Evaluation of the Double-Deficit Hypothesis in College Students Referred for Learning Difficulties

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Abstract

The present study explored the double-deficit hypothesis (DDH) in a sample of 146 college students with and without reading disabilities (RD). The results indicated that although both phonological awareness (PA) and visual naming speed (VNS) contributed to performance on measures of decoding and comprehension, their relative contribution was influenced both by the nature of the stimulus (word vs. nonword vs. text) and by the conditions of the task (timed vs. untimed). Similar results were obtained using an individual differences approach, or when between-group comparisons were made of individuals with deficits in PA or VNS. The relative representation of DDH subgroups in groups of adults with RD varied based on the classification criteria used to define RD. These results support the DDH, extend its applicability to adults, and have implications for diagnostic decision making.

Word reading ability is strongly related to phonological processing skills (*phonological awareness*; PA), frequently measured via phoneme deletion and blending tasks (Bradley & Bryant, 1983; Bruck, 1992, 1993; Stanovich & Siegel, 1994; Wagner, Torgesen, & Rashotte, 1994). Deficits in PA may lead to later difficulties with vocabulary development and reading comprehension (Stanovich, Cunningham, & Feeman, 1984; Wagner & Torgesen, 1987). Another correlate of word reading skill is the ability to rapidly retrieve the spoken referent or name for a visual stimulus (*visual naming speed*; VNS), often measured through the rapid naming of alphanumeric stimuli (Bowers & Swanson, 1991; Bowers & Wolf, 1993; Denckla & Rudel, 1974, 1976; Wolf, 1984, 1986). Deficits in VNS may lead to slow word decoding regardless of accuracy, which in turn may reduce reading comprehension, either through their shared variance with phonological skills or decoding (Bowers & Swanson, 1991; Kail & Hall, 1994; Spring & Davis, 1988) or through a reduction in available cognitive resources for holding information, following syntax, and understanding context. Although reading disabilities (RD) may arise through deficits in either PA or VNS alone, the *double-deficit hypothesis* (DDH; Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000) suggests that these skills may interact in the reading process, which has implications for both the prediction of reading skill and the classification of struggling readers.

Evidence for the roles of both PA and VNS in the reading process comes primarily from studies of children. In children, PA is predictive of decoding in both children with RD (Compton, DeFries, & Olson, 2001; Cornwall, 1992; Wolf et al., 2002) and average readers (Wagner, Torgesen, Laughlon, Simmons, & Rashotte, 1993; Wagner et al., 1994). Moreover, PA skills do not appear to differ between children who evidence a discrepancy between IQ and reading and nondiscrepant poor readers (e.g., Fletcher et al., 1994; Stanovich & Siegel, 1994). The relation of VNS with reading is strong in all young readers, although there is typically a maximal (ceiling) performance by the end of the second grade for average (but not impaired) readers (Wolf, Bally, & Morris, 1986). There has been some debate regarding the specific versus general nature of timing deficits, with some studies (e.g., Kail & Hall, 1994) finding that VNS was related to decoding skills through the mediation of general cognitive processing speed. Meyer, Wood, Hart, and Felton (1998) found that in impaired (but not average) readers, VNS was a significant predictor of real-word identification in Grades 5 and 8, even after covarying for Grade 3 real-word reading, IQ, and SES (but not general processing speed).

The correlation between VNS and PA is typically modest (.10 to .40, depending on the sample), which suggests their relative independence from one another (Wolf & Bowers, 1999), although very little is known about their relationship in adult readers. As these two processes have the potential to influence reading via both common and unique pathways, several studies have sought to assess their relative contributions to reading competence. To date, multiple approaches have been used to address this question.

Some investigations have used a regression approach (examining the proportion of variance in reading accounted for by PA and VNS; e.g., Ackerman & Dykman, 1993; Compton et al., 2001; Cornwall, 1992; Wolf et al., 2002). Both VNS and PA independently contribute to both real and nonword decoding (Ackerman & Dykman, 1993; Compton et al., 2001; Wolf et al., 2002) after covarying for IQ. Contributions of PA and VNS are generally similar for real words, although PA appears to be a stronger predictor than VNS for nonwords. The relation of PA and VNS to reading comprehension in children is less well defined. For example, although Cornwall (1992) found PA (but not VNS) to be a significant predictor of untimed reading comprehension, other studies (Compton et al., 2001; Wolf et al., 2002) found that PA and VNS were both unique predictors.

Other studies have adopted a between-groups approach (comparing subgroups of readers who are defined based on the presence of deficits in PA or VNS; e.g., Felton, Naylor, & Wood, 1990; Lovett, Steinbach, & Frijters, 2000). Some investigators (Lovett et al., 2000; Wolf et al., 2002) have used the DDH to classify samples of children with severe RD and found that more than half of the children had a double deficit (in PA and VNS); smaller subgroups had only a PA (approximately 25%) or VNS (approximately 15%) deficit. The number of nonclassifiable children ranged from 4% (Wolf et al., 2002) to 16% (Lovett et al., 2000). Compton et al. (2001) noted that 61% to 93% of children with RD were classifiable according to the DDH, depending on the criteria used, and results similar to the Lovett et al. (2000) and Wolf et al. (2002) studies were obtained when cutoffs similar to those in these studies (1 *SD* below normative means) were used.

Although Wolf and colleagues (Wolf & Bowers, 1999; Wolf et al., 2000) predicted differential patterns of performance among these DDH-defined subgroups, some authors have shown that differences among subgroups defined dichotomously according to the DDH may be misleading due to statistical artifacts (Compton et al., 2001; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). These artifacts include a reduction in power as well as the possibility that the double-deficit group is not matched to single-deficit groups on the subtyping variables and may show less regression to the mean. These difficulties are primarily of concern when the subtyping variables are significantly correlated with one another. However, when subtyping variables are not significantly correlated, and differences do arise among subgroups, between-group comparisons may be useful, particularly when used in combination with regression techniques.

A further difficulty in addressing the relationship of DDH subtypes to RD diagnosis is that criteria for RD vary in terms of both the definition used (often across settings) and the criterion skills assessed. For example, in clinical settings, RD is frequently defined using a discrepancy between IQ scores and some aspect of reading performance (Frankenberger & Fronzaglio, 1991). However, there have been critical challenges to the practice of defining RD according to discrepancy criteria (e.g., Siegel, 1992), and in many research studies, RD is often defined on the basis of low reading scores and PA deficits. In any case, some aspect of IQ is typically considered when addressing language or reading deficits, given (or in spite of) the overlapping variance of PA with IQ and "Matthew effects" of reading experience on IQ scores (Stanovich, 1986). Another difficulty in both clinical and research settings is that the diagnosis of RD is based almost exclusively on untimed measures of reading performance. This situation may introduce a methodological bias toward stronger relationships of PA with reading performance relative to VNS, as both PA and reading performance are untimed. In sum, there are reasons for conceptualizing RD rather broadly, using both low achievement (LA) and discrepancy (DIS) definitions and both decoding and comprehension skills, under timed and untimed conditions, as criterion skills.

Wolf et al. (2000) noted the importance of automaticity to changes in the relative relations of VNS and PA to reading skills across the early elementary school years. The pattern of relationships among these constructs in adult readers is less clear, given that many fewer studies of the DDH have focused on adults. Automatized skills linked to VNS may become more critical for both rate of reading and comprehension in adults, particularly college students, as the expectations given to both volume and understanding of reading material are high.

Other aspects of the DDH and its constituent cognitive processes in adult readers are also unclear. Studies of adults with RD have focused on the impact of PA deficits on untimed decoding ability (Bone, Cirino, Morris, & Morris, 2002; Bruck, 1992, 1993; Elbro, Nielsen, & Petersen, 1994; Pratt & Brady, 1988). PA deficits are present in many of these adults (including those who had received remediation), whether real-word reading was adequate (Bruck, 1992) or below average (Pratt & Brady, 1988). However, the impact of PA on reading comprehension in these individuals is less clear. Moreover, there are few reports of the impact of VNS (alone or in combination with PA) on decoding or comprehension skills in adults. An exception was the study of Felton et al. (1990), who found that both PA and VNS discriminated between readers with and without a history of RD. It is not known, however, to what degree VNS deficits affect reading skills in adults over and above PA skills; also, no known studies have identified subgroups of adult readers using the DDH framework and compared their reading performances.

