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The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia

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Abstract. An increasing body of dyslexia research demonstrates, in addition to phonological deficits, a second core deficit in the processes underlying naming speed. The hypothesized independence of phonological awareness and naming-speed variables in predicting variance in three aspects of reading performance was studied in a group of 144 severely-impaired readers in Grades 2 and 3. Stepwise regression analyses were conducted on these variables, controlling for the effects of SES, age, and IQ. Results indicated that phonological measures contribute more of the variance to those aspects of reading skill that involve decoding or word attack skills; naming-speed measures contribute more to skills involved in word identification. Subtype classification findings were equally supportive of the independence of the two deficits: 19% of the sample had single phonological deficits; 15% had single naming-speed deficits; 60% had double-deficits; and 6% could not be classified. The implications of these findings for diagnosis and intervention are discussed.

Keywords: Dyslexia, Naming speed, Phonology, Reading, Reading disability

Introduction

From work at the start of the century with Sir Edmund Huey (1908), to current imaging (fMRI) studies of the brain as it reads (Shaywitz, Shaywitz, Pugh, Fulbright, Constable, Mencl, Shankweiler, Liberman, Skudlarski, Fletcher, Katz, Marchione, Lacadie, Gatenby & Gore 1998), the reading process has provided a long series of challenges to those who would explain the nature of its components and the sources of its breakdown. There is a rich history of differing names used to characterize reading disability (e.g., amnesia visualis verbalis, strephosymbolia, and word blindness), with each name usually designating a different hypothesized source of failure. In contrast to this past history, the last two decades of reading research have been characterized by the systematic building of knowledge about one principal locus of reading disability, the phonological system.

Research on the phonological basis of reading acquisition failure underscores the advantages and disadvantages of understanding one locus of reading disability well. Since the landmark studies by Shankweiler & Liberman (1972), over two and a half decades of research on phonological processing have produced the most systematically studied body of work in the history of reading research (Bradley & Bryant 1983; Brady & Shankweiler 1991; Bruck & Treiman 1990; Byrne 1998; Catts 1996; Chall 1983; Foorman et al. 1997; Kamhi & Catts 1989; Lyon 1995; Lyon & Moats 1997; Olson et al. 1989; Perfetti, 1985; Shankweiler & Liberman 1972; Siegel & Ryan, 1988; Stanovich 1986, 1992; Tunmer, 1995; Vellutino & Scanlon 1987; Wagner, Torgesen & Rashotte 1994). We now know that a child's ability to represent and manipulate the individual phonemes of the language in its spoken form is critical for learning the grapheme-phoneme correspondence rules that are the foundation for decoding, fluency, and comprehension. This conceptualization represents a fundamental tenet of reading research, including the present study, and underlies some of the most important advances in diagnosis and intervention.

There are, however, disadvantages in using only a single, phonological lens to study reading disorders. These include the tendency to subsume other possible explanatory processes under the rubric of phonology, and to overlook or minimize the importance of other factors in explaining the heterogeneity of poor readers. Deficits in naming speed, for example, represent one of the additional, important predictors of reading disability (Ackerman & Dykman 1993; Badian 1995, 1996a,b; Bowers, Steffy & Tate 1988; Denckla & Rudel 1976a,b; Grigorenko et al. 1997; Lovett 1992; McBride-Chang & Manis 1996; Meyer et al. 1998; Snyder & Downey 1995; Spring & Capps 1974; Spring & Davis 1988; Wolf 1979; Wolf, Bally & Morris 1986; Wolff, Michel & Ovrut 1990a,b; Wood & Felton 1994). Nevertheless, until very recently processes underlying naming speed have been categorized by most researchers as 'part of the same phonological family' (Torgesen et al. 1997), rather than as a potentially separate source of additional disruption. The consequences of such categorizations of a second potential core deficit are not trivial. If correct, few changes are indicated in current research. If, however, phonological and naming-speed processes represent two independent sources of breakdown, there are critical implications for diagnosis, subtyping efforts, and, most importantly intervention.

In recent years Bowers & Wolf (1993; Wolf 1997; Wolf & Bowers 1999; Wolf, Bowers & Biddle 2000) have developed an alternative conceptualization of developmental reading disabilities to the well known phonological-deficit view: This conceptualization is the double-deficit hypothesis, which incorporates both phonology and naming-speed processes as two sources

Table 1. Classification of subtypes according to the double-deficit hypothesis

Average group	*Rate group*
Average phonological awareness	Intact phonological awareness
Average naming speed	Naming-speed deficit
Average comprehension	Impaired comprehension
Phonology group	*Double-deficit*
Phonological-awareness deficit	Phonological-awareness deficit
Intact naming speed	Naming-speed deficit
Impaired comprehension	Severely impaired comprehension

of reading breakdown. According to the Double-Deficit Hypothesis (see Table 1), the majority of disabled readers can be classified as one of two single-deficit subtypes that are relatively independent of each other (i.e., phonological-deficit reader; rate-deficit reader) or one combined subtype (i.e., the double-deficit reader), which is composed of children who are typically the most severely impaired readers across all aspects of reading performance.

At no point do we suggest that the two deficits and their combination encompass all the possible sources of breakdown in reading failure. Rather, this view is explicitly directed towards a more comprehensive understanding of the heterogeneity of impaired readers by directing attention to a second source of breakdown. There will be other sources investigated in future research. At the present stage of theory development there are multiple issues in clarifying the role of this second source. For example, an important question in this special issue concerns whether rate-related linguistic functions like naming-speed processes are related to domain-general timing mechanisms, or to more specific perceptual, linguistic, or motoric sources; or to some combination of factors (in addition to this issue, see Breznitz 1996; Farmer & Klein 1995; Merzenich et al. 1996; Ojemann 1984; Tallal et al. 1996; Wolf 1991; Wolf & Bowers 1999; Wolf, Bowers & Biddle 2000).

In this article we will be involved in a more basic task of clarifying the roles of naming speed and phonological processes in profound reading disabilities. As will be exemplified in the literature review that follows, most samples reported in the literature that address this question have been comprised of relatively small classroom samples of unselected poor readers. In the present study we will use findings from a carefully defined sample of severely impaired readers to help resolve whether naming-speed deficits represent a second core deficit independent of phonology in such a sample of dyslexic children. In the process we will study the relationship between naming-speed processes and three dimensions of reading skill development (i.e., word attack, word identification and comprehension), in conjunction with the effects of IQ, age, and SES level on these relationships. Finally, we will ask how the results of this study relate to the double-deficit hypothesis subtypes defined by phonological and/or naming-speed deficits. To begin, we will present a brief review of the history and major principles of the research on naming-speed, followed by the specific questions that emerged from this review.

Background

The history of this research began with an hypothesis by Geschwind (1965), who contended that a young child's color-naming ability would be a good predictor of later reading achievement. His logic was a precursor to current thinking. He hypothesized that the components involved in color-naming – which include connecting a verbal label to an abstract symbol that is perceived and processed in the visual domain – are also involved in the reading processes. Thus, color naming, which is learned first, would be a strong predictor of later developing reading skills. This hypothesis led to the body of early research by Denckla and Rudel (Denckla 1972; Denckla & Rudel 1974, 1976a,b) who found that the retrieval speed of color names, rather than accuracy in color naming, distinguished dyslexic children from average readers and other learning-disabled children. Denckla designed and, in collaboration with Rudel (1974, 1976a,b), tested the prototype of serial or continuous naming-speed tasks, the Rapid Automatized Naming (RAN) tests. These tasks measure the speed with which a child can name an array of 50 stimuli in one of four symbolic categories: letters, numbers, colors, objects. (See Figure 1).

o a s d p a o s p

Figure 1. Example of one line of rapid automatized naming test for letters.

In a series of cross-sectional, longitudinal, and cross-linguistic studies, Wolf (1979, 1982, 1991, 1997; Wolf, Bally & Morris 1986), Bowers (Bowers, Steffy & Tate 1988; Bowers & Swanson 1991; Bowers & Wolf 1993; Bowers, Golden, Kennedy & Young 1994) and their colleagues investigated the development of naming speed, the componential structure of naming and naming-speed tasks, and the differential abilities of particular types of naming tasks to predict specific aspects of reading performance in able and disabled reading groups. Their findings, in conjunction with an extensive body of other research by some of the authors in this volume, now indicate a series of conclusions that will be divided here into three categories: (1) development and group differences; (2) relationship of naming-speed task to reading processes; and (3) prediction.

