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The Double-Deficit Hypothesis for the Developmental Dyslexias

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The authors propose an alternative conceptualization of the developmental dyslexias, the *double-deficit hypothesis* (i.e., phonological deficits and processes underlying naming-speed deficits represent 2 separable sources of reading dysfunction). Data from cross-sectional, longitudinal, and cross-linguistic studies are reviewed supporting the presence of 2 single-deficit subtypes with more limited reading impairments and 1 double-deficit subtype with more pervasive and severe impairments. Naming-speed and phonological-awareness variables contribute uniquely to different aspects of reading according to this conception, with a model of visual letter naming illustrating both the multicomponential nature of naming speed and why naming speed should not be subsumed under phonological processes. Two hypotheses concerning relationships between naming-speed processes and reading are considered. The implications of processing speed as a second core deficit in dyslexia are described for diagnosis and intervention.

A major tenet of the best developed theory of reading disabilities is that a core deficit in phonological processes impedes the acquisition of word recognition skills, which, in turn, impedes the acquisition of fluent reading (Bradley & Bryant, 1983; Brady & Shankweiler, 1991; Bruck & Treiman, 1990; Catts, 1996; Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997; Kamhi & Catts, 1989; Lyon, 1995; Olson, Wise, Connors, Rack, & Fulker, 1989; Perfetti, 1985; Shankweiler & Liberman, 1972; Siegel & Ryan, 1988; Stanovich, 1986, 1992; Stanovich & Siegel, 1994; Torgesen, Wagner, & Rashotte, 1994; Tunmer, 1995; Vellutino & Scanlon, 1987; Wagner, Torgesen, & Rashotte, 1994). The central question of this article is whether the processes underlying naming speed represent a second core deficit in children with developmental dyslexia.

On the basis of research in the neurosciences, there is extensive evidence that many severely impaired readers have naming-speed deficits; that is, deficits in the processes underlying the rapid recognition and retrieval of visually presented linguistic stimuli (Ackerman & Dykman, 1993; Badian, 1995, 1996a, 1996b; Bowers, Steffy, & Tate, 1988; Denckla & Rudel, 1976a, 1976b; Grigorenko et al., 1997; Lovett, 1992, 1995; McBride-Chang & Manis, 1996; Meyer, Wood, Hart, & Felton, 1998a, 1998b; Snyder & Downey, 1995; Spring & Capps, 1974; Spring & Davis, 1988; Swanson, 1989; Wolf, 1979; Wolf, Bally, & Morris, 1986; Wolff, Michel, & Ovrut, 1990a, 1990b; Wood & Felton, 1994). 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 and Rudel (1974, 1976a, 1976b). This test involves the rapid naming of a visual array of 50 stimuli, consisting of five symbols in a given category (e.g., letters, numbers, colors, or objects) that are presented 10 times in random order (see Figure 1).

There is little disagreement concerning the behavioral evidence of naming-speed deficits in dyslexic readers. There are substantive differences regarding how these deficits should be categorized. The extent to which these two deficits are independent sources of reading failure has profound implications for how researchers diagnose, predict, and treat children with developmental reading disabilities. Current practice among most reading researchers is to subsume naming speed under phonological processes; for example, "retrieval of phonological codes from a long-term store" (Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993, p. 84), or phonological recoding in lexical access (Wagner & Torgesen, 1987). In contrast, researchers in the cognitive neurosciences tend to view phonological processes as separate, specific sources of disability (Meyer et al., 1998a, 1998b; Wolf, 1991a, 1997).

In this article, we propose an alternative, integrative

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o a s d p a o s p d

s d a p d o a p s o

a o s a s d p o d a

d s p o d s a s o p

s a d p a p o a p s

Figure 1. Example of rapid automatized naming (RAN) for letters.

view—the *double-deficit hypothesis*—that phonological deficits and the processes underlying naming speed are separable sources of reading dysfunction, and their combined presence leads to profound reading impairment. The ramifications of adopting one or the other view for diagnosis and treatment illustrate the importance of this question. If current practice of placing naming-speed problems under the phonological rubric is correct, then the vast majority of impaired readers are sufficiently served by the prevailing emphasis on phonological-based skills in diagnosis and intervention. If, however, the two deficits are to some important extent independent, then two dissociated, single-deficit subgroups and one combined deficit subgroup would be hypothesized. Table 1 presents an overview of the prototypical characteristics of each subtype. (See more detailed descriptions in Wolf & Bowers, in press.) The phonological subtype has no identifiable deficit in naming-speed performance (usually measured by letter, number-naming speed, or both) but does have significant decrements in performance on phonological tasks (e.g., phoneme elision, phonological blending, or both), word attack, and reading comprehension. The naming-speed deficit subtype has no identifiable deficit on phonological awareness or decoding tasks but does have significant problems on naming-speed tasks, timed reading and fluency measures, and reading comprehension. Some data, described later, indicate accuracy and latency problems in word identification, particularly for irregular or exception words. The double-deficit subtype is characterized by deficits in both phonological and naming-speed areas and in all aspects of reading.

