Demographic	PA n = 31	VNS n = 69	DD n = 88	ND n = 37	χ^2	*p*
Age (mean)	20.71	21.28	22.11	21.30	1.39[a]	.246
Female (%)	48.4	42.0	40.9	47.4	.833	.842
Ethnicity[b]					18.58	<.001
European American	74.2	85.5	63.6	94.7		
African American	19.4	5.8	27.3	0		
Asian	0	1.4	3.4	0		
Hispanic	6.5	2.9	3.4	0		
Multiracial	0	4.3	2.3	5.3		
Handedness	93.5	85.5	87.5	84.2	1.33	.723
Anxiety Disorder	12.9	5.8	6.8	13.2	2.83	.419
Mood Disorder	6.5	10.1	13.6	7.9	1.73	.631

Note: [a]t-value; [b]European American vs. All Other Groups used for chi-square tests due to small *n*.

Multivariate Analysis of Covariance

Based on differences in ethnic representation across the subgroups, ethnicity was included as a covariate in the reading achievement and neuropsychological measures MANCOVA. Although subgroups did not differ in self-reported symptoms of inattention, Inattention severity scores from Barkley's ADHD Behavior Checklist were also utilized as a covariate in each MANCOVA to control for the significant relations between inattention symptoms and several academic and neuropsychological measures (Table 8).

Reading Achievement

The first analysis examined subgroup differences in performance on reading achievement measures while covarying for reported inattention symptoms and ethnicity. Box's M was found to be significant ($F(108, 37919) = 1.69$, $p < .001$); however, all Levene's tests were non-significant and the variance ratios (F_{max}) were good. The latter findings in a large sample suggest that Box's M may be too stringent. Thus, the results of this analysis were deemed acceptable for interpretation. With the use of Wilks' criterion, the combined dependent variables were significantly related to the inattention ($F(8, 203) = 2.752$, $p = .007$, partial $\eta^2 = .098$) but not the ethnicity covariate ($F\ (8, 203) = 1.731$, $p = .093$, partial $\eta^2 = .064$).

The effect of subgroup on the dependent variables was examined after adjusting for the inattention severity scores and ethnicity. A significant effect was observed ($F(24, 589) = 5.854$, $p < .001$, partial $\eta^2 = .187$). Univariate analyses revealed statistically significant differences for each dependent variable. Adjusted means are presented in Table 9 and can be viewed graphically in Figure 1. The DD subgroup performed significantly below the ND group on every reading achievement measure, except for the Nelson Denny Reading Rate. Furthermore, the ND subgroup scored higher on average than the PA and VNS subgroups on all measures.

Table 7

Subgroup Means and Standard Deviations for Classification Measures

	PA	VNS	DD	ND
Rapid Digit Naming**	10.10 (.32)	7.24 (.327)	6.94 (.235)	10.16 (.24)
Rapid Letter Naming**	9.23 (.21)	6.27 (.32)	6.31 (.32)	9.62 (.30)
Rapid Naming Composite**	98.00 (1.42)	80.52 (1.86)	79.26 (1.34)	99.35 (1.33)
Rapid Color Naming**	11.03 (.443)	7.71 (.28)	7.31 (1.9)	10.78 (.39)
Rapid Object Naming**	9.23 (.41)	6.14 (.25)	6.34 (.26)	9.76 (.42)
Alternative Rapid Naming Composite**	100.80 (2.15)	81.55 (1.49)	80.55 (2.15)	101.62 (1.88)
Elision**	5.00 (.41)	9.64 (.20)	6.00 (.94)	10.11 (.20)
Blending Words**	6.13 (.28)	9.77 (.26)	6.69 (.86)	10.14 (.35)
Phonological Awareness Composite**	72.63 (1.62)	98.52 (.88)	72.99 (.97)	100.73 (1.28)

*$p \leq .05$
**$p < .001$

Table 8

Covariate Correlations with Dependent Variables

	Inattention Severity Scores	Ethnicity
LWID	.226**	-.147*
WA	.248**	-.083
PC	.018	-.257**
RF	-.064	-.266**
NDComp	-.002	-.234**
NDRate	-.126	-.107
TOWRE-s	.100	-.108
TOWRE-p	.150*	-.185*
Spelling	.272**	-.008
Calculation	.104	-.054
Math Fluency	.003	-.007
VCI	.102	-.212**
LogMem Recall	-.215**	-.125
RCFT Delay	-.040	-.271**
BD	.035	-.316**
DigSym	-.065	-.025
GPDom	-.029	-.280**
GPNondom	.019	-.296**

*$p \leq .05$. **$p \leq .01$. Note. LWID = Letter-Word Identification; WA = Word Attack; PC = Passage Comprehension; RF = Reading Fluency; NDComp = Nelson-Denny Reading Test, Comprehension; NDRate = Nelson-Denny Reading Test, Reading Rate; TOWRE-s = Test of Word Reading Efficiency, Sight Word Efficiency; TOWRE-p = Test of Word Reading Efficiency, Phonemic Decoding Efficiency; VCI = Verbal Comprehension Index; LogMem Recall = Logical Memory I Recall Total; RCFT Delay = Rey Complex Figure Test Delayed Recall; BD = Block Design; DigSym = Digit Symbol Coding; GPDom = Grooved Pegboard, dominant hand trial; GPNondom = Grooved Pegboard, nondominant hand trial.

A clear pattern emerged on untimed measures of reading decoding and comprehension (Figure 1). Subjects in the PA and DD subgroups performed significantly below the VNS and ND subgroups on LWID ($F(3, 211) = 25.09$, $p < .001$, partial $\eta^2 = .26$), WA ($F(3, 211) = 19.69$, $p < .001$, partial $\eta^2 = .22$), and PC ($F(3, 211) = 20.41$, $p < .001$, partial $\eta^2 = .23$).