1. *Development and group differences*
(i) *Typical readers*. In kindergarten there is little differentiation in naming speed across various linguistic categories, including letters, numbers, colors, and objects. By the end of Grade 1, differentiation between the more 'automatic', alphanumeric symbols (letters and numbers) and nongraphological symbols (colors and objects) occurs (Wolf, Bally & Morris 1986). The largest gains in speed for all symbols is completed by the end of Grade 2 for most children, with dyslexic readers a notable exception (Carver 1991; McBride-Chang & Manis 1996; Wolf et al. 1986). It is of interest that in studies reported after 1979, this rapid increase in naming speed occurs two years *earlier* than in Doehring's (1976) comprehensive study of rate changes in letter naming and other reading-related processes. For example, our Grade 1 and Grade 2 subjects were most similar to Doehring's Grade 3 and Grade 4 subjects on letter-naming speed, but similar in color-and object-naming speed (Wolf, Bally & Morris 1986).

(ii) *Dyslexic children*. Processes underlying naming speed differentiate dyslexic readers from average readers in all studies reported to date (Ackerman & Dykman 1993; Badian 1995, 1996a,b; Berninger et al. 1994; Bowers, Steffy & Tate 1988; Denckla & Rudel 1976 a,b; Felton & Wood 1992; Grigorenko et al. 1997; Lovett 1992; McBride-Chang & Manis 1996; Meyer et al. 1998; Nicolson & Fawcett 1994; Snyder & Downey 1995; Spring & Capps 1974; Spring & Davis 1988; Wolf 1982, 1991, 1997; Wolff et al. 1990a,b, 2000; Wood & Felton 1994). Few of these group comparison studies attempted to examine whether naming speed would differentiate dyslexic readers after differences in phonological performance had been controlled or vice versa. This same limitation would be true for all other group comparisons discussed below. (Note, however, in a later section we discuss the fact that most prediction studies involving both variables indicate unique contributions for naming speed to reading after phonological awareness is controlled.)

Impaired readers have a different developmental sequence from average readers with some variation attributable to subtype differences. There appears to be no period for dyslexic children that is similar to the above description of Kindergarten for typical readers, when all symbols are named at the same general rates. Although all symbols are named more slowly than for average readers, letter-and number-naming speeds are significantly slower from the outset, with letter-naming slowest (this is despite adequate knowledge of letter names). Thus, impaired readers begin their early primary grades with both a general naming-speed deficit and a particular deficit for automatic, alphanumeric symbols (Wolf, Bally & Morris 1986). Similar to average peers, rapid increases in speed occur by the end of Grade 1, with most large increases made by the end of Grade 2.

(iii) '*Nondiscrepant*' *or* '*garden-variety*' *poor readers*. This category represents a particular grouping of children. Gough & Tunmer (1986) reified a categorization that Rutter (1975) had used earlier, and included in the term those children whose low reading performance is commensurate with their IQ and achievement level. Considerable, careful research (Fletcher et al. 1994; Siegel & Stanovich 1994) has shown that this group of children has no significant differences from poor readers whose IQ is discrepant from their reading levels on phonological and many other cognitive and linguistic measures.

There are, nevertheless, several suggestive studies indicating that nondiscrepant readers may be more similar in the development of naming speed to average readers than to dyslexic readers for automatized, alphanumeric symbols (Badian 1996a; Biddle 1996; Wolf & Obregón 1990). This finding, if replicated, would suggest that naming speed for letters and numbers, unlike phonological awareness tasks, differentiates discrepant dyslexic children from nondiscrepant readers and from able readers. This information will be critical to resolve in future studies, and may explain why some studies find lower reading prediction capacities for naming speed. It may be that the more non-discrepant readers in a reading disabled sample, the less predictive naming speed will be of reading.

(iv) *Attention-disabled children*. Several studies have reported that dyslexic readers are slower in naming speed tasks than attention-disabled children (Ackerman & Dykman 1993, 1995; Denckla & Rudel 1976b; Felton & Wood 1992; Felton, Wood, Brown & Campbell 1987; Wood & Felton 1994). Important ongoing work by Tannock (Martinussen, Frijters & Tannock 1998) and her colleagues indicates differences between dyslexic readers and children with attention deficits. Their data suggest that the latter attention-disabled group has greater difficulties with color-naming and less difficulty with automatized categories. Tannock hypothesizes that these findings may be based on difficulties that children with attention-related disabilities have with regard to executive function, specifically in the areas of selective attention and poor response organization.

(v) *Reading-age match children*. There are mixed data on comparisons between dyslexic children and reading-age matched younger children.

Although the majority of studies to date indicate strong differences (Ackerman & Dykman 1993; Biddle 1996; Segal & Wolf 1993; Wimmer 1993; Wolf 1991; Wolf & Segal 1999), there are no differences found for reading-age comparisons in Badian (1996) and Olson (1995).

(vi) *African-American readers*. Ongoing studies by Gidney in our lab (Gidney et al. 1998), by Sankaranarayanan (1998), and by Scarborough & Domgaard (1998) indicate that naming-speed deficits in African-American children with severe reading disabilities are as prevalent as in European-American reading-disabled children. What appears more interesting, at least in our preliminary evidence, is that African-American children with reading disabilities may be distinguished from their European-American cohort on the basis of phonological characteristics. An important question concerning African-American children who speak Vernacular English is the possible role of dialect in the development of phonological awareness abilities in standard English.

(vii) *Indian readers*. Sankaranarayanan (1998) found similar patterns of naming-speed and phonological deficits in English-speaking children with reading disabilities in India; interestingly, she found faster naming-speed latencies among young, able, Indian readers when compared to American able readers. In this English-speaking population, both deficits were found to characterize poor readers.

(viii) *Cross-linguistic differences*. Naming-speed differences distinguish dyslexic readers from peers across all languages tested to date, including German (Näslund & Schneider 1991; Wimmer & Hummer 1990; Wimmer 1993; Wolf, Pfeil, Lotz & Biddle 1994), Dutch (van den Bos 1998; Yap & van der Leij 1993, 1994), Finnish (Korhonen 1995), and Spanish (Novoa & Wolf 1984; Novoa 1988). The importance of studying naming speed in languages with greater regularity than English is that they provide a means of examining the influence of naming speed and phonological awareness tasks when phonological demands are decreased by a more transparent orthography than that of English. Results from four languages indicate than when demands for phonological analysis are reduced for the young reader (due to orthographic regularity), naming-speed deficits are the dominant diagnostic index for at-risk readers (see van den Bos 1998; Wimmer 1993; Wolf et al. 1994).

2. *Nature of naming-speed tasks and their relationship to reading*

(i) *Cognitive structure*. The cognitive structure of naming speed is conceptualized as a temporally-ordered ensemble of perceptual processes (that are responsible for basic-level feature detection, discrimination, and letter, number, color, and pattern recognition); lexical processes (that are responsible for access and retrieval of phonological information and its integration with semantic information); and motoric processes (that are responsible for articulation). Precise, rapid timing is critical for the efficiency of individual processes and their integration. Demands for rapidity differ according to task requirements, with alphanumeric stimuli requiring the greatest degree of automatic processing (see Cattell 1886; Wolf 1991). The cognitive structure of naming speed is described in greater detail in a model of letter naming in Wolf & Bowers (1999).

(ii) *General relationship to reading*. As hypothesized in part by Geschwind (1965), many of the same processes underlying naming speed are employed at a higher level of complexity in reading (Wolf 1979, 1981, 1991). As discussed, this structural overlap, coupled with the earlier development of naming processes, make naming-speed tasks excellent, early predictors of later reading performance, particularly letter and number tasks. The additional serial requirements of RAN-like tasks, in contrast to a discrete presentation of the same symbols, make continuous naming speed measures a closer approximation to the reading act (Blachman 1984) and a better reading predictor than discrete trial naming tasks (see Perfetti, Finger & Hogaboam 1978).