This study incorporated both regression and between-group analyses to examine the impact of PA and VNS on reading performance and RD group membership in college students, using multiple criterion measures of reading. First, we assessed the relative contributions of PA and VNS to reading ability in a sample in which significant variability in reading performance was present. Second, we used the DDH to identify mutually exclusive subtypes within this sample, based on the presence or absence of deficits in PA or VNS, and compared their performance on reading measures. Finally, we explored the representation of these DDH subgroups in samples selected using different RD classification criteria.

Hypotheses

Several hypotheses were investigated based on the preceding literature review, taking into consideration the results of numerous child studies of the DDH and the limited studies of PA and VNS in adults:

1. When PA and VNS were considered alone, each would be related to performance in all aspects of reading.
2. When PA and VNS were considered together, PA would be more important than VNS for decoding under untimed conditions (particularly for nonwords). Conversely, VNS would be more important than PA for timed reading comprehension. PA and VNS were expected to have a similar impact on untimed reading comprehension and timed decoding.
3. When the DDH was used as a framework to identify four mutually exclusive subgroups of readers based on patterns of processing deficits (PA Only, VNS Only, Double-Deficit, Neither), we hypothesized that the Double-Deficit subgroup would have the lowest (and the Neither subgroup the highest) performance in all aspects of reading. We expected that the VNS Only subgroup would outperform the PA Only subgroup on measures of untimed decoding, and that the opposite pattern would occur for timed comprehension.
4. Finally, we also hypothesized that DDH subgroups would be related to the diagnostic criteria used to define RD. We expected that the Double-Deficit subgroup would be the most (and the Neither subgroup the least) represented when RD was defined according to any criterion. Specific patterns of differences were also expected according to the reading criterion employed, with the PA Only subgroup being more represented relative to the VNS Only subgroup when untimed decoding was the reading criterion for RD, and the opposite pattern manifesting when timed reading comprehension was the reading criterion for RD.

Method

Participants

One hundred sixty-five college or university students who were referred to an on-campus assessment center for evaluation of academic difficulties and who completed all of the relevant measures constituted the initial sample. Many students were self-referred in order to determine whether or not a learning disability was present, although, as indicated in Table 1, other diagnoses that can affect academic functioning were quite common. Students with a history of neurological disorder (e.g., traumatic brain injury, epilepsy) or psychopathology other than depression or anxiety (e.g., schizophrenia) were excluded from the study sample (n = 19). Diagnoses of attention-deficit/hyperactivity disorder (ADHD) or mood or anxiety disorders were made by an assessment team led by a licensed clinical psychologist on the basis of the *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition* (*DSM-IV*; American Psychiatric Association, 1994) but were not excluded from analysis given their frequency. The mean age of the final sample (N = 146) was 23.5 (SD = 7.1), and the mean *Wechsler Adult Intelligence Scale–III* (WAIS-III; Wechsler, 1997) Full Scale IQ score was 103.7 (SD = 12.7).

Measures

Each participant received a comprehensive examination that investigated intellectual, academic, neuropsychological, and socioemotional functioning and typically took place over the course of two sessions. For this study, the primary measures were those of reading achievement (timed and untimed decoding and comprehension) and language processing (phonological awareness and visual naming speed).

Reading Achievement. The *Woodcock-Johnson Psychoeducational Battery–*

TABLE 1
Participant Characteristics

Characteristic	*n*	%
Gender (women)	78	53
Race (European American)	123	84
Right handed	122	84
Attention-deficit/hyperactivity disorder[a]	49	34
Anxiety or mood disorder[b]	44	30

Note. N = 146.
[a]Diagnoses were made according to *DSM-IV* criteria; 30 participants (21%) were predominantly inattentive type, and 19 (13%) were predominantly impulsive–hyperactive or combined types.
[b]Diagnoses were made according to *DSM-IV* criteria; 16 (11%) met only criteria for an anxiety disorder, 21 (14%) met only criteria for a mood disorder, and 7 (5%) met criteria for both anxiety and mood disorder.

Revised (WJ-R; Woodcock & Johnson, 1990) is a well-standardized instrument concordant with U.S. Census statistics (Woodcock & Mather, 1990). Reading subtests used as measures of untimed decoding were Letter–Word Identification and Word Attack (the Basic Skills Composite, composed of these subtests, was also used). The Passage Comprehension subtest was used as a measure of untimed comprehension. Letter–Word Identification requires the reading of real words, Word Attack requires the reading of nonwords, and Passage Comprehension is a cloze task requiring the participant to supply a missing word from a sentence. Dependent measures were standard scores. Median coefficients alpha ranged from .90 to .92 across all age ranges for the subtests used, and concurrent validity data were also available (McGrew, Werder, & Woodcock, 1991; Woodcock & Mather, 1990).

The *Test of Word Reading Efficiency* (TOWRE; Torgesen, Wagner, & Rashotte, 1999) has two subtests that were used as measures of timed decoding. The first is Sight Word Efficiency, which measures the number of real words of increasing length and difficulty correctly read in 45 seconds. The second is Phonemic Decoding Efficiency, measuring the number of nonwords of increasing length and difficulty correctly read in 45 seconds. The normative base consists of 1,507 individuals ages 6 to 24 similar to 1997 U.S. Census statistics. Dependent measures were age-based standard scores; for participants older than age 25 (n = 42; 28%), norms for the oldest age group (19 to 24) were used (86% of all participants were age 30 or younger, and 94% were age 39 or younger). Coefficients alpha for several different subgroups in the normative sample ranged from .92 to .98 for both subtests; alternate form reliability for the oldest age group was .89 (Sight Word Efficiency) and .94 (Phonemic Decoding Efficiency).

The *Nelson Denny Reading Aptitude Test* (ND; Brown, Fishco, & Hanna, 1993) is a commonly used measure of silent reading comprehension. Participants are given 20 minutes to read seven passages and answer 38 questions, with no penalty for guessing. Alternate form reliability for the Comprehension subtest was .81. The normative base includes nearly 10,000 students at 39 two-year colleges and 38 four-year colleges and universities stratified by geographic region, district enrollment, and socioeconomic status (Brown et al., 1993). Two dependent measures from the ND were used as measures of timed comprehension; both of these measures were provided by the standard administration of this task under timed conditions. One measure was the standard score generated from normative data. The second measure was a derived raw score that was produced by dividing the number of correct items (within the time limit) by the number of items attempted (within the time limit). Thus, an individual who obtained a raw score of 12 would achieve a given standard score regardless of the number of items attempted, but the percentage correct score would be influenced by the number of items attempted (e.g., 12/12 = 100%; 12/24 = 50%; 12/36 = 33%). This percentage-correct measure, therefore, could reduce the impact of time, which was important for this sample because many participants (n = 122; 84%) did not complete all of the items within the allotted time, and many (n = 117; 80%) did not complete at least 85% of the items.

Language Processing. The *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999) contains nine subtests measuring phonological awareness (PA), rapid visual naming speed (VNS), and phonological working memory. The normative base consisted of 1,656 individuals ages 5 to 24 similar to 1997 U.S. Census statistics.

The Elision and Blending Phonemes subtests were used as measures of PA. Elision requires a participant to listen to an audiotape and repeat a real word, then repeat the word with a specified phoneme deleted, which may appear in the initial, middle, or rime portion of a word; in each case, the result is a real word. Blending Phonemes requires a participant to blend several phonemes heard from an audiotape into a real word; items increase in difficulty by increasing the number of phonemes to be blended from two to eight.

Two measures, Rapid Letter Naming and Rapid Digit Naming, were used as measures of VNS. Rapid Letter Naming requires a participant to read from left to right and line to line a series of six letters (*s*, *t*, *a*, *n*, *c*, *k*) arranged in a 9 × 4 format. The process is repeated with a second set of the same letters in a different order. Standard scores are based on the time taken to read all 72 stimuli. The Rapid Digit Naming subtest is methodologically identical, except that the stimulus set is composed of six numbers (2, 3, 4, 5, 7, 8).

Dependent measures were standard scores for the PA and VNS Composites (combinations of the aforementioned subtests as per the CTOPP manual); for students above age 25 (n = 42; 28%), norms for the oldest age group (19 to 24) were used (86% of all participants were age 30 or younger, and 94% were age 39 or younger). Coefficients alpha for several different subgroups in the normative sample ranged from .83 to .98 for both composites; coefficients alpha for the oldest age group were .90 (PA Composite) and .92 (VNS Composite).