On timed measures of reading fluency ($F(3, 210) = 22.26$, $p < .001$, partial $\eta^2 = .24$), comprehension ($F(3, 210) = 4.45$, $p = .005$, partial $\eta^2 = .06$), and rate ($F(3, 210) = 3.15$, $p = .026$, partial $\eta^2 = .043$), the three deficit subgroups did not significantly differ and the PA subgroup did not differ significantly from the ND subgroup. The ND subgroup performed significantly better than both subgroups with a VNS deficit (i.e., VNS and DD); however, on the timed reading comprehension measure, the ND subgroup performed significantly better than only the DD subgroup, and on the reading rate measure the ND subgroup performed significantly better than only the VNS subgroup.

Subgroups also differed significantly on timed word ($F(3, 210) = 17.24$, $p < .001$, partial $\eta^2 = .20$) and nonword decoding ($F(3, 210) = 17.87$, $p < .001$, partial $\eta^2 = .20$) measures. The DD, VNS, and PA subgroups scored significantly below the ND subgroup on TOWRE Sight Word Efficiency (TOWRE-s) and TOWRE Phonemic Decoding Efficiency (TOWRE-p). The

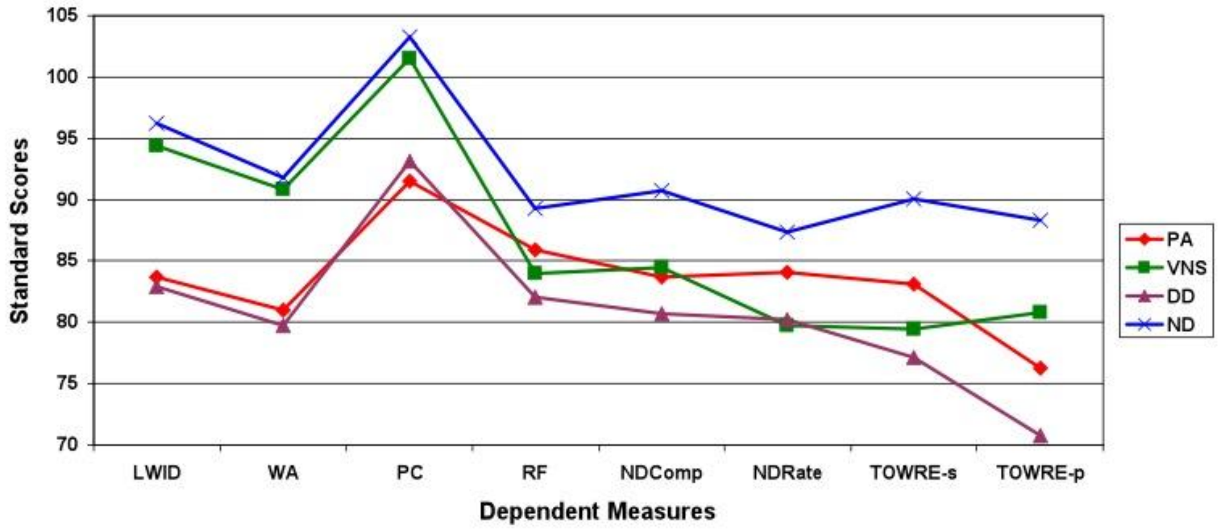

Figure 1. Marginal means for reading achievement measures adjusted for inattention severity scores and ethnicity

PA subgroup performed significantly better than the DD subgroup on Sight Word Efficiency, and the VNS subgroup performed significantly better than the DD subgroup on Phonemic Decoding Efficiency.

<u>Other Academic Achievement Measures</u>

The second analysis examined subgroup differences in performance on other academic achievement measures while covarying for reported inattention symptoms. Box's M was not significant (F(18, 60415) = .68, p = .839). With the use of Wilks' criterion, the combined dependent variables were significantly related to the inattention covariate (F(3, 214) = 5.71, p = .001, partial η^2 = .07).

Table 9

Marginal Means for Reading Achievement Measures Adjusted for Inattention Severity Scores and Ethnicity

	PA	VNS	DD	ND
LWID	83.67_{a}	94.42_{b}	82.95_{a}	96.20_{b}
WA	80.97_{a}	90.85_{b}	79.72_{a}	91.78_{b}
PC	91.54_{a}	101.50_{b}	93.17_{a}	103.26_{b}
RF	$85.92_{a,b}$	83.98_{a}	82.01_{a}	89.33_{b}
NDComp	$83.67_{a,b}$	$84.44_{a,b}$	80.70_{a}	90.75_{b}
NDRate	$84.11_{a,b}$	79.77_{a}	$80.24_{a,b}$	87.40_{b}
TOWRE-s	83.16_{a}	$79.43_{a,b}$	77.09_{b}	90.07_{c}
TOWRE-p	$76.24_{a,b}$	80.78_{a}	70.75_{b}	88.31_{c}

Note. Means in the same row that do not share subscripts differ at $p < .05$ in the Bonferroni comparison. LWID = Letter-Word Identification; WA = Word Attack; PC = Passage Comprehension; RF = Reading Fluency; NDComp = Nelson-Denny Reading Test, Comprehension; NDRate = Nelson-Denny Reading Test, Reading Rate; TOWRE-s = Test of Word Reading Efficiency, Sight Word Efficiency; TOWRE-p = Test of Word Reading Efficiency, Phonemic Decoding Efficiency.

The effect of subgroup on the dependent variables was examined after adjusting for the inattention severity scores (Table 10). A significant effect was observed ($F(9, 521) = 6.83$, $p < .001$, partial $\eta^2 = .09$). Univariate analyses revealed statistically significant differences for each dependent variable. Adjusted means are presented in Table 10. As hypothesized, the VNS and ND subgroups performed better than the DD and PA subgroups on Spelling ($F(3, 216) = 8.49$, *p*

< .001, partial $\eta^2 = .11$). While univariate analyses indicated significant findings for Math Fluency, pairwise comparisons revealed no significant differences among subgroups, contrary to predictions ($F(3, 216) = 3.22$, $p = .024$, partial $\eta^2 = .04$); however, it is still important to note that the VNS and DD subgroups had lower average scores than the PA and ND subgroups. On an untimed calculation task, the VNS subgroup performed significantly better than the PA and DD subgroups ($F(3, 216) = 7.32$, $p < .001$, partial $\eta^2 = .09$). The ND subgroup did not differ significantly from any subgroup.