(iii) *Specific relationships with reading*. Although the data for this question are based largely on small, unselected samples of poor readers, individual naming and naming-speed tasks appear to be related to specific aspects of reading performance. Summarized below (see detailed description in Wolf & Bowers 1999), these relationships are influenced by developmental factors, reader group characteristics, and the tasks' utilization of particular components and needs for rapidity:

1. Letter-and number-naming speed best predict word identification (accuracy and speed); text expressiveness; and the speed for reading passages in text (Young & Bowers 1995).
2. Confrontation object naming and object-naming speed are better predictors of reading comprehension than other naming-speed tasks (Wolf & Goodglass 1986; Wolf & Obregón 1992). The added semantic requirements of the tasks are in contrast to the heavier emphases on automatic rates of processing and lower-level perceptual processes in letter and number-naming speed, and in word identification.
3. Letter-and number-naming speed appear to be related to comprehension largely through the shared variance with word identification (Bowers et al. 1988; Spring & Davis 1988; Wolf 1991).

(iv) *Comparative findings between phonology-reading relationships and naming-speed-reading relationships*. In order to understand the hypothesized independence of the two deficit types, it is important to compare the differential naming speed-reading relationships in the preceding section with the differential predictive capacities of phonological processes in reading research. Like the reservation for naming studies articulated above, the following findings are also based heavily on small, unselected populations of poor readers (see McBride-Chang & Manis 1996 for discussion of unselected samples; that is, those children who are members of a larger population and meet some cut-off criteria, as opposed to a prescribed number of poor readers selected for study only because they qualify on a set of usually stricter criteria).

1. Phonological awareness tasks are related to word attack (accuracy for real and nonsense words) and comprehension (Bowers & Swanson 1991; Spring & Davis 1988) in able and disabled populations.
2. When compared with naming-speed tasks, phonological awareness tasks, like phoneme elision, contribute both shared and independent variance to word identification accuracy (real and nonsense word; regular and irregular words), and to oral reading (Bowers & Swanson 1991; Manis & Doi 1995; Manis, Doi & Bhadha 2000).
3. Both phonological and naming tasks contribute shared and independent variance to a range of orthographic variables, with naming speed contributing more of the variance to 'purer' orthographic tasks (Manis & Doi 1995).

The present study will also look at each of these relationships between naming speed and the various reading skills, but, as stated, in a large, highly selected group of profoundly impaired readers.

3. *Prediction*

The issue of prediction represents one of the most unresolved areas in this literature. In addition to the already discussed differential capacities of individual measures to predict specific aspects of reading, there appear to be differences in predictive relationships that may be attributable to developmental and subject/sample characteristic differences. For example, two major studies in recent years have come to opposite conclusions about the prediction power of naming speed and phonological tasks for later reading development. Both studies questioned whether either task would contribute variance to later word recognition when the shared variance between naming speed and early word recognition and between phonological awareness and early word recognition was controlled. Torgesen et al. (1997) found that Grade 2 phonemic awareness contributed a small, but significant amount of variance to Grade 4 word recognition beyond its shared variance with Grade 2 word recognition. Naming speed did not. This finding was true for their average *and* impaired readers. By contrast, Meyer, Wood, Hart & Felton (1998) found that Grade 3 naming speed was the only variable that significantly predicted Grade 5 and Grade 8 word identification in impaired readers, after controlling for Grade 3 word identification, as well as IQ and SES. This result was true only for impaired readers, and not for average readers.

Several sample factors are important to consider in order to understand the diverging findings of Torgesen et al. (1997) and Meyer et al. (1998), and the general complexity of prediction in this area: (1) IQ and SES; (2) quality and type of reading instruction (see Torgesen et al. 1997); (3) developmental and subtype differences that affect the variability in individual predictors.

(i) *IQ*. As discussed in the section on reader group differences, there is some evidence to suggest that children whose IQ is below average and consistent with their reading level do not have the same profile of naming-speed deficits. This, in turn, would affect the reading-naming-speed predictions in samples that are more highly represented by lower-IQ, poor readers. A more complex question that emerged in longitudinal data by the first author is the interaction between IQ level and development. The relative absence of naming-speed deficits in non-discrepant poor readers may not hold for children whose IQ is very low (e.g., in the 70's). This remains unresolved.

(ii) *Quality of reading instruction*. As discussed by Torgesen, Wagner and their colleagues (1997), some otherwise average readers develop a 'curricular disability' due to poor instruction or a poor match between method and pupil. These children could be part of the impaired reader group in unselected classroom samples and exhibit minimal or no naming-speed deficits, thus diminishing predictions between naming speed and reading in any impaired reader group analysis.

(iii) *Developmental variations and subtypes*. There are developmental reader-group differences that affect predictions. Average readers approach asymptotic performance on naming speed by the end of Grade 2, with no strong predictive naming speed-reading relationships found among average readers from Grade 2 on (Carver 1991). Most impaired readers, however, do *not* fully reach asymptote levels by this point, making RAN tasks a continuously good predictor of later reading in this population.

As will be discussed more fully in the next section, there appears to be one subtype of poor reader, who possesses phonological deficits without concurrent naming-speed deficits and one subtype with the converse pattern. Like the low-IQ pattern, poor readers, no strong relationship would be predicted between naming speed and reading for the phonological subtype of poor readers. Growth curve analyses by Biddle (1996) indicate that the single, naming-speed deficit subgroup without phonological problems makes only small speed increments each year. More developmental data are needed in this area; however, it appears that those dyslexic subtypes with naming-speed deficits do not reach adult-like fluency levels, while single-phonological subtypes are increasingly similar to average readers after first grade in naming speed (Biddle 1996).

To summarize how these sample-based factors might influence the differing predictive findings in the two studies, to the degree that any dyslexic or poor reader group is comprised of heavier proportions of curricular-disabled subjects, the predictive capacities of naming speed will be diminished, while the 'predictive power' of phonological tasks will be maintained. This same principle could apply to lower IQ, poor readers, if it is shown in future research that they have naming-speed profiles more similar to average readers. In addition, if many sample children have phonological but not naming-speed deficits, there will also be differences found. McBride-Chang & Manis (1996) have suggested that when an unselected classroom population is used, as in the Torgesen et al. (1997) sample, there may be a lower proportion of profoundly impaired dyslexic readers, resulting in a decreased likelihood for strong, predictive results for naming speed. We suggest also the converse for the Meyer et al. (1998) results: Because their children represented a more highly selected group of profoundly impaired readers, there was an increased likelihood that there would be a stronger set of predictive relationships between naming speed and later word identification, after controlling for early Grade 3 word recognition.

Because the Meyer et al. (1998) study included a somewhat older sample than Torgesen et al.'s (1997) early primary grade sample, there remain a series of questions about the nature of these relationships in a younger selected sample of very impaired readers, when IQ is controlled. A central purpose of the present study is, therefore, to investigate the nature and independence of contribution(s) made by naming-speed and phonological variables to three measures of reading in a selected sample of young, severely impaired readers. Based on issues raised in the current literature, our specific questions are:

1. a. What is the relationship between phonological awareness variables and naming-speed variables in a well-defined sample of young, severely impaired readers?
   b. What are the relationships between each variable and age? IQ? SES?
2. a. What is the relationship between each variable and three types of reading measures: word attack, word identification, and comprehension?

b. What proportion of the variance in word identification, word attack, and reading comprehension is uniquely attributable to phonological awareness processes and/or naming-speed ability, while controlling for the influence of IQ, SES, and age?

3. Finally, can this sample of selected, severely impaired readers be classified according to the subtyping criteria of the Double-Deficit Hypothesis? What is the prevalence of each subtype?

Method

Subjects. The present sample consisted of 144 severely reading-impaired children in Grades 2 and 3 who participated in the first and second years of a four year, multi-site, NICHD-funded reading intervention study. Subjects were recruited from three large metropolitan areas (Boston, Atlanta, and Toronto). Subjects were selected by their performance on a screening battery that included the Kaufmann Brief Intelligence Test (K-BIT, Kaufman & Kaufman 1990), the Woodcock Reading Mastery Test-Revised (WRMT-R, Woodcock 1987), and Wide Range Achievement Test-3 (WRAT-3, Wilkinson 1993). The use of multiple sites was crucial for increased generalizability of these findings to children of different regional cultures and dialects.