Covariates. Several variables have been identified as potential difficulties to documenting the impact of PA and VNS on reading ability, and in several previous studies of the DDH, analyses were often presented that used covariates (e.g., Ackerman & Dykman, 1993; Cornwall, 1992; Felton et al., 1990; Kail & Hall, 1994; Meyer et al., 1998; Wolf et al., 2002). Three covariates were considered in the present study, given its focus on the specific, unique contributions of PA and VNS: general processing speed (for VNS), general vocabulary (for PA), and single-word reading (for reading comprehension). The first two covariates were included to address the specific versus general contribution of speed and language skills. Single-word reading was included for reading comprehension because the precursors of decoding skills have been extensively studied, and because of the hierarchical nature of reading (decoding can occur without comprehension, although comprehension rarely occurs without decoding skill; e.g., Shankweiler et al., 1999). Using covariates in this manner allows a more stringent test of the specific impact that PA or VNS has on reading skills, over and above more general or known factors. However, given the debate on the use of covariates in quasi-experimental research, analyses were conducted both with and without covariates. For enhanced clarity, in subsequent sections, results are first described without covariates, and then the effect of inserting covariates is discussed. Descriptions of the vocabulary measure and the general processing speed measure follow. Single-word decoding measures were obtained from the set of reading achievement measures described earlier.

The *Wechsler Adult Intelligence Scale–III* (WAIS-III; Wechsler, 1997) Vocabulary (VOC) subtest involves the provision of verbal definitions to verbally and visually presented words. VOC age-based scaled score was used as a proxy measure of IQ, as it has the highest subtest correlation with both the Verbal and Full Scale IQ composites (Psychological Corp., 1997). The mean coefficient alpha for the VOC subtest was .93 across age ranges, and the test–retest coefficient was .89 in 100 individuals over 2 to 12 weeks within the 16–29 age subgroup (Psychological Corp., 1997).

The *Visual Search and Attention Test* (VSAT; Trenerry, Crosson, DeBoe, & Leber, 1990) is a speeded scanning task that requires crossing out of identified targets (a blue letter *H* and the blue symbol /) from among perceptually similar distractors. It was selected as a measure of general processing speed that requires scanning and recognition of visual stimuli but does not require explicit naming. The normative base for the VSAT included 272 adults ages 18 to 85 years, with neurological, psychiatric, or physical illness excluded (where these were thought to interfere with VSAT performance). Test–retest reliability for 28 participants over 2 months was .95, with practice effects noted (Trenerry et al., 1990). The standard score for the number of correctly crossed target items in 60 seconds was used for analysis.

Criteria for DDH and RD Categorization. Criteria for these two types of classifications were based on deficits of 1 *SD* (for DDH, and for low achievement in RD) or one standard error of the estimate (for regression-based discrepancy in RD). The details of these categorizations appear in the Results section just prior to the presentation of the analyses.

Analysis Overview

Preliminary analyses included examination of normality, box, and stem-and-leaf plots as well as other univariate statistics. Each of the primary measures examined exhibited adequate variability, and skewness and kurtosis values were all less than 1. Age was positively skewed, as would be expected in a population of college students; however, this variable did not correlate significantly with any variable of interest using a conservative criterion ($p < .01$) to compensate for the number of comparisons performed, and, therefore, it was not used in further analyses.

Simple linear regression analyses were performed to examine the predictive relationship of PA and VNS with measures of reading achievement. Multiple regression analyses (to examine the relative and combined ability of PA and VNS to predict outcomes on reading measures) were also conducted, with PA and VNS entered simultaneously into each model; standardized regression coefficients were used as measures of effect size. Between-group analyses were performed using the general linear modeling (GLM) procedure in SAS (SAS Institute, 1988), with DDH subgrouping as the independent variable and reading achievement as the outcome variable. Where omnibus between-group analyses were significant, post hoc Tukey analyses were conducted to explore inter-subgroup differences; effect sizes between specific groups for most hypotheses were calculated using Cohen's *d* (Cohen, 1988). Finally, chi-square and frequency-based analyses were used to determine the impact of RD classification criteria on the relative representation of DDH subgroups.

Results

Hypothesis 1: PA and UNS Alone

Both PA and VNS, considered separately, were significantly predictive of each aspect of reading achievement (subtests and composites), as expected, except that VNS was not predictive of WJ-R Passage Comprehension or ND percentage correct. These results are presented in Table 2.

Hypothesis 2: PA and VNS Together

Although PA and VNS were each predictive of most aspects of reading skill when considered alone, more specific hypotheses concerned the *relative* impact of these skills. A series of multiple regression analyses evaluated the relative degree to which PA and VNS accounted for variance on measures of decoding and comprehension. The results are presented in Table 3, including model values (where PA and VNS were entered simultaneously) as well as standardized regression coefficients for the individual predictors; these coefficients were interpreted as relative effect sizes (the *SD* change in criterion

TABLE 2
Effects of Language Processing Variables Taken Separately on Measures of Reading Achievement

Measure	Adj. R^2	β	t	p
Untimed decoding				
WJ-R Letter–Word Identification				
PA	.30	.554	7.98	.0001
VNS	.04	.219	2.69	.008
WJ-R Word Attack				
PA	.37	.611	9.27	.0001
VNS	.07	.282	3.53	.0006
Timed decoding				
TOWRE Sight Word Efficiency				
PA	.12	.349	4.45	.0001
VNS	.50	.712	12.23	.0001
TOWRE Phonemic Decoding Efficiency				
PA	.31	.564	8.17	.0001
VNS	.27	.523	7.34	.0001
Untimed comprehension				
WJ-R Passage Comprehension				
PA	.20	.453	6.09	.0001
VNS	.00	.097	1.17	*ns*
Timed comprehension				
ND Reading Comprehension (standard score)				
PA	.07	.268	3.33	.001
VNS	.05	.235	2.89	.005
ND Reading Comprehension (% correct)				
PA	.12	.357	4.58	.0001
VNS	.01	.112	1.35	*ns*

Note. N for each analysis was either 145 or 146, and degrees of freedom were correspondingly (1, 144) or (1, 145). WJ-R = *Woodcock-Johnson Psychoeducational Battery-Revised* (Woodcock & Johnson, 1990); TOWRE = *Test of Word Reading Efficiency* (Torgesen, Wagner, & Rashotte, 1999); ND = *Nelson-Denny Reading Aptitude Test* (Brown, Fishco, & Hanna, 1993); PA = *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999) Phonological Awareness composite; VNS = CTOPP Rapid Naming composite; Adj. R^2 = adjusted proportion of variance accounted for by individual predictors; β = standardized regression coefficients for individual predictors; t = test of significance for the variable (the t value squared is equivalent to Type III sums of squares in the general linear model); p = probability of t.

corresponding to a 1 *SD* change in predictor).

For untimed word reading (WJ-R Letter-Word Identification), the model was significant, $p < .0001$, $R^2 = 32\%$. Although PA and VNS each contributed significantly over the other, PA had a much larger effect size (and larger t value) than VNS. Similar results were obtained for untimed nonword reading (WJ-R Word Attack). The model was significant, $p < .0001$, $R^2 = 41\%$, and PA and VNS each contributed significantly over the other, but again PA had a much larger effect size than VNS.

For timed word reading (TOWRE Sight Word Efficiency), the model was significant, $p < .0001$, $R^2 = 58\%$, and PA and VNS each made contributions over the other, but VNS had a much larger effect size than PA. For timed nonword reading (TOWRE Phonemic Decoding Efficiency), the model was significant, $p < .0001$, $R^2 = 53\%$. However, in contrast to timed word reading, the effect sizes for PA and VNS were similar.

For untimed reading comprehension (WJ-R Passage Comprehension), the model was significant, $p < .0001$, $R^2 = 20\%$. Although PA contributed over VNS, with an effect size of .448, the reverse was not the case, and VNS was not significant over PA. However, for timed reading comprehension (ND standard scores), the model was significant, $p < .0002$, $R^2 = 10\%$, and both PA and VNS were significant contributors, with similar and modest effect sizes for PA and VNS. For timed reading comprehension using the ND percentage correct (which adjusts for the number of items attempted), the results were similar to those for WJ-R Passage Comprehension; the model was significant, $p < .0001$, $R^2 = 12\%$, and PA was the only significant contributor.