Neuropsychological Measures

The third analysis examined subgroup differences in performance on neuropsychological measures while covarying for ethnicity and reported inattention symptoms. Box's M was found to be significant ($F(84, 39479) = 1.38$, $p = .013$); however, all but one (Grooved Pegboard Non-Dominant) Levene's tests were non-significant and the variance ratios (F_{max}) were good for each dependent variable. The latter findings in a large sample suggest that Box's M may be too stringent. Thus, the results of this analysis were deemed acceptable for interpretation. With the

Table 10

Marginal Means for Other Academic Achievement Measures Adjusted for Inattention Severity Scores

	PA	VNS	DD	ND
Spelling	83.75_a	91.01_b	83.62_a	92.93_b
Calculation	89.88_a	101.55_b	92.21_a	$99.09_{a,b}$
Math Fluency	87.68_a	83.37_a	83.46_a	89.57_a

Note: Means in the same row that do not share subscripts differ at $p < .05$ in the Bonferroni comparison.

use of Wilks' criterion, the combined dependent variables were significantly related to the inattention (F(7, 197) = 2.31, p = .028, partial η^2 = .08) and ethnicity covariates (F(7, 197) = 3.26, p = .003, partial η^2 = .10).

The effect of subgroup on the dependent variables was examined after adjusting for the inattention severity scores and ethnicity (Table 11). A significant effect was observed (F(21, 566) = 4.25, p < .001, partial η^2 = .13). Univariate analyses were statistically significant for all but one dependent variable. Adjusted means are presented in Table 11. As hypothesized, the VNS and ND subgroups performed better than the DD and PA subgroups on a measure of verbal abilities (WAIS-III VCI; F(3, 203) = 12.60, p < .001, partial η^2 = .16). Similarly, the VNS and ND subgroups had a higher mean score than the DD subgroup on a verbal memory task, Logical Memory I Recall Total (F(3, 203) = 3.19, p = .025, partial η^2 = .05), although the subgroups did not differ significantly upon pairwise comparisons. As predicted, the VNS and ND subgroups scored significantly higher on RCFT Delay (F(3, 203) = 6.20, p < .001, partial η^2 = .08) and Block Design (F(3, 203) = 8.46, p < .001, partial η^2 = .11) than the DD subgroup. The PA subgroup did not differ from any other deficit subgroup on visuospatial processing measures, but did perform significantly below the ND subgroup on Block Design. Finally, the ND subgroup also consistently performed better on cognitive and motor processing speed tasks than the DD subgroup (Digit Symbol Coding: F(3, 203) = 11.84, p < .001, partial η^2 = .15; Grooved Pegboard Nondominant Hand: F(3, 203) = 5.32, p < .001, partial η^2 = .07), although the difference was not significant for Grooved Pegboard Dominant Hand (F(3, 203) = 2.13, p = .097, partial η^2 = .03). The deficit subgroups did not significantly differ from each other on Digit Symbol Coding and all performed significantly below the ND subgroup. On the nondominant hand trial of the Grooved Pegboard task, the VNS subgroup performed comparably to the ND subgroup

Table 11

Marginal Means for Neuropsychological Measures Adjusted for Inattention Severity Scores and Ethnicity

	PA	VNS	DD	ND
VCI	99.12_{a}	109.22_{b}	98.16_{a}	111.71_{b}
LogMem Recall	8.66_{a}	9.64_{a}	8.41_{a}	9.88_{a}
RCFT Delay	$19.38_{a,b}$	22.25_{a}	18.13_{b}	23.06_{a}
BD	$9.95_{a,b}$	$11.59_{b,c}$	9.70_{a}	12.19_{c}
DigSym	9.12_{a}	8.25_{a}	8.40_{a}	11.07_{b}
GPDom	91.23_{a}	92.63_{a}	89.24_{a}	95.13_{a}
GPNondom	$90.05_{a,b}$	94.48_{a}	87.11_{b}	95.70_{a}

Note: Means in the same row that do not share subscripts differ at $p < .05$ in the Bonferroni comparison. VCI = Verbal Comprehension Index; LogMem Recall = Logical Memory I Recall Total; RCFT Delay = Rey Complex Figure Test Delayed Recall; BD = Block Design; DigSym = Digit Symbol Coding; GPDom = Grooved Pegboard Dominant Hand Trial; GPNondom = Grooved Pegboard Nondominant Hand Trial.

and both performed significantly better than the DD subgroup; the PA subgroup did not differ from any other subgroup. Finally, no significant differences were observed among the subgroups on the dominant hand trial of the Grooved Pegboard task.

A chi square analysis was used to compare subgroups on the Copy Trial of the RCFT; differences between subgroups were not significant on this measure ($x^2 = 11.76$, $p = .067$).

DISCUSSION

The current study represents one of few investigating the DDH in a college-level adult sample. It was predicted that the prevalence of males would be greater in the DD subgroup compared to the other DDH subgroups and that a higher proportion of the VNS deficit subgroup would be diagnosed with ADHD compared to all other subgroups. It was also predicted that the subgroups would differ in performance on reading achievement, other academic achievement, and neuropsychological measures. In general, the ND subgroup was predicted to perform above all other subgroups and the DD subgroup was predicted to perform below all other subgroups. The single-deficit subgroups were expected to vary in performance depending on the nature of the task (i.e., timed or untimed). Predictions were made for non-reading academic and neuropsychological measures based on previous findings in the literature (Lovett et al., 2000; Waber et al., 2004); however, as predicted for reading achievement, the ND subgroup was expected to achieve higher scores on all measures compared to the DD subgroup.