Students were initially referred by their teachers due to significant difficulties in learning to read. Inclusion criteria consisted of: English as the primary language; chronological age between 6–6 and 8–6; Grade 1 or 2 at the time of screening; hearing and vision within normal limits; and ethnicity either Caucasian or African heritage. Children were excluded if they had repeated a grade, achieved a K-BIT composite score below 70, or had a serious psychiatric or neurological illness. The co-occurrence of a disorder common in reading-impaired populations (e.g., ADHD) did not exclude a child. Children from average and below average socioeconomic levels were systematically included. The demographic characteristics of the sample are reported in Table 2.

Subjects were considered for inclusion in the study if they met either *low achievement* or ability-achievement (regression-corrected) *discrepancy* criteria (Fletcher et al. 1994). The K-BIT composite standard score was used as a screening measure of intellectual ability, and reading level was established on the basis of any one or more of the following combinations: (1) the average standard score of the WRMT-R Passage Comprehension, WRMT-R Word Identification, WRMT-R Word Attack, and WRAT-3 reading subtests (reading); (2) the standard score of the WRMT-R Word Identification and Word Attack subtests (WRMT-R, Basic Skills Cluster); (3) and/or the WRMT-R Word Identification and Passage Comprehension subtests (Total

Table 2. Demographic information for the Year 1 and 2 sample (n = 144)

	%		%
Gender		*SES*	
Female	32	*Average*	51
Male	68	*Low*	49
Ethnicity		*IQ*	
African-American	49	Average	55
Caucasian	51	Low	45

Reading Cluster). Subjects were included under the low achievement criteria if their K-BIT composite score was greater than 70, and if standard scores of reading were 85 or less. Subjects were included under the regression-corrected discrepancy criteria if their actual reading performance was more than one standard error of the estimate (approximately 13 points) below their expected standard scores, based on an average correlation of 0.60 between measures of reading performance and intellectual ability. (Note, however, that all the regression-defined subjects had been initially referred to this study because of significant reading problems).

There were 30 subjects who fulfilled the criteria for a low achievement definition of reading disability; 15 who met the discrepancy-based definition; and 99 who met criteria for both low achievement and discrepancy definitions.[1] Psychometric data for the sample are summarized in Table 3.

Table 3. Sample characteristics

Standard score	M	SD	Range
WRMT-R word identification	76.33	10.38	49–98
WRMT-R word attack	71.85	10.28	40–94
WRMT-R passage comprehension	74.54	12.33	26–96
K-BIT composite	92.10	11.24	71–123

General procedures

Subjects were screened in order to ascertain eligibility for the study. After criteria for selection were met, a treatment evaluation battery administered pre-treatment, mid-treatment, post-treatment and one-year post treatment.

The screening and pre-treatment batteries included an extensive set of standardized achievement, neuropsychological, and intelligence tests and experimental measures. This article reports on a small subset of those measures (administered in the screening and pre-treatment batteries) that were related to the specific questions investigated in this study. These included the following tasks.

Measures

Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman 1990)
The K-BIT, which assesses vocabulary and nonverbal concept formation, was used in the initial screening battery as a screening estimate of IQ.

Rapid Automatized Naming Test-Letters (RAN; Denckla & Rudel 1976)
The best known measure of serial or continuous naming speed is the Rapid Automatized Naming (RAN) test, designed by Denckla (1972) and developed by Denckla & Rudel (1974, 1976a,b). In this study, only the Letters test was used. It involves the rapid naming of a visual array of 50 stimuli, consisting of 5 high-frequency, lower case letters (a, d, o, s, p) presented 10 times in random order (refer back to Figure 1). We chose to use only one subtest, Letters, because of several reasons: (1) Letters and Digits have always proven significantly better predictors of reading performance than Colors and Objects; (2) the latter two, nonautomatized tasks.

Comprehensive Test of Phonological Processing – Elision and Blending Phonemes-Words (Wagner, Torgesen & Rashotte 1999)
The test of Elision is a measure of phoneme deletion. It requires the individual to say a word produced by the experimenter, and to repeat the word after deleting a syllable or phoneme specified by the experimenter. The Blending Phonemes-Words subtest involves orally presenting the subject with a series of isolated syllables or phonemes. The subject must blend these phonemes together to form a word.

Woodcock Reading Mastery Test-Revised (WRMT-R; Woodcock 1987)
Subjects were administered the Word Identification, Word Attack, and Passage Comprehension subtests. The Word Identification test requires identification of individual words with a 5-second time limit per word. The Word Attack subtest assesses a child's ability to apply grapheme-phoneme rules and word analysis skills to the pronunciation of unfamiliar printed nonwords (i.e., phonetically regular nonwords, or low-frequency words in the English language). The Passage Comprehension subtest uses a cloze procedure that

requires the subject to read sentences that are missing a word that is important to the meaning of the passage. Subjects must supply the missing word.

Wide Range Achievement Test – Third Edition – Reading (WRAT-3; Wilkinson 1993)
The WRAT-3 Reading subtest measures the ability to recognize and name letters and pronounce words. There is a ten-second time limit per word on the word identification portion of the test.

Results

1. *Relationship among phonological, naming-speed, age, and IQ variables*

To investigate the relationship between phonological and naming-speed variables in this population, Pearson product-moment correlations were calculated between the variables shown in Table 4. Unlike past results from unselected poor readers where there were no significant correlations between phonological and rapid-naming tasks, in this sample there were correlations between letter-naming speed and Blending Phonemes (r = 0.25, $p < 0.001$) and Phoneme Elision (r = 0.28, $p < 0.001$). Like prior results, IQ level was significantly correlated only with phonological measures. There were no significant correlations between level of IQ and the naming-speed variable. The two measures of phonological awareness were correlated at 0.57 ($p < 0.001$). Again, as in past analyses, there were significant relationships between phonological variables and age (r = 0.27, $p < 0.001$ for Phoneme Elision; 0.18 for Blending Phonemes, $p < 0.05$), but not for naming speed and age.

2a. *Relationships between phonological and reading variables*

Both Pearson correlations and multiple regression analyses were used to address questions concerning the relationships between phonological variables and each reading outcome measure. Table 4 depicts the correlation matrix for standard scores. Correlations for standard scores that come from standardization of the Wagner, Torgesen & Rashotte (1999) battery indicated that Blending Phonemes was significantly related to Word Attack (r = 0.42; $p < 0.001$), Word Identification (r = 0.32; $p < 0.001$), and Passage Comprehension (r = 0.27; $p < 0.001$). Phoneme Elision was significantly related to Word Attack (r = 0.40, $p < 0.001$), Word Identification (r = 0.40, $p < 0.001$), and Passage Comprehension (r = 0.34, $p < 0.001$).

Correlations for raw scores among variables also indicated significant relationships among all variables; however, as more frequently reported in

Table 4. Pearson correlations among naming speed, phonological, reading, IQ, and age variables using standard scores

	1	2	3	4	5	6	7	8
1. RAN-letters	—							
2. Elision	0.28***	—						
3. Blending phonemes	0.25**	0.57***	—					
4. Word identification	0.41***	0.40***	0.32***	—				
5. Word attack	0.34***	0.40***	0.42***	0.65***	—			
6. Passage comprehension	0.36***	0.34***	0.27***	0.77***	0.58***	—		
7. Age (in months)	–0.04	0.27**	0.18*	–0.29***	–0.46***	–0.28***	—	
8. IQ level	0.12	0.37***	0.37***	0.32***	0.41***	0.37***	0.14	—

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

the literature, there were higher relationships for phonological variables with Word Attack (Phoneme Elision, r = 0.63, $p < 0.001$ and Blending r = 0.61, $p < 0.001$) than for Word Identification (Blending, $r = 0.39$ and Phoneme Elision r = 0.44, $p < 0.001$). Elision raw scores were correlated with Passage Comprehension (r = 0.53, $p < 0.001$); Blending Phonemes was also correlated (r = 0.38; $p < 0.001$) with Passage Comprehension.

2b. *Relationships between naming speed and reading variables*

Findings indicated that naming-speed standard scores were significantly correlated to Word Attack ($r^2 = 0.34$, $p < 0.001$), Word Identification ($r^2 = 0.41$, $p < 0.001$) and Passage Comprehension ($r^2 = 0.36$, $p < 0.001$). Findings with naming-speed raw or latency scores more closely resembled patterns in past analyses, including our own (Bowers et al. 1988; Wolf & Bowers 1999). Raw score results indicated significant relationships between naming speed and Word Identification ($r^2 = 0.57$, $p < 0.001$), and Passage Comprehension ($r^2 = 0.51$, $p < 0.001$). There were also significant relationships between naming speed and Word Attack ($r^2 = 0.35$, $p < 0.001$). These pattern of relationships between phonological awareness tasks and Word Attack, and between naming speed and Word Identification correspond closely to findings reported widely in the literature (see review in Wolf & Bowers 1999).