Corresponding results using covariates are presented in Table 4. These analyses allow for examination of the role of potential mediating factors such as vocabulary knowledge and visual scanning speed (for all analyses), untimed word reading (for untimed reading comprehension), and timed word reading (for timed reading comprehension) and their impact on the degree of *incremental* variance attributable to PA or VNS over these covariates.

The results of the analyses conducted with covariates were similar to those performed without covariates; however, there were two primary effects of including PA and VNS in the second step of a hierarchical regression (i.e., after first including covariates). One effect was to increase the degree of variance in reading accounted for by the entire set of predictor measures (from 2% to 9% for decoding, and from 14% to 35% for comprehension). Of the covariates, vocabulary was a significant contributing factor to all reading measures except Word Attack, whereas processing speed was significant only for timed decoding measures; single-word decoding measures were significant for reading comprehension. The second effect of covariate inclusion was to simultaneously decrease the amount of unique variance accounted for by PA and VNS (10% to 21% across all measures). However, few substantive changes were noted. For decoding skills (timed and untimed), both PA and VNS remained significant, and the pattern of their contribution did not change (e.g., PA remained a stronger predictor than VNS for Word Attack). For comprehension (timed and untimed), however, the inclusion of covariates diminished the unique contributions of PA and VNS to nonsignificance.

Hypothesis 3: DDH Subgroups

Based on the DDH, four mutually exclusive subgroups (PA Only, VNS Only, Double-Deficit, or Neither) were identified within the study sample. The PA Only subgroup had a CTOPP PA composite standard score at least 1 *SD* below the normative mean of 100 on this measure (i.e., 85 or less), and a CTOPP VNS composite standard score higher than 85; the VNS Only subgroup exhibited the opposite pattern. The Double-Deficit subgroup had standard scores at or below 85 on both composites, and the Neither subgroup had standard scores above 85 on both composites. The correlation between the CTOPP PA and VNS composite scores in this sample was $r = .13$, $p > .05$, which reduces the possibility of statistical difficulties associated with creating double-deficit groups.

The results of the between-group comparisons among DDH subgroups are presented in Table 5. On the composite measure of PA, the PA Only and Double-Deficit subgroups performed similarly and significantly below each of the other two subgroups, who did not differ from one another. On the composite measure of VNS, the VNS Only and Double-Deficit subgroups performed similarly and significantly below each of the other two subgroups, who did not differ from one another. These results were as expected on these definitional variables and show that the Double-Deficit subgroup was matched to the single-deficit subgroups on subgrouping variables.

DDH categorization was predictive of performance on measures of untimed decoding: WJ-R Letter–Word Identification, $F(3, 142) = 14.73$, $p < .0001$, $R^2 = .24$; WJ-R Word Attack, $F(3, 142) = 21.03$, $p < .0001$, $R^2 = .31$. Post hoc analyses indicated that in both cases, the Neither subgroup performed significantly higher than each of the three deficit subgroups, which was supportive of our hypothesis, and the size of these differences was large (d = .53–1.94). However, the PA Only and VNS Only subgroups did not differ significantly from one another, which was not supportive of our hypothesis, although the effect sizes were moderate (d = .48–.51). For WJ-R Letter–Word Identification, the Double-Deficit subgroup had significantly weaker performance than the VNS Only but not the PA Only subgroup. For WJ-R Word Attack, the Double-Deficit subgroup had significantly lower performance than both PA Only and VNS Only subgroups. However, across measures, the Double-Deficit subgroup had the lowest absolute scores, and the effect size of this difference was large (d = .70–1.94).

DDH categorization was also predictive of timed decoding measures: TOWRE Sight Word Efficiency, *F*(3,

TABLE 3
Effects of Language Processing Variables Taken Together on Measures of Reading Achievement

Measure	Adj. R^2	β	*F* or *t*	*p*
Untimed decoding				
WJ-R Letter Word Identification	.32		35.11	.0001
PA		.535	7.75	.0001
VNS		.151	2.19	.0298
WJ-R Word Attack	.41		51.06	.0001
PA		.585	9.09	.0001
VNS		.209	3.24	.0015
Timed decoding				
TOWRE Sight Word Efficiency	.58		99.72	.0001
PA		.272	5.00	.0001
VNS		.684	12.56	.0001
TOWRE Phonemic Decoding Efficiency	.53		80.87	.0001
PA		.512	8.86	.0001
VNS		.466	8.07	.0001
Untimed comprehension				
WJ-R Passage Comprehension	.20		18.61	.0001
PA		.448	5.96	.0001
VNS		.041	0.54	*ns*
Timed comprehension				
ND Reading Comprehension (standard score)	.10		9.16	.0002
PA		.245	3.08	.0025
VNS		.207	2.60	.01
ND Reading Comprehension (% correct)	.12		10.87	.0001
PA		.348	4.43	.0001
VNS		.068	0.87	*ns*

Note. *N* for each analysis was either 145 or 146, and degrees of freedom were correspondingly (2, 143) or (2, 144). WJ-R = *Woodcock-Johnson Psychoeducational Battery-Revised* (Woodcock & Johnson, 1990); TOWRE = *Test of Word Reading Efficiency* (Torgesen, Wagner, & Rashotte, 1999); ND = *Nelson-Denny Reading Aptitude Test* (Brown, Fishco, & Hanna, 1993); PA = *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999) Phonological Awareness composite; VNS = CTOPP Rapid Naming composite. Adjusted R^2 values, listed in the row of the reading measure, are not specific to the individual predictors (PA or VNS) but rather reflect their combined contribution; in contrast, β values are specific to individual predictors. *F* or *t*: the values in this column represent either the *F* statistic (for the entire model on the row of the particular reading measure) or the *t* statistic (for the individual predictors).

TABLE 4
Multiple Regression Analyses: Measures of Reading Decoding and Reading Comprehension

Measure	Adj. R^2	ΔR^2	β	*F* or *t*	*p*
Untimed decoding					
WJ-R Letter–Word Identification					
Step 1					
VOC	.29	—	.302	3.91	.000
VSAT			.101	1.38	*ns*
Step 2					
PA	.41	.12	.378	4.82	.000
VNS			.147	2.05	.043
WJ-R Word Attack					
Step 1					
VOC	.20	—	.122	1.60	*ns*
VSAT			.096	1.33	*ns*
Step 2					
PA	.43	.23	.502	6.48	.000
VNS			.200	2.82	.006
Timed decoding					
TOWRE Sight Word Efficiency					
Step 1					
VOC	.20	—	.131	2.16	.033
VSAT			.127	2.22	.028
Step 2					
PA	.64	.44	.199	3.22	.002
VNS			.664	11.74	.000
TOWRE Phonemic Decoding Efficiency					
Step 1					
VOC	.25	—	.178	2.68	.008
VSAT			.126	2.01	.046
Step 2					
PA	.57	.32	.380	5.64	.000
VNS			.459	7.45	.000
Untimed comprehension					
WJ-R Passage Comprehension					
Step 1					
VOC	.52	—	.576	7.83	.000
VSAT			.034	0.52	*ns*
LWID			.205	2.57	.011
Step 2					
PA	.52	.00	.037	0.49	*ns*
VNS			.042	0.64	*ns*

(table continues)

141) = 25.89, $p < .0001$, $R^2 = .36$; TOWRE Phonemic Decoding Efficiency, $F(3, 141) = 25.95$, $p < .0001$, $R^2 = .36$. Post hoc analyses revealed that in both cases, the Neither subgroup performed significantly higher than the three deficit subgroups, which was supportive of our hypothesis, and the size of these differences in general was large (d = .58–2.01). On the TOWRE Sight Word Efficiency subtest, the Double-Deficit and VNS Only subgroups did not differ from one another, and each had significantly lower performance than the PA Only subgroup. For the TOWRE Phonemic Decoding Efficiency subtest, the Double-Deficit subgroup performed significantly lower than the PA Only and VNS Only subgroups, who did not differ from one another. Across measures, however, the Double-Deficit subgroup had the lowest absolute scores, and the effect size of these differences was modest to large (d = .29–1.94).