Sex Differences

Contrary to our prediction, there were no significant differences in the proportion of males to females among the four subgroups; however, when proportions were compared, the largest proportion of males was observed in the DD subgroup. The male to female ratios reported among child studies vary according to the sample, with referred samples demonstrating a much higher prevalence of males than females. In the current college-level sample of students seeking academic accommodations, one might expect to see similar results.

It is possible that more adult females may seek accommodations for learning disabilities in adulthood compared to those that are referred in childhood, which may help explain why the ratio of males to females was near even in this adult sample. Another explanation may be that the extent of RD in this particular sample is not as severe as other studies that reported an overrepresentation of males in the most severely impaired individuals (Feldman et al., 1995; Hawke et al., 2007). Specifically, the current sample of college-level students may represent those with less severe RD who were able to progress to a more advanced academic level than those that may have suffered from more severe forms of the disorder.

Representation of ADHD

More ADHD-identified participants were observed in the VNS subgroup compared to the other subgroups, although this was not a significant difference. ADHD representation was also evaluated using only a clinician's diagnosis, thus representing a typical clinic setting, to assess whether more individuals would be identified based on this more lenient criterion. Subgroup differences remained non-significant when the less stringent criterion for ADHD was utilized. Furthermore, findings remain non-significant when the VNS and DD subgroups are combined and compared to the PA and ND subgroups, thus comparing those with a VNS deficit and those without (x^2 = .868, p = .868).

These results are not consistent with previous reports that children with ADHD are slower at rapid naming tasks, especially more semantically complex forms of the task (i.e., rapid object and color naming) (Brock & Christo, 2003; Tannock, Martinussen, & Frijters, 2000). Interestingly, in the current sample, a positive relation between Inattention severity and performance on VNS tasks was observed. Specifically, only alternative rapid naming times significantly correlated with Inattention severity scores (rapid color naming: r = .159, p = .018; rapid object naming: r = .187, p = .005), suggesting that more severe inattention symptoms predict slower visual naming speed for some types of stimuli.

Thus, the current findings suggest that a relation exists between inattention and more semantically complex rapid naming, however a significant relation between ADHD diagnosis and VNS subgroup was not observed. It is possible that the criteria used to identify participants with ADHD was insufficient. The gold standard would be two independent psychologists diagnosing participants via a structured diagnostic interview. Finally, it is possible that while a sample of individuals with ADHD may perform slower than a control sample on measures of VNS, ADHD may not have an additive impact on rapid naming abilities in an RD sample, and no differences across subgroups would emerge.

Reading Achievement

Subgroup differences on measures of reading achievement were observed for all dependent variables. The DD subgroup performed consistently below the ND subgroup as predicted, suggesting an association between poor PA and VNS performance and reading achievement. Furthermore, on the majority of reading measures, the DD subgroup performed significantly below at least one single-deficit subgroup, suggesting an additive impact of deficits in these two linguistic abilities.

A clear pattern emerged among the DDH subgroups on untimed measures of reading decoding and comprehension with the DD and PA subgroups exhibiting more difficulty than the VNS and ND subgroups. However, the PA and VNS subgroups did not significantly differ in performance on timed measures. On all timed measures but one (i.e., Nelson-Denny Comprehension), the VNS subgroup performed significantly below the ND subgroup and did not differ from the PA subgroup. The DD, VNS, and PA subgroups scored significantly below the ND subgroup on TOWRE Sight Word Efficiency and TOWRE Phonemic Decoding Efficiency. Among the deficit subgroups, the PA subgroup performed significantly better than the DD subgroup on Sight Word Efficiency, and the VNS subgroup performed significantly better than the DD subgroup on Phonemic Decoding Efficiency.

The pattern of performance observed in this sample of adults with RD is largely consistent with previous child studies and the one available adult study. Specifically, Cirino and colleagues (2005) reported similar findings regarding performance of DDH subgroups on measures of reading achievement. In their independent sample of college-level adults, obtained from the same setting as the current study, the DD subgroup consistently performed significantly below the ND subgroup on all measures. The performance of the DD subgroup was consistently below the other subgroups, and typically significantly below at least one of the single-deficit subgroups. Results for timed reading comprehension were consistent between the two studies. The results were inconsistent, however, with regard to performance of single-deficit subgroups on untimed measures of decoding. Unlike the current findings, Cirino et al. (2005) observed no significant differences between the PA and VNS subgroups on these measures. Furthermore, the authors reported that the PA subgroup scored significantly higher than the DD subgroup on an untimed nonword decoding task. Cirino and colleagues reported a signficant difference between the PA and VNS subgroups on timed word decoding, a finding contrary to the current outcomes.

The current findings support the DDH, and suggest that a double deficit results in a more severe RD, and a single-deficit in either PA or VNS is associated with more reading difficulties than no deficit. Furthermore, a deficit in PA is associated with low or impaired performance in all measures of reading achievement, while this is not always true for those impaired in VNS. The current study also suggests that there are no significant differences in performance between the single-deficit groups on timed measures.

The single-deficit subgroups can also be differentiated from one another based on the pattern of intragroup performance across timed and untimed reading measures. Specifically, the VNS subgroup exhibits average performance on untimed measures, comparable to the ND subgroup, but performs below expectation on timed measures; the PA subgroup performs below expectation on all timed and untimed reading tasks, with the exception of Passage Comprehension.

Other Academic Achievement

As predicted, the VNS subgroup performed significantly better than the PA and DD subgroups on a spelling task. This supports similar reports in child samples (Lovett et al., 2000). Spelling requires the ability to identify phoneme-grapheme correspondences, which is believed to be impaired in the PA subgroup, thus the observed subgroup differences are to be expected. More interesting are the results of the timed and untimed mathematical tasks. On the timed math task, Math Fluency, the PA and ND subgroups performed above the VNS and DD subgroups, although no significant differences were observed. However, the trend for poorer performance in subgroups with a VNS deficit is consistent with the idea that Math Fluency requires the rapid retrieval of phonological representations from memory, much like RAN tasks that are highly dependent on automaticity (e.g., Garnett & Fleischner, 1983; Geary, 1993; Zentall, 1990); therefore, the poor performance demonstrated by the VNS and DD subgroups is expected.