2c. *Unique contributions of each variable to reading*

A series of stepwise regression analyses was conducted to determine whether phonological and naming-speed processes accounted for independent variance in the three types of reading measures, controlling for the effects of SES, age and IQ. As depicted in Table 5, approximately 43% ($R^2 = 0.43$; adjusted $R^2 = 0.40$; F = 25.80; $p < 0.0001$) of the variance in Word Identification was explained by the combined phonological (Elision), naming-speed, age, and IQ variables. SES and the Blending-Phonemes measure were not significant contributors. Thus both naming speed and phonological awareness measures made unique contributions to this reading outcome in this sample.

Shown in Table 6, approximately 62% ($R^2 = 0.62$; adj. $R^2 = 0.60$, F = 44.09, $p < 0.0001$) of the variance in Word Attack was explained by the combined variables, with all variables significant except SES. Naming speed made a small, independent contribution to Word Attack.

As shown in Table 7, approximately 36% ($R^2 = 0.36$; adj. $R^2 = 0.34$, F = 19.12, $p < 0.0001$) of the variance in Passage Comprehension is explained by the combination of these variables with all variables significant, except SES and the Blending-Phonemes measure.

Table 5. Results from stepwise regression analyses of word identification by phonological and naming-speed variables, IQ, and age

Step	Partial R^2	Model R^2	F	Probability
1. IQ (K-BIT composite)	0.22	0.22	39.18	0.0001
2. RAN letter	0.11	0.33	23.43	0.0001
3. Age	0.04	0.37	8.27	0.0050
4. Elision	0.06	0.43	14.70	0.0002

Table 6. Results from stepwise regression analyses for prediction of word attack by phonological and naming-speed variables, IQ, and age

Step	Partial R^2	Model R^2	F	Probability
1. IQ (K-BIT composite)	0.31	0.31	62.40	0.0001
2. Age	0.13	0.43	31.08	0.0001
3. Elision	0.12	0.55	37.27	0.0001
4. Blending phonemes	0.05	0.60	15.44	0.001
5. RAN letter-naming speed	0.02	0.615	7.02	0.009

Table 7. Results from stepwise regression analyses of passage comprehension by phonological and naming-speed variables, IQ, and age

Step	Partial R^2	Model R^2	F	Probability
1. IQ (K-BIT composite)	0.19	0.19	32.80	0.0001
2. RAN letters	0.08	0.27	16.25	0.0001
3. Age	0.04	0.31	7.90	0.006
4. Elision	0.04	0.355	9.61	0.002

Subtype analyses according to the Double-Deficit Hypothesis

In order to determine how this sample of profoundly impaired readers would be characterized by the Double-Deficit Hypothesis subtypes (Wolf & Bowers 1999), children were classified into four subgroups based on their performance on rapid letter naming and a composite of the phonological measures. A cut-off score of one standard deviation below the mean of standard scores was used to form a naming-speed deficit subgroup, a phonology deficit subgroup, a double-deficit subgroup and a no-deficit subgroup. As shown in Figure 2, 19% of this sample of highly impaired children were classified as phonolo-

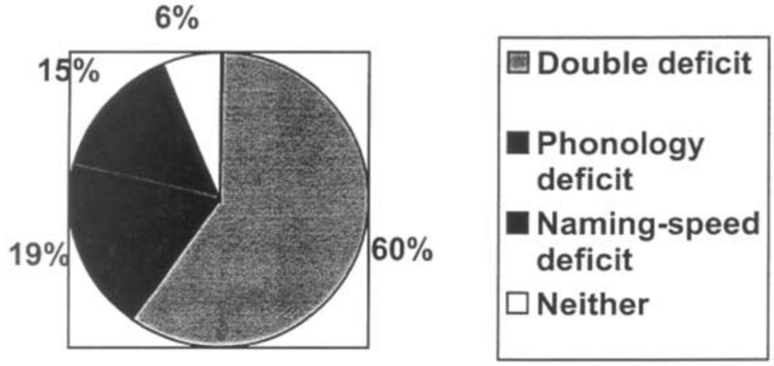

Figure 2. Sample distribution according to subtypes of the double-deficit hypothesis.

gical deficit; 15% rate or naming-speed deficit; 60% as double deficit; and 6% were unclassified using these criteria. See means for each subgroup on Table 8.

Discussion

The central question raised by this study concerns the hypothesized independence of phonological awareness and naming-speed variables in predicting variance in specific reading skills in a sample of young, impaired readers. Several types of evidence were brought to bear. First, in a correlational analysis, it was shown that there are significant relationships between two forms of phonological awareness tasks (i.e., phoneme elision and phoneme blending) and a naming-speed task. These results are similar to the modest relationships reported by Bowers and her colleagues in samples of average readers and less impaired poor readers (see review in Wolf & Bowers 1999). In other analyses by us with smaller samples, there were no significant relationships found (Goldberg et al. 1998; Wolf et al. 2000).

This first result, we believe, corresponds to our general view of the underlying cognitive structure of naming speed (see model of naming in Wolf & Bowers 1999). In this view, phonological processes occupy a critical, limited role in the ensemble of multiple lower-level perceptual, lexical, and motoric processes that make up naming. These results, when combined with the results from multiple regression analyses, do not support a view in which naming speed, as measured by RAN tasks, is subsumed under the rubric of a phonological process.

Next, to understand some of the divergent findings in previous samples studied that may be due to IQ and age, we examined the relationships among two phonological tasks, naming-speed tasks, IQ, and age. In fact, the IQ estimate accounted for the greatest amount of variance in each of the reading measures. A consideration of general cognitive function, assessed by this screening instrument, and specific speed and language functions, measured by the present phonological and naming speed tasks, is beyond the scope of this paper, but will be addressed in future work.

Results indicated significant relationships between IQ level and the phonological measures; significant relationships between age and phonological measures; and no significant relationships among IQ level, age, and naming-speed measures. Because of the correlations found between IQ and phonological measures in this and other studies (see review in Wolf & Bowers1999), it is important to include IQ in any analyses that involve phonological tests to insure that the predictive relationships that are found will be measuring the independent variance involved in phonological process measures.

The more specific focus of the present study was to explore the *unique* contributions of naming speed and phonological processes in three different components of reading skill, while including the influence of IQ and age. We conducted a series of multiple regression analyses with the following pattern of results: Both phonological and naming speed variables contributed independently to the predictive variance in all three measures. There were, however, contrasting patterns within these independent contributions. The phonological measures, particularly phoneme elision, contributed the most variance to word attack measures with a limited, unique contribution by naming speed. Conversely, naming speed contributed the most variance to the word identification measure, with a more limited contribution by phoneme elision.

Conceptually, these two patterns of results support our view of the underlying requirements of these two reading behaviors. Word attack primarily requires phoneme analysis skills like segmentation, elision, and blending, with a relatively smaller contribution from automaticity-related processes. Word identification with its emphases on orthographic pattern recognition and fluency would place less stress on phoneme blending skills and more emphases on the requirements for rapid identification and name retrieval that are also tapped by letter-naming speed tasks.

Both variables made unique contributions, along with IQ and age, to passage comprehension. Because of the redundancy between comprehension and both word attack and word identification, it is likely that the contributions by phonology and naming speed to comprehension are in large part the result of the shared contributions with word identification and word attack, a finding identified by Bowers and her colleagues (Bowers et al. 1994) and by Spring & Davis (1988). It is also important to state that many of the failed items on the passage comprehension subtest can be based on decoding or word identification problems, rather than comprehension skills, per se.

The cumulative results from these correlational and regression analyses replicate findings from other studies using both selected and unselected classroom samples (Bowers & Swanson 1991; Cornwall 1992; Manis & Doi 1995; McBride-Chang & Manis 1996; Torgesen et al. 1997). That is, phonological measures contribute more of the variance to those aspects of reading skill that involve decoding or word attack skills, while naming-speed measures contribute more to skills involved in word identification.