Results were similar for untimed and timed reading comprehension. On the measure of untimed reading comprehension (WJ-R Passage Comprehension), the model was significant, $F(3, 142) = 7.84$, $p < .0001$, $R^2 = .14$. We hypothesized that the Neither subgroup would have the highest and the Double-Deficit subgroup the lowest performances; however, this did not best characterize the results. Instead, all performances were within the average range, although the PA Only and Double-Deficit subgroups (who did not differ from one another) performed significantly lower than the VNS Only and Neither subgroups, who also did not differ from one another; the effect sizes of these differences were large (d = .76–.95). On measures of timed reading comprehension (ND standard scores and ND percentage correct), the models were significant: ND standard score, $F(3, 141) = 3.97$, $p < .01$, $R^2 = .09$; ND percentage correct, $F(3, 142) = 4.80$, $p < .004$, $R^2 = .08$. Post hoc analyses revealed that the Double-Deficit subgroup performed significantly lower than the Neither subgroup on both measures, which was supportive of our hypothesis, and the size of these differences was large (d = .90–1.00). Although it was hypothesized that the PA Only subgroup would outperform the VNS Only subgroup for timed comprehension, this was not the case, and no significant inter-subgroup differences were observed on these measures; moreover, the effect size of these differences was negligible (d = .02–.12)

When covariates were added, the results did not change substantively for decoding measures (both timed and untimed). In each case, DDH categorization remained significant, and the order of the subgroups' performance did not change. However, there were, in general, fewer between-subgroup differences; the overall pattern was for the range of adjusted means to be more compressed than that of the raw means. DDH categorization was not predictive of reading comprehension measures (both timed and untimed) over covariates: WJ-R Passage Comprehension, $F(3, 126) < 1$, $p > .05$; ND standard score, $F(3, 125) < 1$, $p > .05$; ND percentage correct, $F(3, 126) = 1.06$, $p > .05$. The significant effect of including covariates on reading skills in these between-group analyses paralleled that resulting from the regression analyses.

(Table 4 continued)

Measure	Adj. R^2	ΔR^2	β	*F* or *t*	*p*
Timed comprehension					
ND Reading Comprehension (standard score)					
Step 1					
VOC	.45	—	.606	7.94	.000
VSAT			–0.57	–0.79	ns
T-SWE			.309	2.82	.006
Step 2					
PA	.45	.00	–1.34	–1.69	.094
VNS			.063	0.62	ns
ND Reading Comprehension (% correct)					
Step 1					
VOC	.26	—	.356	3.88	.000
VSAT			.076	0.92	ns
LWID			.221	2.23	.028
Step 2					
PA	.26	.00	.003	0.03	ns
VNS			.035	0.42	ns

Note. *N* for each analysis was either 132 or 133, and degrees of freedom for the full models were correspondingly (4, 127), (5, 126), (4, 128), or (5, 127). WJ-R = *Woodcock-Johnson Psychoeducational Battery-Revised* (Woodcock & Johnson, 1990); TOWRE = *Test of Word Reading Efficiency* (Torgesen, Wagner, & Rashotte, 1999); ND = *Nelson-Denny Reading Aptitude Test* (Brown, Fishco, & Hanna, 1993); VOC = *Wechsler Adult Intellgence Scale–III* (WAIS-III; Wechsler, 1997) Vocabulary subtest; VSAT = *Visual Search and Attention Test* (Trenerry, Crosson, DeBoe, & Leber, 1990); PA = *Comprehensive Test of Phonological Processing* (CTOPP; Wagner, Torgesen, & Rashotte, 1999) Phonological Awareness composite; VNS = CTOPP Rapid Naming composite; LWID = WJ-R Letter–Word Identification subtest; T-SWE = TOWRE Sight Word Efficiency subtest. Adjusted R^2 values represent total proportion of variance accounted for by all variables entered into the model up to and including that step. ΔR^2 represents the proportion of variance accounted for by the variables in that step in addition to the proportion of variance accounted for by variables entered in all previous steps.

Hypothesis 4: DDH Subgroups by RD Criteria

Four sets of dichotomous subgroups were formed (RD vs. no RD), each based on a different criterion of reading skill. The criterion for the untimed decoding RD group was the WJ-R Basic Reading composite, and the criterion for the untimed comprehension RD group was the WJ-R Passage Comprehension subtest. The criterion for the timed decoding RD group was the TOWRE Reading Efficiency composite, and the criterion for the timed comprehension RD group was the ND Reading Comprehension subtest. We compared the representation of each of the four mutually exclusive DDH subgroups within *each* of the RD groups, as we expected different degrees of overlap (see Hypothesis 4 in the introduction). In all cases of RD, participants met *either* discrepancy (DIS) *or* low achievement (LA) criteria to ensure broad coverage. LA criteria were based on reading performances 1 *SD* below the normative mean of 100 of these measures (i.e., standard scores of 85 or less). DIS criteria were based on a difference between expected and actual reading scores of one standard error of the estimate (i.e., 1 *SD* of prediction errors), where the expected reading score was predicted from the correlation of an individual's WAIS-III Full Scale IQ score with the criterion reading skill under study.

The results of the overlap of DDH and RD categorization are included in Table 6. Composite measures of decoding skill (as opposed to individual subtests) were used for clarity of presentation, and mean scores on PA and VNS are presented for groups who did and did not meet criteria for RD using different reading measures. When untimed decoding (WJ-R Basic Skills) was the criterion measure for RD, DDH subgroupings were significantly predictive of RD classification, $\chi^2(3, N = 137) = 31.4$, $p < .0001$. Examination of cell counts revealed that the largest percentage of RD diagnoses occurred in the Double-Deficit subgroup (13 of 21 cases; 62%). When corrected for low expected cell counts, subgroups were delimited to two (Any Deficit versus Neither), and results were similar, $\chi^2(1, N = 137) = 14.2$, $p < .0002$. Lack of a

TABLE 5
Between-Group Analyses: Subtyping According to the Double-Deficit Hypothesis

	PA only[a]		VNS only[b]		Double deficit[c]		Neither[d]	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Subtyping measures								
CTOPP								
PA	74.0	11.1[l]	100.3	7.2[k]	73.0	10.9[l]	104.3	8.4[k]
VNS	103.5	15.4[k]	73.0	11.7[l]	70.5	11.5[l]	102.3	11.2[k]
Untimed decoding								
WJ-R								
Letter–Word Identification	95.0	12.2[lm]	101.2	13.4[l]	87.8	7.7[m]	109.2	16.4[k]
Word Attack	92.8	18.6[l]	100.8	13.8[l]	80.1	10.6[m]	109.0	16.2[k]
Timed decoding								
TOWRE								
Sight Word Efficiency	86.1	10.8[l]	77.7	6.5[m]	75.9	5.7[m]	93.3	13.0[k]
Phonemic Decoding Efficiency	80.6	12.1[l]	79.9	11.5[l]	67.0	8.9[m]	93.3	14.3[k]
Untimed comprehension								
WJ-R Passage Comprehension	95.3	10.1[l]	106.0	15.8[k]	94.3	12.4[l]	107.3	14.1[k]
Timed comprehension								
ND Reading Comprehension								
Standard Score	89.1	13.7[kl]	89.4	15.3[kl]	82.3	11.7[l]	94.0	13.4[k]
% correct	77.0	15.7[kl]	79.2	18.6[kl]	71.6	20.8[l]	85.3	9.9[k]

Note. See text for criteria for subgroups. Numbers across a row not sharing at least one superscript are significantly different from one another according to post hoc Tukey's studentized range (honestly significant difference) tests to control for experimentwise error rate. CTOPP = *Comprehensive Test of Phonological Processing* (Wagner, Torgesen, & Rashotte, 1999); PA = CTOPP Phonological Awareness composite; VNS = CTOPP Rapid Naming composite; WJ-R = *Woodcock-Johnson Psychoeducational Battery-Revised* (Woodcock & Johnson, 1990); TOWRE = *Test of Word Reading Efficiency* (Torgesen, Wagner, & Rashotte, 1999); *Nelson-Denny Reading Aptitude Test* (Brown, Fishco, & Hanna, 1993).
[a]*n* = 23. [b]*n* = 42. [c]*n* = 22. [d]*n* = 58, or 59 due to missing values.

deficit (the Neither subgroup) was associated with RD in only 3 of 56 cases (5%). However, the presence of a deficit in PA or VNS was associated with RD in only 26 out of 81 cases (32%). Moreover, participants who met untimed decoding criteria for RD had lower PA scores, $F(1, 135) = 42.9$, $p < .0001$, and lower VNS scores, $F(1, 135) = 6.23$, $p < .02$, than those who did not. Although the proportion of participants in the PA Only subgroup (32%) was larger than that in the VNS Only subgroup (16%), as hypothesized, there were no statistical differences between these two subgroups, $\chi^2(1, N = 60) = 2.11$, $p > .05$.