It is intriguing, however, that those with a PA deficit and ND also performed below expectation. One explanation for the low performance of the PA subgroup may be that the initial encoding of phonological representations is impaired. It is also possible that these findings are a reflection of the frequent comorbidity of RD with math disabilities (MD; e.g., Badian, 1983; Gross-Tsur, Manor, & Shaleve, 1996), highlighting the possibility that a proportion of the participants might also suffer from a mathematics impairment. MD was not directly assessed in this study to address this question. The fact that all subgroups performed below age expectation may suggest the presence of associated academic difficulties in multiple domains. Another possibility is that poorer performance on Math Fluency may simply be a reflection of the population from which the sample was taken (i.e., students experiencing academic difficulties, which includes a variety of etiologies, such as depression, inattention, etc.).

On the Calculation subtest, the VNS subgroup performed significantly above the other deficit subgroups. The ND subgroup did not significantly differ from any subgroup. One may wonder if there is a link between language-based deficits and math, and in fact, associations between both PA and VNS and mathematical abilities have been identified. Hecht, Torgesen, Wagner, and Rashotte (2001) presented evidence supporting the influence of PA and VNS on the development of general math computation skills, as measured by the same Calculation subtest utilized in the current study. A growth analysis from second to fifth grade demonstrated a unique PA influence, while VNS was smaller and redundant. Hecht and colleagues also observed a reduced correlation between reading and general computation skills when the effects of PA and VNS were removed. They interpreted these results to mean that the “reason for the often reported associations between math computation and reading skills is that certain kinds of underlying phonological processing abilities influence both academic domains rather than because reading itself proximally influences variability in math computation skills (or vice versa)” (p. 216-217). Thus, the findings by Hecht and colleagues (2001) suggest that reading and math impairments share similar underlying cognitive deficits.

Neuropsychological Measures

Results from neuropsychological testing supported previous findings suggesting a VNS subgroup advantage in verbal intellectual abilities over the PA and DD subgroups (Lovett et al., 2000). Subgroup differences were significant for verbal comprehension. Although the VNS subgroup demonstrated a higher average performance on a measure of verbal memory compared to the DD and PA subgroups, no significant subgroup differences were found. The Matthew

Effect (Stanovich, 1986) may help explain the VNS subgroup advantage for verbal comprehension, but not verbal memory. Bast and Reitsma (1998) described the Matthew Effect as a phenomenon in which “over time, better readers get even better, and poorer readers become relatively poorer” (p. 1373). Thus, one might hypothesize that because those with only a VNS deficit typically exhibit a less severe form of RD, they may read more and become more advanced readers, thus expanding their vocabulary. The measure of verbal comprehension utilized in the current study (i.e., WAIS-3 Verbal Comprehension Index) is highly dependent on vocabulary knowledge and verbal expression, both of which tend to excel in good readers. Another explanation for a VNS advantage on verbal measures may be that early PA deficits impact later development of semantic language skills. This has far-reaching consequences and may lead to a more pervasive impact on a broad range of functions.

As predicted, the DD subgroup was more impaired than the VNS subgroup on a measure of visuospatial memory (RCFT), although subgroups did not differ on the copy trial of the RCFT. The RCFT is a figure that is easily verbalized, thus it is possible that the DD subgroup, which has more pervasive language problems in both PA and VNS, was unable to effectively utilize verbal strategies. Furthermore, it is possible that the DD subgroup is a more pervasively impacted group, i.e., not just language impaired, but with a broader array of cognitive problems beyond language. Consistent with this hypothesis, the DD subgroup also was significantly impaired compared to the ND subgroup on measures of cognitive and motor processing speed.

Classification of Subgroups

As postulated by the DDH, four mutually exclusive subgroups were identified based on the presence or absence of language deficits. The majority of individuals from our sample of reading impaired college stuents were identified as having a DD (n = 88). The next largest subgroup demonstrated a VNS impairment (n = 69), while the PA subgroup had the lowest number of participants (n = 31). Previous studies have at times identified a larger VNS subgroup compared to PA (Cirino et al., 2005; Goldberg et al., 1998, as cited in Wolf & Bowers, 1999; Lovett et al., 2000; Wolf et al., 2002), while others reported larger PA subgroups (Compton et al., 2001; Manis et al., 2000), and still others reported nearly equal sizes (Sunseth & Bowers, 2002). No pattern is easily discerned (i.e., type of sample utilized or the measures employed to classify subgroups) to explain the variation in subgroup sizes.

It is important to emphasize that a subgroup of impaired adult readers without deficits in PA and VNS was identified (ND subgroup = 38), suggesting that deficits in PA and VNS are not the sole sources of reading impairment in this sample. The ND subgroup was expected to be the smallest group, but this was not the case for the current sample. Interestingly, the proportion of individuals identified by the discrepancy criterion only was significantly higher in the ND subgroup compared to the deficit subgroups (Table 12; $x^2 = 41.18$, $p < .001$). Approximately 50% of the ND subgroup was identified based on a discrepancy criterion alone, not low achievement. The deficit groups on the other hand were primarily identified by meeting criterion for low achievement. Thus, as one might expect based on the portion of subjects identified by discrepancy only, the ND subgroup achieved scores predominantly in the average range. This finding might suggest that a low achievement criterion is more effective at capturing the "true positive" RD cases.