A final form of evidence for independence between phonological and naming-speed variables was the classification of the impaired readers in this sample into the putative subtypes of the double-deficit hypothesis. The notion here was that if subtypes of readers with dissociated phonological and naming-speed deficits can be found in this group of very poor readers, then there is additional evidence for the disentangling of the two deficits in our theories of reading disabilities. Results indicated that, similar to the assumptions of the double-deficit hypothesis, 60% of the subjects were categorized with both deficits. As in other analyses, these subjects were the most impaired across all categories of reading performance. In addition, 19% of the sample were classified as having a single phonological deficit; 15% were classified with naming-speed deficits only; and 6% were not able to be classified using these criteria. Only one other study (Lovett, Steinbach & Frijters 2000) has used the double-deficit hypothesis to investigate the potential classification of such a severely impaired population. Lovett, Steinbach & Frijters (2000) classified 140 subjects in their clinically-referred population into the double-deficit categories: double-deficit –54%; phonological deficit –22%; naming-speed deficit –24%. It is important to note that in addition to the 140 subjects described, 26 students in their clinical population were not identified by using either of the deficit criteria.

Taken together, these results provide a case for the independent variance in both phonological and naming-speed processes in developmental dyslexia. There are significant, unique contributions to different aspects of reading skill development by both measures, and there are dissociated, identifiable subtypes, defined by each deficit dimension. There are implications of these findings for both diagnosis and intervention that we will briefly describe here (see also Wolf et al. 2000).

Implications for research

Diagnosis. The results of the present study highlight the importance of including naming-speed measures, in addition to core phonological measures, in diagnostic and prediction test batteries. As demonstrated in a reading prediction study by Hurford and colleagues, phonological awareness tasks do not consistently predict later reading development as sufficiently as might be expected (Hurford, Johnston, Nepote, Hampton, Moore, Neal, Mueller, McGeorge, Huff, Awad, Tarto, Juliano & Huffman 1994). It has been demonstrated that the combination of serial naming measures with phonological awareness measures provides the strongest prediction capabilities to date (Catts 1996; Wagner, Torgesen & Rashotte 1994). The inclusion of serial-naming tasks in kindergarten and first grade screening batteries will also serve to identify the small group of children whose naming-speed problems presage later possible delays in fluent reading and comprehension, but who may have otherwise been missed due to their average phonological awareness and adequate decoding skills (Morris et al. 1998).

It is critical to design batteries which incorporate the range of skills that have been associated with reading acquisition failure. The use of batteries with a unitary focus may result not only in the underrepresentation of children who have multiple areas of difficulty, but also in overrepresentation of one subtype. For example, it remains unclear whether reading difficulties in African-American children may also be related to dialectical differences that may influence the development of metaphonological and phonological skills in standard English.

Intervention. The most important and most difficult implication of a naming-speed deficit is that the processes underlying it require new forms of intervention involving fluency and automaticity. To our minds, this is a time of many challenges and unresolved questions. A central issue is how to design interventions that go to the sources of naming-speed deficits, when the possible root causes are multiple and not well understood. For example, if weaknesses indexed by naming-speed tasks are indicative of more specific, lower-level, perceptual processing-speed deficits in some children (see discussion of Hypothesis 1 in Wolf et al. 2000), then systematic attention to increasing fluency in visual pattern recognition and orthographic skills might be key (e.g., see the accelerated reading rate program in Breznitz 1997). If these same weaknesses are indicative of a more domain-general processing-speed problem, then more comprehensive work on increasing fluency and automaticity in all major component skills of reading might be required (see Hypothesis 2 in Wolf et al. 2000).

Another issue is equally difficult. We do not yet know to what degree problems in rate of processing are amenable to treatment or whether underlying gains will generalize to reading. We have frequently hypothesized that the 'treatment resisters' described by Torgesen, Wagner & Rashotte (1994) may have rate of processing problems that require interventions that go beyond solely phonological-based treatments. It is an open question whether a combination of phonological and fluency emphases will better ameliorate the range of disabilities in these reading-disabled children and result in improved outcomes.

With these issues in mind, over the last two years as part of an NICHD-supported intervention project, we have designed an experimental, comprehensive, fluency-based program called RAVE-O (Retrieval, Automaticity, Vocabulary Elaboration-Orthography, Wolf & Miller 1997; Wolf, Miller & Donnelly 1998). The program is based on a connectionist view of reading (Adams 1990; Foorman 1994). There is a simultaneous, dual focus: First, on fluency in reading outcomes like word attack, word identification, and comprehension; and second, on automaticity in the underlying phonological, orthographic, semantic, and lexical retrieval skills that collectively contribute to (or impede) overall reading fluency. A more comprehensive approach is employed in an attempt to address the multiple sources of dysfluency in different readers (see Wolf & Bowers 1999).

Systematically introduced, game-like activities stress both accuracy and speed in each reading outcome and in each underlying component skill, such as letter and letter-pattern recognition, auditory discrimination of phonemes, lexical retrieval, and vocabulary growth. Within the component skills, orthographic pattern recognition is particularly emphasized through specially designed computer games, called Speed Wizards (Wolf & Goodman 1996).

The RAVE-O program is conceptualized as one-half of an intervention package that moves daily from a phonological-analysis and blending program based on Lovett's findings (Lovett et al. 1994) to emphases on orthographic pattern recognition, semantic development, and retrieval strategies. The major theoretically-based objectives are to help children activate phonological, orthographic, and semantic information about words more automatically to facilitate fluency in word recognition and comprehension.

Conclusion

These findings present another piece of evidence that helps to identify a second, possible source of reading disabilities in the processes underlying naming speed. These processes, we believe, are related to, but also separate from phonological processes. There is now cumulative evidence from this and the reviewed studies that phonological and naming-speed tasks make independent, as well as shared, contributions to the variance in word attack, word identification, and reading comprehension measures.

The implications of these findings are straightforward, but more difficult to implement. First, it is essential that diagnostic and predictive batteries incorporate both phonological awareness and naming-speed measures in kindergarten and the primary grades. Second, intervention efforts must begin to integrate a systematic, phonologically-based foundation in decoding skills with additional emphases on fluency and automaticity. Whether these emphases should be at the word level or on component skills or a combination of both is unresolved. The present RAVE-O program represents a comprehensive model that attempts to facilitate both.

In summary, dyslexia is the consequence of breakdown in a very complex set of processes. Our measurement tools and our interventions must incrementally build new models to meet the complexity of these processes and the compelling heterogeneity of reading impaired children. Research on the naming-speed process pushes our understanding of reading acquisition and the variety of ways it can fail to develop.

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Note

[1] It is important to note that by the end of data collection in Year 4, all of the cells will be evenly distributed according to the study design.

References

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

Ackerman, P.T. & Dykman, R.A. (1995). *The speed factor and learning disabilities: The toll of slowness in adolescents*. Unpublished manuscript.

Adams, M.J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: MIT Press.

Badian, N. (1995). Predicting reading ability over the long-term: The changing roles of letter naming, phonological awareness and orthographic processing, *Annals of Dyslexia: An Interdisciplinary Journal* 45: 79–86.