When timed decoding (TOWRE composite) was the criterion for RD, overall results were again significant, $\chi^2(3, N = 140) = 35.5$, $p < .001$. In contrast to untimed decoding, the Neither subgroup had similar proportions of individuals who met criteria for RD (46%) and who did not (54%). However, 71 of 83 individuals (85%) with a deficit in PA or VNS met criteria for RD; 93% of the VNS Only subgroup and every member of the Double-Deficit subgroup met criteria for RD. Furthermore, those who met timed decoding criteria had lower PA scores, $F(1, 138) = 10.7$, $p < .002$, and lower VNS scores, $F(1, 138) = 67.6$, $p < .0001$, than those who did not.

For untimed comprehension (WJ-R Passage Comprehension), overall results were significant, $\chi^2(3, N = 141) = 10.2$, $p < .017$, and similar to those for untimed decoding. However, when corrected for low expected cell counts, and with subgroups delimited to two (Any Deficit versus Neither), the results were no longer significant, $\chi^2(1, N = 141) = 2.66$, $p > .05$. The Neither subgroup had a low likelihood (7 of 58 cases; 12%) of meeting RD criteria, and having a deficit in PA or VNS increased the chances of meeting RD criteria only to 23% (19 of 83 cases), although 73% of those who met criteria for RD had a processing deficit. Those who met untimed comprehension criteria had lower PA scores, $F(1, 139) = 11.4$, $p < .002$, but similar VNS scores, $F(1, 139) < 1$, $p > .05$, relative to those who did not.

For timed comprehension (ND Reading Comprehension standard score), overall results were not significant, $\chi^2(3) = 6.8$, $p > .05$. The Neither subgroup had similar proportions of individuals who met criteria for RD (44%) and individuals who did not (56%), and the presence of deficits in PA or VNS was also not discriminative (57% met criteria for RD, and 43% did not). Those who met timed comprehension criteria had marginally lower PA scores, $F(1, 138) = 3.61$, $p < .06$, and lower VNS scores, $F(1, 138) = 8.34$, $p < .005$, relative to those who did not. It

TABLE 6
Double-Deficit Hypothesis Subtyping by Reading Disability (RD) Definition

RD Definition	*n*	PA Only[a]	VNS Only[b]	Double deficit[c]	Any deficit[d]	Neither[e]	PA *SS*	PA *SD*	VNS *SS*	VNS *SD*
Untimed decoding										
Yes	29	7	6	13	26	3	77.7	16.2	82.1	19.9
No	108	15	32	8	55	53	97.4	13.9	92.0	18.7
Timed decoding										
Yes	97	13	37	21	71	26	90.6	16.5	82.2	15.4
No	43	9	3	0	12	31	100.1	14.3	105.9	16.5
Untimed reading comprehension										
Yes	26	4	6	9	19	7	84.2	21.4	87.5	25.6
No	115	18	34	12	64	51	95.8	14.4	90.2	17.6
Timed reading comprehension										
Yes	72	10	21	16	47	25	90.9	18.0	85.1	18.9
No	68	12	19	5	36	32	96.2	14.2	94.2	18.4

Note. PA = phonological awareness deficit; VNS = visual naming speed deficit.
[a]*n* = 22. [b]*n* ranged from 38 to 40 because of missing values. [c]*n* = 21. [d]*n* ranged from 81 to 83 due to missing values. [e]*n* ranged from 56 to 58 due to missing values.

was hypothesized that the proportion of participants in the VNS Only subgroup meeting criteria for an RD in timed comprehension would be larger than that of the PA Only subgroup; however, there were no differences between these two subgroups (VNS, 53%; PA, 45%), $\chi^2(1, N = 62) < 1, p > .05$.

Discussion

The double-deficit hypothesis (DDH) suggests that phonological awareness (PA) and visual naming speed (VNS) are each important for reading skill, and that individuals with deficits in both PA and VNS have the most significant reading difficulties (Wolf & Bowers, 1999; Wolf et al., 2000). The results of the present study clearly indicate that both PA and VNS are important for the prediction of reading skill in adults, although their relative importance varied with the characteristics of the reading outcome measure. The results also indicate that individuals with both PA and VNS deficits had a different and more severe pattern of difficulty for some aspects of reading (timed and untimed nonword reading), relative to those with single deficits in either area. The present study extends the literature on the DDH in three important ways: (a) a sample of college students was employed; (b) the relative impact of PA and VNS deficits on reading skill was explored using different methods, which aided in conceptualizing results; and (c) the impact of diagnostic criteria on the prevalence of DDH subgroups in an RD sample was examined. A discussion of the results by hypothesis follows.

Hypotheses 1 and 2: PA and UNS

As predicted by the first hypothesis, both PA and VNS contributed individually to success in most aspects of reading performance examined—in most cases to a substantial degree, with effect sizes of one third to one half of a standard deviation. One exception was that VNS was not predictive of untimed reading comprehension. It may be that when time pressures are absent—particularly for a task that does not require a high volume of reading—the demands for holding syntax and context are not highlighted as much as when time pressures are involved, particularly for adults who have had a significant amount of text exposure (college students).

The second hypothesis concerned the *relative* contributions of PA and VNS to reading, and, as predicted, these contributions varied with the nature of the item content (word vs. nonword) and the nature of the task (timed vs. untimed). For untimed decoding, we expected that PA would be a stronger predictor (relative to VNS), and this was clearly supported, with an effect size of more than one half of a standard deviation. The advantage of PA was present for both nonwords and real words, whereas in studies of children (e.g., Wolf et al., 2002), PA and VNS have been found to be equivalent predictors of untimed real-word reading. For timed decoding, however, the contributions of PA and VNS were similar for nonwords (as hypothesized), and effect sizes were large (equivalent to one half of a standard deviation); for real words, the effect of VNS was greater than that of PA, and effect sizes were more than one half of a standard deviation. This pattern of decoding prediction in adults suggests that the contribution of VNS is increased in timed conditions relative to untimed conditions, and, to a somewhat lesser degree, the contribution of PA is increased when nonword relative to real-word reading is assessed; this general pattern is similar to that found in children (Compton et al., 2001).

For untimed reading comprehension, PA and VNS were hypothesized to be equal predictors. In fact, PA was a significant contributor to untimed reading performance, and large in effect size (one half of a standard deviation), but the contribution of VNS was not significant above and beyond the impact of PA; VNS also had a negligible effect size. These results were similar whether a truly untimed measure (WJ-R Passage Comprehension) was examined or whether the impact of accuracy over speed was emphasized on a timed measure (ND percentage correct). These results are consistent with a previous study of children, which also found that a measure of PA (but not VNS) was predictive of reading comprehension that did not rely on speed (Cornwall, 1992). However, in two other studies of children (Compton et al., 2001; Wolf et al., 2002), VNS was also a significant predictor of untimed reading comprehension. It may be that in college students, VNS is not sensitive to brief reading comprehension when time limits are not at issue, given these students' wider vocabulary, contextual, and general skills that could be used to determine the meaning of connected text. It is also possible that alternative measurements of untimed reading comprehension might have led to different results, because of weaknesses with the present measures, such as the cloze nature of the WJ-R Passage Comprehension subtest and the derived nature of the percentage-correct measure from the *Nelson-Denny Reading Aptitude Test.*

For timed reading comprehension, no previous studies were available that had compared the relative degree of importance of PA and VNS on this criterion, but we hypothesized that VNS would be the stronger predictor. In fact, both PA and VNS were similarly predictive of performance, and both were statistically significant, although effect sizes were small to moderate in magnitude. Although the posited hypothesis was not generally supported, when these results are compared to those with untimed reading comprehension, the importance of VNS is found to increase when there are time demands imposed on reading; this may indeed be the case, particularly for college students, for whom reading volume is high relative to the time available.