Controversy exists in the validity of creating mutually exclusive subgroups based on PA and VNS deficits, because some claim that they are different aspects of the same underlying construct, phonological processing (Torgesen et al., 1997; Wagner et al., 1993). However,

Table 12

Percentage of Subgroups Identified by Discrepancy, Low Achievement, or Both Criteria

Subgroup	% Identified by DISCR Criteria Only	% Identified by LA Criteria Only	% Identified by Both Criteria
PA	12.9	9.7	77.4
VNS	30.4	7.2	62.3
DD	4.5	9.1	86.4
ND	52.6	2.6	44.7

numerous studies have presented evidence to the contrary by demonstrating only a modest relation or the absence of a significant relation between the two constructs (Blachman, 1984; Compton et al., 2001; Cornwall, 1992; Goldberg et al., 1998, as cited in Wolf & Bowers, 1999; Swanson, et al., 2003; Wolf & Bowers, 1999). Supporting these findings, the relation between performance on PA and VNS measures in the present study was not significant (r = .116, p = .083).

Subgroup Differences in Ethnicity

A significantly larger proportion of ethnic minorities than European Americans were identified as having a double deficit. One explanation for such findings involves the effect of culture, specifically in relation to academic and neuropsychological assessment. Ardila (2005) outlined several cultural values specific to psychometric cognitive testing that may be unfamiliar to many examinees, or even go as far as to violate others' cultural norms. Two that may be particularly relevant include the value of "best performance" and "speed". These values assert that an examinee will try their best on a task, no matter how irrelevant and mundane. "At best" performance may be expected, despite the examinee's personal cultural values of doing so only when a task is perceived as extremely important and significant. Furthermore, Ardila argues that speeded tasks are often considered inappropriate in some cultures. Speed and accuracy are contradictory. Speed, competitiveness, and high productivity are values of literate Anglo-American society, but not necessarily values of many other cultures (Ardila, 2005). Thus, depending on the examinee's ethnicity and level of acculturation, one might expect to see a higher proportion of ethnic minorities with decreased performance on VNS tasks.

Along the same vein, PA may be disproportionately affected in minority groups. For example, Thompson, Craig, and Washington (2004) noted that individuals who speak Standard American English (SAE) may be at an advantage over those that speak other linguistic variations or dialects, such as African American English (AAE), as the school curriculums are taught in the former. Those that are more efficient at "code-switching" (the ability to switch between two dialects) have been found to achieve better academically than those that are poor code-switchers. Furthermore, Green (2002) noted that the phonological system of AAE speakers is the same as SAE, but the rules governing the occurrence of the sounds differ. Dialect differences, therefore, may have far-reaching effects on academic-achievement and PA test performance.

Strengths and Weaknesses

The results of the current study support and extend the DDH literature in several important ways. Most studies utilize child samples when studying RD and its cognitive underpinnings. This is one of few studies to investigate the DDH in an adult sample. Along the same line, this study provides evidence to support the persistence of PA and VNS deficits into adulthood. It is clear that some adults exhibit impairments in the ability to manipulate word sounds and rapidly retrieve phonological representations from memory, and that these deficiencies are associated with difficulties in reading abilities.

Previous studies on the DDH have generally had moderate to small sample sizes that were further reduced when subgroups were created. The sample utilized here includes a large number of participants, providing subgroup sizes adequate for statistical analyses. Furthermore, the sample was well-characterized. Multiple criteria were utilized to ensure identification of participants with RD based on low achievement as well as a regression-corrected aptitude-achievement discrepancy. More than one achievement measure was also utilized in hopes of tapping into reading difficulties associated with a VNS deficit. Two measures of VNS were utilized and composite measures of PA and VNS served as classification criteria. Previous studies have frequently utilized individual measures of similar constructs. The use of composite scores generally allows for more reliable data, thus strengthening confidence in our results.

A limitation of many studies of children is the lack of timed reading measures. The nature of a VNS deficit is a diminished ability to rapidly retrieve items from memory; therefore, applying time limits to reading tasks is necessary to fully capture the difficulties experienced by individuals with the VNS subtype of RD. The research presented here addresses this issue by including multiple measures of rate and fluency.

The current study further extends the DDH literature by moving beyond the reading domain to investigate academic and neuropsychological patterns of performance in college-level adults. Only two other known studies (Lovett et al., 2000; Waber et al., 2004) have investigated non-reading academic achievement and other cognitive and motor tasks, but there were limitations to these studies. Lovett et al. (2000) did not include an ND subgroup to compare RD children with PA, VNS, and double deficits to RD children without either deficit. However, this may have been difficult to attain, given that her sample was comprised of severely RD children. Waber and associates (2004) only identified 2% of their sample as having a PA-only deficit, possibly as a result of utilizing a word decoding task to determine PA deficits; therefore, they could not include a PA subgroup to address the link between PA deficits and other neuropsychological abilities.

There are also a number of limitations in the current study. Most striking is the lack of a control or non-reading impaired contrast group. The focus was on the DD subgroups and the characterization of their patterns of deficits and comparisons to each other. Future studies should include either a contrast group of students experiencing difficulty in other academic domains, or a control group of matched normally-achieving students. A control group would allow further characterization of the impact of language-based deficits on academic achievement and neuropsychological abilities compared to typically achieving individuals. For example, the VNS subgroup performed significantly higher than the DD subgroup on a task of rapid nonword decoding, however, it is important to note that the VNS subgroup still performed more than one standard deviation below the norm-based average. Therefore, a control group would allow the extent of impairments in all subgroups to be highlighted as compared to typically achieving students. Furthermore, select demographics were evaluated, but no measure of socioeconomic status (SES) was available in the database from which the sample was selected. SES might have a significant impact on academic achievement and possibly other cognitive and motor abilities. The relationship between subgroup membership and ethnicity highlights the importance of further exploration of other variables that may help elucidate the relationship, such as SES and acculturation (e.g., Manly et al., 1998).