Badian, N. (1996a). *Dyslexia: Does it exist? Dyslexia, garden-variety poor reading and the double-deficit hypothesis*. Paper presented at Orton Dyslexia Society. Boston, MA.
Badian, N. (1996b). Dyslexia: A validation of the concept at two age levels, *Journal of Learning Disabilities* 29: 102–112.
Berninger, V., Cartwright, A., Yates, C., Swanson, H.L. & Abbott, R. (1994). Developmental skills related to writing and reading acquisition in the intermediate grades: Shared and unique variance, *Reading and Writing: An Interdisciplinary Journal* 6: 161–196.
Biddle, K.R. (1996). *The development of visual naming speed and verbal fluency in average and impaired readers: The implications for assessment intervention and theory*. Unpublished doctoral dissertation. Tufts University, Boston, MA.
Blachman, B.A. (1984). Relationship of rapid naming ability and language analysis skills to kindergarten and first-grade reading achievement, *Journal of Educational Psychology* 76: 610–622.
Bowers, P.O., Golden, J., Kennedy, A. & Young, A. (1994). Limits upon orthographic knowledge due to processes indexed by naming speed. In: V.W. Berninger (ed.), *The varieties of orthographic knowledge*, Vol. I: *Theoretical and developmental issues* (pp. 173–218). Dordrecht/Boston/London: Kluwer Academic Publishers.
Bowers, P.O., Stefty, R. & Tate, B. (1988). Comparison of the effects of IQ control methods on memory and naming speed predictors of reading disability, *Reading Research Quarterly* 23: 304–309.
Bowers, P.O. & 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.O. & 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.
Brady, S. & Shankweiler, D. (eds.) (1991). *Phonological processes in literacy: A tribute to Isabelle Y. Liberman*. Hillsdale, NJ: Erlbaum.
Breznitz, Z. (1996). *Perceptual deficits among developmental dyslexics*. Unpublished manuscript.
Breznitz, Z. (1997). Enhancing the reading of dyslexics by reading acceleration and auditory masking, *Journal of Educational Psychology* 89: 103–113.
Bruck, M. & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters, *Journal of Experimental Child Psychology* 50(1): 156–178.
Byrne, B. (1998). *The foundations of literacy*. East Sussex, UK: Psychology Press.
Carver, R.P. (1991). Using letter naming speed to diagnose reading disability, *RASE-Remedial and Special Education* 12: 33–43.
Carver, R.P. (1997). Reading for one second, one minute, or one year from the perspective of reading theory, *Journal for the Scientific Study of Reading* 1: 4–44.
Cattell, M. (1886). The time it takes to see and name objects, *Mind* 2: 63–85.
Catts, H.W. (1996). Defining dyslexia as a developmental language disorder: An expanded view, *Topics in Language Disorders* 16(2): 14–29.
Chall, J.S. (1983). *Stages of reading development*. New York: McGraw-Hill.
Cornwall, A. (1992). The relationship of phonological awareness, rapid naming, and verbal memory to severe reading and spelling disability, *Journal of Learning Disability* 25: 532–538.
Denckla, M.B. (1972). Color-naming defects in dyslexic boys, *Cortex* 8: 164–176.

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

Denckla, M.B. & Rudel, R.G. (1976a). Naming of objects by dyslexic and other learning-disabled children, *Brain and Language* 3: 1–15.

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

Doehring, D. (1976). Acquisition of rapid reading responses, *Monographs of the Society for Research in Child Development* 41(2).

Farmer, M.E. & Klein, R.M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review, *Psychonomic Society* 2: 460–493.

Felton, R.H. & Wood, F. (1992). Cognitive deficits in reading deficits in reading disability and attention deficit disorder, *Journal of Learning Disabilities* 22: 3–13.

Felton, R.H., Wood, F.B., Brown, I.S. & Campbell, S.K. (1987). Separate verbal memory and naming deficits in attention deficit disorder and reading disability, *Brain and Language* 31: 171–184.

Fletcher, J.M., Shaywitz, S.E., Shankweiler, D.P., Katz, L., Liberman, LY., Stuebing, K.K., Fowler, A., Francis, D.J. & Shaywitz, B.A. (1994). Cognitive profiles of reading disability: Comparisons of discrepancy and low achievement definitions, *Journal of Educational Psychology* 85: 1–18.

Foorman, B. (1994). Phonological and orthographic processing: Separate but equal? In: V. Berninger (ed.), *The varieties of orthographic knowledge* (pp. 321–358). Dordrecht/Boston/London: K1uwer Academic Publishers.

Foorman, B., Francis, D., Shaywitz, S., Shaywitz, B. & Fletcher, J. (1997). The case for early reading intervention. In: B. Blachman (ed.), *Foundations of reading acquisition* (pp. 243–264). Mahwah, NJ: Erlbaum.

Geschwind, N. (1965). Disconnection syndrome in animals and man (Parts I, II). *Brain* 88: 237–294, 585–644.

Gidney, C., Deeney, T., Wolf, M., Holmes, J., Cirino, P. & Morris, R. (1998). *The presence of phonological and naming-speed deficits in Africa-American children*. Poster presented at the Conference on Language Development in African-American Children. Memphis, TN.

Goldberg, A., Wolf, M., Cirino, P., Morris, R. & Lovett, M. (1998). *A test of the 'Double Deficit Hypothesis'*. Paper presented at the meeting of the Society for the Scientific Study of Reading. San Diego, CA.

Gough, P. & Tunmer, W. (1986). Decoding, reading, and reading disability, *Remedial and Special Education* 7: 6–10.

Grigorenko, E., Wood, F., Meyer, M., Hart, L., Speed, W., Shuster, A. & Pauls, D. (1997). Susceptibility loci for distinct components of developmental dyslexia on chromosomes 6 and 15, *American Journal of Human Genetics* 60: 27–39.

Huey, B. (1908). *The psychology and pedagogy of reading*. Cambridge: MIT Press.

Hurford, D.P., Johnston, M., Nepote, P., Hampton, S., Moore, S., Neal, J., Mueller, A., McGeorge, K., Huff., L., Awad, A., Tarto, C., Juliano, C. & Huffman, D. (1994). Early identification and remediation of phonological-processing deficits in first-grade children at risk for reading disabilities, *Journal of Learning Disabilities* 27: 647–659.

Kamhi, A. & Catts, H. (1989). *Reading disabilities: A developmental language perspective*. Austin, TX: Pro-ed.

Kaufman, A. & Kaufman, N. (1990). *Kaufman Brief Intelligence Test*. Circle Pines, MN: American Guidance Service.

Korhonen, T. (1995). The persistence of rapid naming problems in children with reading disabilities: A nine-year follow-up, *Journal of Learning Disabilities* 28: 232–239.

Lovett, M.W. (1992). Developmental dyslexia. In: F. Boller & J. Grafman (eds.), *Handbook of Neuropsychology*, Vol. 7 (pp. 163–185). Amsterdam: Elsevier.

Lovett, M.W., Borden, S., DeLuca, T., Lacerenza, L., Benson, N. & Brackstone, D. (1994). Treating the core deficits of developmental dyslexia: Evidence of transfer of learning after phonologically and strategy-based reading training programs, *Developmental Psychology* 30: 805–822.

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

Lyon, G.R. (1995). Toward a definition of dyslexia, *Annals of Dyslexia: An Interdisciplinary Journal* 45: 3–27.

Lyon, G.R. & Moats, L.C. (1997). Critical conceptual and methodological considerations in reading intervention research, *Journal of Learning Disabilities* 30: 578–588.

Manis, F. & Doi, L. (1995). *Word naming speed, phonological coding and orthographic knowledge in dyslexic and normal readers*. Symposium paper presented at the Society for Research in Child Development. Indianapolis, IN.

Manis, F., Doi, L. & Bhadha, B. (2000). Naming speed, phonological awareness and orthographic knowledge in second graders, *Journal of Learning Disabilities* 33: 325–333, 374.

Martinussen, R., Frijters, J. & Tannock, R. (1998). *Naming speed and stimulant effects in inattention-deficit/hyperactivity disorder*. Paper presented at American Academy of Child and Adolescent Psychiatry. Anaheim, CA.

McBride-Chang, C. & Manis, F. (1996). Structural invariance in the associations of naming speed, phonological awareness, and verbal reasoning in good and poor readers: A test of the double deficit hypothesis, *Reading and Writing: An Interdisciplinary Journal* 8: 323–339.

Merzenich, M.M., Jenkins, W.M., Johnston, P., Schreiner, C., Miller, S. & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training, *Science* 271: 77–80.

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.

Morris, R., Stuebing, K., Fletcher, J., Shaywitz, S., Lyon, R., Shankweiler, D., Katz, L., Francis, D. & Shaywitz, B. (1998). Subtypes of reading disability: A phonological core with cognitive variability, *Journal of Educational Psychology* 90: 1–27.

Näslund, J.C. & Schneider, W. (1991). Longitudinal effects of verbal ability, memory capacity, and phonological awareness on reading performance, *European Journal of Psychology of Education* 4: 375–392.

Nicolson, R.I. & Fawcett, A.J. (1994). Reaction times and dyslexia, *Quarterly Journal of Experimental Psychology* 47: 29–48.

Novoa, L. (1988). *Word-retrieval process and reading acquisition and development in bilingual and monolingual children*. Unpublished doctoral dissertation. Harvard University, Cambridge, MA.

Novoa, L. & Wolf, M. (1984). *Word- retrieval and reading in bilingual children*. Paper presented at Boston University Language Conference, Boston, MA.