For decoding skills, the inclusion of covariates did not alter the pattern of PA and VNS contributions, suggesting that PA and VNS contribute to decoding skills above and beyond the contributions of vocabulary and general processing speed; in fact, general processing speed was not predictive as a covariate when the decoding measure itself was not timed. For reading comprehension, when covariates were included, neither PA nor VNS accounted for significant unique variance; among the covariates, both vocabulary and single-word reading skill were strongly predictive of comprehension, indicating the importance of these skills to the reading process, even in adults. Comparison with other studies of the impact of PA and VNS on comprehension (Compton et al., 2001; Cornwall, 1992; Wolf et al., 2002) is difficult because the focus of these studies was on children, and also because they did not include a measure of single-word reading as a covariate. However, the results of these analyses indicate that at least in college students, the impact of PA or VNS on reading comprehension appears to be mediated by both vocabulary and single-word reading.

Hypothesis 3: DDH Subgroups

The use of subtyping analyses offered the advantage of directly comparing single-deficit and double-deficit subgroups, which is important, given that, at least in children, the nature of intervention and treatment outcomes may be related to DDH subgroups (Lovett et al., 2000). We hypothesized that the Double-Deficit subgroup would have the lowest and the Neither subgroup the highest performance in all aspects of reading. Indeed, the Double-Deficit subgroup had the lowest absolute performance and differed significantly from the Neither subgroup on all reading measures (see Table 4); the size of this difference was in general rather large (d = .90–2.01). Although these results are consistent with expectations and consistent with the DDH (Wolf & Bowers, 1999; Wolf et al., 2000), fewer differences were noted between single-deficit subgroups. We hypothesized that the VNS Only subgroup would outperform the PA Only subgroup for untimed decoding and that the PA Only subgroup would outperform the VNS Only subgroup for timed comprehension, although no such difference manifested. The Double-Deficit subgroup did, however, evidence lower performance on most measures of reading relative to at least one of the single-deficit subgroups, who in turn evidenced lower performance than the Neither subgroup.

These results were obtained despite the reduction in power associated with subgrouping continuous variables, and despite the fact that PA and double-deficit subgroups are often mismatched on PA severity, in part because of the significant correlation of PA and VNS in children (Compton et al., 2001; Schatschneider et al., 2002). In the present study of college students with and without RD, using composite measures of PA and VNS, their correlation was low and not significant, which meant that the double-deficit subgroup was matched to the single-deficit subgroups, allowing for subtype comparisons in the whole sample without producing artifacts that are common to dual-deficit subtype comparison studies. It will be helpful in future studies to identify different patterns of cognitive processing strengths and weaknesses within these single- and double-deficit subgroups (in both children and adults) that may inform instructional interventions within the context of effective reading improvement programs and provide a context for exploring theories regarding the nature and cause of reading failure.

Hypothesis 4: DDH Subgroups by RD Criteria

An additional focus of this study was to examine the level of concordance between patterns of cognitive processing deficits and traditional methods of RD diagnosis, and we hypothesized that the Double-Deficit subgroup would be the most (and the Neither subgroup the least) represented when RD was defined according to any criterion. For every reading criterion, the Double-Deficit subgroup did have a greater proportion of individuals relative to the Neither subgroup, and no single-deficit group had a greater representation than the Double-Deficit subgroup.

When untimed reading (both decoding and comprehension) was used as the criterion reading measure, rates of RD were low overall (21% and 18%, respectively), and DDH categorizations identified 90% and 73% (respectively) of these groups. Although many *other* individuals with a single or double deficit did *not* meet either DIS or LA criteria for RD, this finding was balanced by the finding that of those individuals with *no* deficit, 95% (untimed decoding) and 89% (untimed comprehension) also did not meet DIS or LA criteria for RD. These results suggest that adults with an impairment in untimed decoding (relative to age peers or to their own potential) are highly likely to have co-existing deficits in PA or VNS. Adults with an impairment in untimed reading comprehension are also likely to have co-occurring deficits in PA or VNS, although this overlap was less than for untimed decoding, suggesting a broader range of mechanisms for comprehension failure. Clearly, however, false positives were quite common, with 66% of those with a deficit in PA or VNS *not* meeting the definition for traditional RD when the criterion was untimed decoding (this proportion was 77% when the criterion was untimed comprehension). These individuals may have qualified as having RD under some other criterion (e.g., timed decoding) or, alternatively, they may not have had RD at all; it is also possible that some of these individuals may have achieved some degree of reading compensation. We had expected that the proportion of individuals meeting criteria for RD would be greater for those who had deficits only in PA (32%) relative to those who had deficits only in VNS (16%), and this was the case, although there was, in fact, not a statistical difference between them, which may have been due to the small sample size.

For timed decoding, the presence of a deficit (particularly in VNS or a double deficit) made it quite likely that some DIS or LA criteria for RD would be met; conversely, 46% of participants with average performance on both VNS and PA also met timed decoding criteria for RD. This pattern suggests that although cognitive processing deficits (particularly in VNS) lead to a deficit in timed decoding, there are additional routes to low performance on these timed decoding measures. For timed comprehension, DDH categorization was not significant in predicting whether RD criteria would be met, and prediction levels were at chance; however, more than 75% of those with a double deficit met this RD criterion, relative to rates of near chance for the other three subgroups, including the PA Only and VNS Only subgroups, although it had been predicted that a greater proportion of the VNS Only group would meet RD criteria relative to the PA Only group.

These results highlight the complexity of diagnostic decision making in RD. The proportion of participants who met criteria for RD based on measures of timed decoding (69%) and timed comprehension (51%) was high relative to those who met RD criteria for untimed decoding (21%) and untimed comprehension (18%). The benefit of this distinction is that timed measures of reading may be more sensitive to reading difficulties in adults than untimed measures of reading, which suggests that they should be included in the evaluation of such individuals to enhance diagnostic decision-making accuracy. However, it should be noted that the large proportion of individuals identified as having RD when timed measures are used makes it unlikely that all of these individuals who read slowly have "true" RD. For example, on timed decoding, a large majority of individuals identified as having RD also had a cognitive deficit (typically in VNS), but on timed comprehension, many individuals identified as having RD did not have a specific cognitive deficit in either PA or VNS. Because RD diagnosis in this study was empirically and not clinically based, reasons for slow reading may include test characteristics (e.g., the use of a young, general normative sample for the TOWRE, and the use of a college-based normative sample for the ND), poor educational background, overall low ability, specific linguistic deficits in a lexical or semantic system, or the contribution of comorbid disorders such as mood, anxiety, or attention disorders (see Table 1). For example, slow processing speed in general can also be a concomitant of attention-deficit/hyperactivity disorder (ADHD; McBurnett, Pfiffner, & Frick, 2001; Rapport, Van Voorhis, Tzelepis, & Friedman, 2001; Woods, Lovejoy, & Ball, 2002) or affective and anxiety disorders (Ashcraft & Kirk, 2001; Paradiso, Lamberty, Garvey, & Robinson, 1997; Purcell, Maruff, Kyrios, & Pantelis, 1997). However, in the present study, controlling for general processing speed did not alter results substantively, and, in fact, the only reading skills that this covariate was related to were measures of timed decoding.

Conclusions

This study provided both methodological and practical contributions to the study of the DDH. First, a broad exploration of the *relative* predictive roles of PA and VNS in the reading process was undertaken, using both individual differences and between-group methods. Second, this study explored RD concordance, comparing DDH subgroups with those identified through more traditional methods (LA or DIS criteria), and did so using a variety of reading criterion measures (both timed and untimed). Finally, the focus of this study was on college students, extending the applicability of the DDH beyond children. Specifically, the results indicate that PA and VNS remain relevant to reading performance in adults, particularly for decoding; their contribution to comprehension is mediated by more general skills. Replication of these results, perhaps in a nonreferred sample, may allow even stronger connections to the literature on the DDH in children. Further elucidating the role of PA and VNS in the reading process may be ultimately useful in the development of intervention strategies for those struggling with the reading process as children or adults.

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AUTHORS' NOTES

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REFERENCES

Ackerman, P. T., & Dykman, R. A. (1993). Phonological processes, confrontation naming, and immediate memory in dyslexia. *Journal of Learning Disabilities, 26,* 597–609.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General, 130*, 224–237.