Finally, the generalizability of these results may be limited because the sample is comprised of a clinical sample of college students and is not representative of the population of adults with reading disabilities. Furthermore, it is crucial to note that the measure utilized to classify subgroups, the CTOPP, only provides normative data up to age 24, while this sample includes individuals between the ages of 24 and 39. Some evidence suggests that PA skills begin to plateau by the 8th grade (Meyer et al., 1998a; Wagner et al., 1999), suggesting that the oldest normative age range for the CTOPP might adequately characterize the PA skills of the older participants in the sample. These normative limitations may be more problematic for the VNS measures. Age was significantly correlated with the alternative RAN tasks (i.e., objects and colors [$r = -.178$, $p = .008$], but not letters and digits [$r = -.096$, $p = .151$]) in this sample, so the possibility remains that VNS deficits were over-identified because older participants were being compared to younger participants from the CTOPP normative sample.

Implications

The results of the current study support the existence of different patterns of deficits based on DD subtype within reading impaired individuals. This has implications for the identification of RD, the types of interventions employed, and the types of accommodations offered. Most evaluations of RD in the past have focus on untimed measures of decoding, which may potentially lead to under-identification of reading impairment, especially in adults. It is not as common, however, to include timed measures of fluency and rate. The results of the present study suggest that timed measures of decoding and reading fluency and rate should be standard in the evaluation of individuals with possible reading disability. These are especially crucial for the present sample of college-level adults, who are typically expected to complete large quantities and advanced levels of readings each week.

Findings from the present study also suggest that reading impaired individuals with deficits in PA or VNS, and particularly with deficits in both (DD), also exhibit weaknesses in other academic and neuropsychological areas. This also has implications for evaluation and accommodations. Specifically, students may be experiencing difficulties in other academic areas due to weaknesses in various cognitive domains, such as verbal intelligence and visuospatial processing. Strengths and weaknesses should be assessed to determine the most appropriate accommodations and recommendations for individual students.

Finally, the current sample did not exhibit subgroup differences in sex or ADHD-diagnosis. This may suggest that both males and females are equally likely to have difficulties in either language area. While there were no significant subgroup differences for ADHD-diagnosis, a significant correlation between Inattention severity score and alternative rapid naming was observed, suggesting a link between inattention and rapid naming of semantically complex stimuli. Although ADHD was observed to exist comorbidly with RD in the current sample, it appeared as though ADHD was not associated with any particular subtype of RD. These findings suggest that sex and ADHD-diagnosis might not aid the identification of RD and the specific subtype.

Future Research

College students with reading disabilities frequently receive academic accommodations. Given the results of the current study demonstrating that different subtypes of RD result in differing types of impairments and varying severities, one might question how and if the accommodations benefit the student. Lovett and colleagues (2000) have investigated the effectiveness of interventions in children with regard to the DDH subgroups, but no studies have been conducted determining the effectiveness of accommodations in college students with various subtypes of RD. Such an investigation might provide support for the need for accommodations or identify areas of improvement or change in the types of accommodations offered.

Of interest were the differences among subgroups on other academic and neuropsychological tasks. These differences in cognitive performance may be suggestive of underlying difference in neural functioning. Neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) or diffusion tensor imaging (DTI) may be helpful in characterizing subgroup differences in cortical function and white matter integrity of relevant areas.

In the current study, between group differences were investigated, but it is unclear how significant the impact of PA and VNS were on individual tasks. Future studies may include multiple regression analyses to determine the amount of influence language performance (i.e., PA and VNS) has on neuropsychological and reading and non-reading academic abilities. Furthermore, different statistical methods might help elucidate our understanding of subgroup performance differences on non-reading measures that are less well understood.

Finally, future research may include race, ethnicity, dialect, and other important demographic variables in the study at the onset. This may be accomplished, for example, by including self-report of race/ethnicity or completing acculturation or SES measures. More qualitative information, such as information about quality of schooling, parental education or parental involvement in the student's learning, may also be helpful to clarify the read difficulties experienced by the ND subgroup.

In summary, the present study demonstrated no significant subgroup differences for sex or ADHD diagnosis. A clear pattern of performance on untimed reading tasks emerged in which the PA and DD subgroups perform significantly more poorly than the VNS and ND subgroups. On timed tasks, the VNS subgroup performed significantly below the ND subgroup on the majority of measures, but did not differ significantly from the PA subgroup. All three deficit subgroups performed significantly more poorly than the ND subgroup on rapid word and nonword decoding tasks, but the PA subgroup significantly scored higher than the DD subgroup on the rapid word decoding trial, while the VNS subgroup performed significantly better than the DD subgroup on the rapid nonword decoding trial. Significant subgroup differences were also observed on non-reading measures. The subgroups with no deficit in PA (i.e., VNS and ND) performed significantly higher than those with a deficit in PA on a spelling measure. No subgroup differences were observed on a math fluency task, but the VNS subgroup performed significantly above the other single-deficit subgroups on a measure of general mathematical abilities (Calculation). Finally, subgroup differences were highlighted on neuropsychological measures, with the VNS subgroup demonstrating stronger verbal comprehension and visuospatial abilities than the DD subgroup. All three deficit subgroups performed below the ND subgroup on a measure of processing speed, and no subgroup differences on a task of psychomotor speed, except for the nondominant hand trial. This study supports previous studies of college-level adults with RD and extends the literature to identify significant subgroup differences in non-reading academic achievement areas and neuropsychological abilities and presented evidence to suggest that sex and ADHD-diagnosis may not be related to RD subtypes in adults.