Ojemann, G.A. (1984). Common conical and thalamic mechanisms for language and motor functions, *American Journal of Physiology* 246: 901–903.

Olson, R.K. (1995). Language deficits in 'specific' reading disability. In: M. Gernsbacher (ed.), *Handbook of psycholinguistics*. San Diego, CA: Academic Press.

Olson, R.K., Wise, B., Connors, F., Rack, J.P. & Fulker, D. (1989). Specific deficits in component reading and language skills: Genetic and environmental influences, *Journal of Learning Disabilities* 22: 339–348.

Perfetti, C.A. (1985). *Reading ability*. New York: Oxford Press.

Perfetti, C.A., Finger, B. & Hogaboam, T. (1978). Sources of vocalization latency differences between skilled and less skilled young readers, *Journal of Educational Psychology* 70: 730–739.

Rutter, M. & Yule, W. (1975). The concept of specific reading retardation, *Journal of Child Psychology and Psychiatry* 16: 181–197.

Sankaranarayanan, A. (1998). *Cognitive profiles of youngchildren: A comparison of good and poor readers*. Unpublished doctoral dissertation. Harvard University, Cambridge, MA.

Scarborough, H.S. & Domgaard, R.M. (1998). *An exploration of the relationship between reading and rapid serial naming*. Poster presented at meeting of Society for Scientific Study of Reading. San Diego, CA.

Segal, D. & Wolf, M. (1993). Automaticity, word retrieval, and vocabulary development in children with reading disabilities. In: L. Meltzer (ed.), *Cognitive, linguistic, and developmental perspectives on learning disorders* (pp. 141–165). Boston: Little & Brown.

Shankweiler, D. & Liberman, I.Y. (1972). Misreading: A search for causes. In: J.F. Kavanagh & I.G. Mattingly (eds.), *Language by ear and by eye* (pp. 293–317). Cambridge, MA: MIT Press.

Shaywitz, S., Shaywitz, B., Pugh, K., Fulbright, R., Constable, R.T., Menel, W.E., Shankweiler, D., Liberman, A., Skudlarski, P., Fletcher, J., Katz, L., Marchione, K., Lacadie, C., Gatenby, C. & Gore, J. (1998). Functional disruption in the organization of the brain for reading in dyslexia, *Neurobiology* 95: 2636–2641.

Siegel, L.S. & Ryan, E.B. (1988). Development of grammatical-sensitivity, phonological, and short-tern memory skills in normally achieving and learning disabled children, *Developmental Psychology* 24: 28–37.

Snyder, L. & Downey, D. (1995). Serial rapid naming skills in children with reading disabilities, *Annals of Dyslexia* 45: 31–50.

Spring, C. & Capps, C. (1974). Encoding speed, rehearsal, and probed recall of dyslexic boys, *Journal of Educational Psychology* 66: 780–786.

Spring, C. & Davis, J. (1988). Relations of digit naming speed with three components of reading, *Applied Psycholinguistics* 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. (1992). Speculations on the causes and consequences of individual differences in early reading acquisition. In: P.B. Gough, L.C. Ehri & R. Treiman (eds.), *Reading acquisition* (pp. 307–342). Hillsdale, NJ: Erlbaum.

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(1): 24–53.

Tallal, P., Miller, S.L., Bedi, G., Byma, G., Wang, X., Nagarajan, S., Schreiner, C., Jenkins, W. & Merzenich, M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech, *Science* 271: 81–84.

Torgesen, J.K., Wagner, R.K. & Rashotte, C.A. (1994). Longitudinal studies of phonological processing and reading, *Journal of Learning Disabilities* 27: 276–286.

Torgesen, J.K., Wagner, R.K., Rashotte, C.A., Burgess, S. & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children, *Scientific Studies of Reading* 1: 161–185.

Tunmer, W. (1995). *Intervention strategies for developing onset-rime sensitivity and analogical transfer in reading disabled children*. Paper presented at the Extraordinary Brain III Conference. Kauai, Hawaii.
Van den Bos, K. (1998). IQ, phonological awareness, and continuous-naming speed related to Dutch children's poor decoding performance on two word identification tests, *Dyslexia* 4: 73–89.
Vellutino, F. & Scanlon, P. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study, *Merrill Palmer Quarterly* 33: 321–363.
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). *Comprehensive test of phonological processing*. Austin, TX: ProEd.
Wilkinson, H. (1993). *Wide range achievement test: Administration manual*. Wilmington, DE: Jastak.
Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system, *Applied Psycholinguistics* 14: 1–34.
Wimmer, H. & Hummer, P. (1990). How German-speaking first graders read and spell: Doubts on the importance of the logographic stage, *Applied Psycholinguistics* 11: 349–368.
Wolf, M. (1979). *The relationship of disorders of word-finding and reading in children and aphasics*. Unpublished doctoral dissertation. Harvard University, Cambridge, MA.
Wolf, M. (1982). The word-retrieval process and reading in children and aphasics. In: K. Nelson (ed.), *Children's language* (pp. 437–493). Hillsdale, NJ: Erlbaum.
Wolf, M. (1991). Naming speed and reading: The contribution of the cognitive neurosciences, *Reading Research Quarterly* 26: 123–141.
Wolf, M. (1997). A provisional, integrative account of phonological and naming-speed deficits in dyslexia: Implications for diagnosis and intervention. In: B. Blachman (ed.), *Foundations of reading acquisition* (pp. 67–92). Mahwah, NJ: Erlbaum.
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 Educational Psychology* 19: 1–24.
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. & Goodglass (1986). Dyslexia, dysnomia, and lexical retrieval, *Brain and Language* 28: 154–168.
Wolf, M. & Goodman, G. (1996). *Speed wizards*. Computerized reading program. Tufts University and Rochester Institute of Technology.
Wolf, M. & Miller, L. (1997). *The Retrieval, Automaticity, Vocabulary Elaboration-Orthography (RAVE-O) reading intervention manual*. An unpublished manual for NICHD grant No. 1R55HD/0D30970-O1A1.
Wolf, M., Miller, L. & Donnelly, K. (2000). Retrieval, Automaticity, Vocabulary Elaboration-Orthography (RAVE-O): A comprehensive, fluency-based reading intervention program, *Journal of Learning Disabilities* 33: 375–386.
Wolf, M. & Obregón, M. (1992). Early naming deficits, developmental dyslexia, and a specific deficit hypothesis, *Brain and Language* 42: 219–247.

Wolf, M., Pfeil, C., Lotz, R. & Biddle, K. (1994). Towards a more universal understanding of the developmental dyslexias: The contribution of orthographic factors. In: V.W. Berninger (ed.), *The varieties of orthographic knowledge*, Vol. I: *Theoretical and developmental issues* (pp. 137–171). Dordrecht/Boston/London: Kluwer Academic Publishers.

Wolf, M. & Segal, D. (1999). Retrieval-rate, Accuracy, and Vocabulary Elaboration (RAVE) in reading-impaired children: A pilot intervention program, *Dyslexia: An International Journal of Theory and Practice* 5: 1–27.

Wolff, P., Michel, C. & Ovrut, M. (1990a). Rate variables and automatized naming in developmental dyslexia, *Brain and Language* 39: 556–575.

Wolff, P., Michel, C. & Ovrut, M. (1990b). The timing of syllable repetitions in developmental dyslexia, *Journal of Speech and Hearing Research* 33: 281–289.

Wood, F.B. & Felton, RH. (1994). Separate linguistic and developmental factors in the development of reading, *Topics in Language Disorders* 14: 42–57.

Woodcock, R.W. (1987). *Woodcock Reading Mastery-Tests-Revised: Examiner's manual*. Circle Pines, MN: American Guidance Service, Inc.

Yap, R. & van der Leij, A. (1993). Word processing in dyslexics: An automatic decoding deficit?, *Reading and Writing: An Interdisciplinary Journal* 5: 261–279.

Yap, R.L. & van der Leij, A. (1994). Testing the automatization deficit hypothesis of dyslexia via a dual-task paradigm, *Journal of Learning Disabilities* 27: 660–665.

Young, A. & Bowers, P.G. (1995). Individual difference and text difficulty determinants of reading fluency and expressiveness, *Journal of Experimental Child Psychology* 60: 428–454.

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