Bone, B., Cirino, P., Morris, M., & Morris, R. (2002). Reading and phonological awareness in reading disabled adults. *Developmental Neuropsychology, 21,* 305–320.

Bowers, P. G., & Swanson, L. B. (1991). Naming speed deficits in reading disability: Multiple measures of a singular process. *Journal of Experimental Child Psychology, 51,* 195–219.

Bowers, P. G., & Wolf, M. (1993). Theoretical links among naming speed, precise timing mechanisms, and orthographic skill in dyslexia. *Reading and Writing: An Interdisciplinary Journal, 5*, 69–85.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read—a causal connection. *Nature, 301*, 419–421.

Brown, J. I., Fishco, V. V., & Hanna, G. (1993). *Nelson-Denny Reading Test: Manual for scoring and interpretation.* Chicago, IL: Riverside.

Bruck, M. (1992). Persistence of dyslexics' phonological awareness deficits. *Developmental Psychology, 28,* 874–886.

Bruck, M. (1993). Word recognition and component phonological processing skills of adults with childhood diagnosis of dyslexia. *Developmental Review, 13,* 258–268.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Compton, D. L., DeFries, J. C., & Olson, R. K. (2001). Are RAN and phonological awareness deficits additive in children with reading disabilities? *Dyslexia, 7*, 125–149.

Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability. *Journal of Learning Disabilities, 25*, 532–538.

Denckla, M. B., & Rudel, R. G. (1974). "Rapid automatized naming" of pictured objects, colors, letters, and numbers by normal children. *Cortex, 10,* 186–202.

Denckla, M. B., & Rudel, R. G. (1976). Rapid automatized naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471–479.

Elbro, C., Nielsen, I., & Petersen, D. (1994). Dyslexia in adults: Evidence for deficits in non-word reading and in the phonological representation of lexical items. *Annals of Dyslexia, 44,* 205–226.

Felton, R. H., Naylor, C. E., & Wood, F. B. (1990). Neuropsychological profile of adult dyslexics. *Brain and Language, 39,* 485–497.

Fletcher, J. M., Shaywitz, S. E., Shankweiler, D. P., Katz, L., Liberman, I. Y., Fowler, A., et al. (1994). Cognitive profiles of reading disability: Comparisons of discrepancy and low achievement definitions. *Journal of Educational Psychology, 85,* 1–18.

Frankenberger, W., & Fronzaglio, K. (1991). A review of states' criteria and procedures for identifying children with learning disabilities. *Journal of Learning Disabilities, 24,* 495–500.

Kail, R., & Hall, L. K. (1994). Processing speed, naming speed, and reading. *Developmental Psychology, 30,* 949–954.

Lovett, M. W., Steinbach, K. A., & Frijters, J. C. (2000). Remediating the core deficits of developmental reading disability: A double deficit perspective. *Journal of Learning Disabilities, 33,* 334–358.

McGrew, K. S., Werder, J. K., & Woodcock, R. W. (1991). *Woodcock-Johnson–Revised technical manual.* Allen, TX: DLM.

McBurnett, K., Pfiffner, L. J., & Frick, P. J. (2001). Symptom properties as a function of ADHD type: An argument for continued study of sluggish cognitive tempo. *Journal of Abnormal Child Psychology, 29*, 207–213.

Meyer, M. S., Wood, F. B., Hart, L. A., & Felton, R. H. (1998). The selective predictive values in rapid automatized naming within poor readers. *Journal of Learning Disabilities, 31,* 106–117.

Paradiso, S., Lamberty, G. J., Garvey, M. J., & Robinson, R. G. (1997). Cognitive impairment in the euthymic phase of chronic unipolar depression. *Journal of Nervous and Mental Disease, 185*, 748–754.

Pratt, A. C., & Brady, S. (1988). Relation of phonological awareness to reading disability in children and adults. *Journal of Educational Psychology, 80*, 319–323.

Psychological Corp. (1997). *WAIS-III/WMS-III: Technical manual.* San Antonio, TX: Author.

Purcell, R., Maruff, P., Kyrios, M., & Pantelis, C. (1997). Neuropsychological function in young patients with unipolar major depression. *Psychological Medicine, 27*, 1277–1285.

Rapport, L. J., Van Voorhis, A., Tzelepis, A., & Friedman, S. R. (2001). Executive functioning in adult attention-deficit hyperactivity disorder. *The Clinical Neuropsychologist, 15*, 479–491.

SAS Institute. (1988). *SAS procedures guide* (release 6.03). Cary, NC: Author.

Schatschneider, C., Carlson, C. D., Francis, D. J., Foorman, B. R., & Fletcher, J. M. (2002). Relationship of rapid automatized naming and phonological awareness in early reading development: Implications for the double-deficit hypothesis. *Journal of Learning Disabilities, 35,* 245–256.

Shankweiler, D., Lundquist, E., Stuebing, K. K., Fletcher, J. M., Brady, S., Fowler, A., et al. (1999). Comprehension and decoding: Patterns of association in children with reading difficulties. *Scientific Studies in Reading, 3*, 69–94.

Siegel, L. S. (1992). An evaluation of the discrepancy definition of dyslexia. *Journal of Learning Disabilities, 25*, 618–629.

Spring, C., & Davis, J. (1988). Relations of digit naming speed with three components of reading. *Applied Linguistics, 9*, 315–334.

Stanovich, K. (1986). "Matthew effects" in reading: Some consequences of individual differences in acquisition of literacy. *Reading Research Quarterly, 4*, 360–407.

Stanovich, K. E., Cunningham, A. E., & Feeman, D. J. (1984). Intelligence, cognitive skills, and early reading progress. *Reading Research Quarterly, 14,* 278–303.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 86*, 24–53.

Trenerry, M. R., Crosson, B., DeBoe, J., & Leber, W. R. (1990). *Visual Search and Attention Test: Professional manual.* Odessa, FL: Psychological Assessment Resources.

Torgesen, J. K., Wagner, R. K., & Rashotte, C. A. (1999). *TOWRE: Test of Word Reading Efficiency. Examiner's manual.* Austin, TX: PRO-ED.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, 101*, 192–212.

Wagner, R. L., Torgesen, J. K., Laughlon, P., Simmons, K., & Rashotte, C. A. (1993). Development of young readers' phonological processing abilities. *Journal of Educational Psychology, 85,* 83–103.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). The development of reading-related phonological processing abilities: New evidence of bi-directional causality from a latent variable longitudinal study. *Developmental Psychology, 30,* 73–87.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1999). *CTOPP: Comprehensive Test of Phonological Processing. Examiner's manual.* Austin, TX: PRO-ED.

Wechsler, D. (1997). *Wechsler adult intelligence scale* (3rd ed.). San Antonio, TX: Psychological Corp.

Wolf, M. (1984). Naming, reading, and the dyslexias: A longitudinal overview. *Annals of Dyslexia, 34*, 87–115.

Wolf, M. (1986). Rapid alternating stimulus naming in the developmental dyslexias. *Brain and Language, 27*, 360–379.

Wolf, M., Bally, H., & Morris, R. (1986). Automaticity, retrieval processes, and reading: A longitudinal study in average and impaired readers. *Child Development, 57*, 988–1000.

Wolf, M., & Bowers, P. (1999). The question of naming-speed deficits in developmental reading disabilities: An introduction to the double-deficit hypothesis. *Journal of Learning Disabilities, 33,* 322–324.

Wolf, M., Bowers, P., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33*, 387–407.

Wolf, M., Goldberg O'Rourke, A., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia. *Reading and Writing: An Interdisciplinary Journal, 15*, 43–72.

Woodcock, R. W., & Johnson, M. B. (1990). *Woodcock-Johnson psychoeducational battery–Revised.* Allen, TX: DLM.

Woodcock, R. W., & Mather, N. (1990). Woodcock-Johnson–Revised Tests of Achievement: Examiners' manual. In R. W. Woodcock & M. B. Johnson (Eds.), *Woodcock-Johnson psychoeducational battery–Revised* (pp. 93–111). Allen, TX: DLM.

Woods, S. P., Lovejoy, D. W., & Ball, J. D. (2002). Neuropsychological characteristics of adults with ADHD: A comprehensive review of initial studies. *The Clinical Neuropsychologist, 16*, 12–34.