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Appendix A

Descriptive Data

	PA	VNS	DD	ND
	n = 31	n = 69	n = 88	n = 37
Age (mean)	20.71	21.28	22.11	21.30
Female (%)	48.4	42.0	40.9	47.4
Ethnicity (%)				
European American	74.2	85.5	63.6	94.7
African American	19.4	5.8	27.3	0
Asian	0	1.4	3.4	0
Hispanic	6.5	2.9	3.4	0
Multiracial	0	4.3	2.3	5.3
Handedness (%)	93.5	85.5	87.5	84.2
Anxiety Disorder (%)	12.9	5.8	6.8	13.2
Mood Disorder (%)	6.5	10.1	13.6	7.9
Rapid Digit Naming	10.10 (.32)	7.24 (.327)	6.94 (.235)	10.16 (.24)
Rapid Letter Naming	9.23 (.21)	6.27 (.32)	6.31 (.32)	9.62 (.30)
Rapid Naming Composite	98.00 (1.42)	80.52 (1.86)	79.26 (1.34)	99.35 (1.33)
Rapid Color Naming	11.03 (.443)	7.71 (.28)	7.31 (1.9)	10.78 (.39)
Rapid Object Naming	9.23 (.41)	6.14 (.25)	6.34 (.26)	9.76 (.42)

Alternative Rapid Naming Composite	100.80 (2.15)	81.55 (1.49)	80.55 (2.15)	101.62 (1.88)
Elision	5.00 (.41)	9.64 (.20)	6.00 (.94)	10.11 (.20)
Blending Words	6.13 (.28)	9.77 (.26)	6.69 (.86)	10.14 (.35)
Phonological Awareness Composite	72.63 (1.62)	98.52 (.88)	72.99 (.97)	100.73 (1.28)
LWID	83.67 (1.91)	94.42 (1.26)	82.95 (1.17)	96.20 (1.72)
WA	80.97 (1.95)	90.85 (1.28)	79.72 (1.19)	91.78 (1.75)
PC	91.54 (1.77)	101.50 (1.77)	93.17 (1.08)	103.26 (1.59)
RF	85.92 (1.55)	83.98 (1.02)	82.01 (.94)	89.33 (1.39)
NDComp	83.67 (2.49)	84.44 (1.64)	80.70 (1.52)	90.75 (2.24)
NDRate	84.11 (2.53)	79.77 (1.67)	80.24 (1.54)	87.40 (2.27)
TOWRE-s	83.16 (1.71)	79.43 (1.13)	77.09 (1.04)	90.07 (1.53)
TOWRE-p	76.24 (2.28)	80.78 (1.50)	70.75 (1.39)	88.31 (2.05)
Spelling	83.75 (2.14)	91.01 (1.44)	83.62 (1.30)	92.93 (1.96)
Calculation	89.88 (2.66)	101.55 (1.79)	92.21 (1.62)	99.09 (2.43)
Math Fluency	87.68 (2.15)	83.37 (1.44)	83.46 (1.31)	89.57 (1.96)
VCI	99.12 (2.45)	109.22 (1.65)	98.16 (1.55)	111.71 (2.29)
LogMem Recall	8.66 (.52)	9.64 (.35)	8.41 (.33)	9.88 (.49)
RCFT Delay	19.38 (1.24)	22.25 (.83)	18.13 (.78)	23.06 (1.15)
BD	9.95 (.53)	11.59 (.35)	9.70 (.33)	12.19 (.49)
DigSym	9.12 (.45)	8.25 (.30)	8.40 (.28)	11.07 (.42)

GPDom	91.23 (2.15)	92.63 (1.45)	89.24 (1.36)	95.13 (2.01)
GPNondom	90.05 (2.33)	94.48 (1.57)	87.11 (1.47)	95.70 (2.18)

Note. LWID = Letter-Word Identification; WA = Word Attack; PC = Passage Comprehension; RF = Reading Fluency; NDComp = Nelson-Denny Reading Test, Comprehension; NDRate = Nelson-Denny Reading Test, Reading Rate; TOWRE-s = Test of Word Reading Efficiency, Sight Word Efficiency; TOWRE-p = Test of Word Reading Efficiency, Phonemic Decoding Efficiency; VCI = Verbal Comprehension Index; DigSym = Digit Symbol Coding; BD = Block Design; LogMem Recall = Logical Memory I Recall Total; RCFT Delay = Rey Complex Figure Test; GPDom = Grooved Pegboard, dominant hand trial; GPNondom = Grooved Pegboard, nondominant hand trial.

Appendix B

Intercorrelations for Dependent Measures

	LWID	WA	PC	RF	ND Comp	ND Rate	TOWRE-s	TOWRE-p	Spelling	Calculation	Math Fluency
LWID											
WA	.811*										
PC	.581**	.448**									
RF	.246**	.112	.395**								
NDComp	.350**	.195**	.439**	.568**							
NDRate	.177**	.063	.175**	.525**	.595**						
TOWRE-s	.567**	.502**	.321**	.440**	.427**	.467**					
TOWRE-p	.699**	.722**	.411**	.287**	.397**	.355**	.725**				
Spelling											
Calculation									.537**		
Math Fluency									.388**	.559**	

	VCI	DigSym	BD	LogMem Recall	RCFT Delay	GPDom	GPNondom
VCI							
DigSym	.028						
BD	.391**	.317**					
LogMem Recall	.408**	.106	.194**				
RCFT Delay	.279**	.194**	.539**	.334**			
GPDom	.306**	.345**	.407**	.095	.277**		
GPNondom	.330**	.254**	.475**	.161*	.319**	.734**	

*$p \leq .05$, **$p \leq .01$. Note. LWID = Letter-Word Identification; WA = Word Attack; PC = Passage Comprehension; RF = Reading Fluency; NDComp = Nelson-Denny Reading Test, Comprehension; NDRate = Nelson-Denny Reading Test, Reading Rate; TOWRE-s = Test of Word Reading Efficiency, Sight Word Efficiency; TOWRE-p = Test of Word Reading Efficiency, Phonemic Decoding Efficiency; VCI = Verbal Comprehension Index; DigSym = Digit Symbol Coding; BD = Block Design; LogMem Recall = Logical Memory I Recall Total; RCFT Delay = Rey Complex Figure Test; GPDom = Grooved Pegboard, dominant hand trial; GPNondom = Grooved Pegboard, nondominant hand trial.