Although single phonological-deficit readers would appropriately be treated by current practice, single naming-speed deficit readers would be either misclassified as having phonological deficits and given insufficient intervention or missed altogether because of these readers' adequate decoding skills. Most important, both the latter group and the combined deficit group would typically receive treatment related to only the phonological deficit, with little attention given to issues related to fluency and automaticity.

Table 1
Double-Deficit Hypothesis Subtypes

Subtype	Characteristics
Average group	No deficits and average reading
Rate group	Naming-speed deficit, intact phonological decoding, and impaired comprehension
Phonology	Intact naming speed
Double deficit	Naming-speed, phonological-decoding, and severe comprehensive benefits

In this article, we present a case for the independent and combined roles of naming-speed and phonological deficits in reading failure through a review of previous and recent findings. The literature review includes a brief statement about the well-known phonological core-deficit literature and a more comprehensive summary of the somewhat less known naming-speed literature. A description of the double-deficit hypothesis integrates both bodies of research. Our final discussion suggests two nonexclusive hypotheses, based on research in the cognitive neurosciences, that begin to account for the relationship of naming-speed deficits to reading failure.

Phonological Processes

There is broad conceptual agreement that phonological processing problems are a primary source of reading disabilities. As articulated in the *phonological-core deficit, variable-difference* view (Stanovich, 1986), researchers recognizing this position believe that phonemic insensitivity and other phonological-based problems are the principal basis for later impaired word recognition, which underlies most reading disability. This position is based on early psycholinguistic work by Liberman, Shankweiler, and their colleagues in the early 1970s (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Shankweiler & Liberman, 1972) and on a series of systematic reading research programs over the past 25 years (Brady & Shankweiler, 1991; Bruck & Treiman, 1990; Catts, 1996; Chall, 1983; Ehri, 1992; Ehri & Wilce, 1983; Foorman et al., 1997; Kamhi & Catts, 1989; Olson et al., 1989; Perfetti, 1985, 1992; Stanovich, 1986, 1988; Torgesen et al., 1994; Vellutino, Scanlon, & Chen, 1995; Wagner & Torgesen, 1987). Rack, Snowling, and Olson (1992) have shown that the most typical indicator of the disabled reader's impaired phonological-based decoding abilities is a severely reduced ability to decode nonsense words (i.e., to apply grapheme–phoneme correspondence rules in a context-free situation).

The principal tenets of Rack et al.'s (1992) position are incorporated within our own. Our position diverges, however, in the differentiation of naming-speed processes from phonological processes and in the implications of this dissociation for diagnosis and intervention. We argue that naming-speed deficits should be categorized separately from phonological-based deficits for theoretical and applied reasons (Wagner et al., 1994). To support our case for separate deficit status, we present five types of evidence about naming speed: (a) a brief overview of its cognitive requirements; (b) data from diverse populations; (c) cross-linguistic findings; (d) its independence from phonological awareness tasks in predicting various aspects of reading skill; and (e) subtype distinctions that include rate dimensions.

Cognitive Requirements

Our rationale for differentiating naming speed from phonological processes begins with an examination of the perceptual, cognitive, and linguistic processes underlying the behavioral requirements of serial or continuous naming speed. As described briefly in the introduction, and shown in Figure 1, the typical naming-speed task requires the participant to name visually presented symbols in a given set (e.g., letters and numbers) as quickly as possible. Unlike confrontation naming tests in which each pictured object is presented discretely, in naming-speed tasks, symbols are presented serially and repeated often up to 10 times in an array; the number of symbols is usually restricted to five in a set.

The letter-naming model shown in Figure 2 is presented as a heuristic in which to examine three issues: the variety of processes involved in visual naming, the critical but circumscribed role of phonological processes within naming, and the correspondence between many components of naming and reading. The letter-naming model makes no claims concerning linearity, the hypothetical sequence of activation among components, or how different aspects of memory operate. Because of the particular correspondence between letter naming and reading, the model depicts only letter

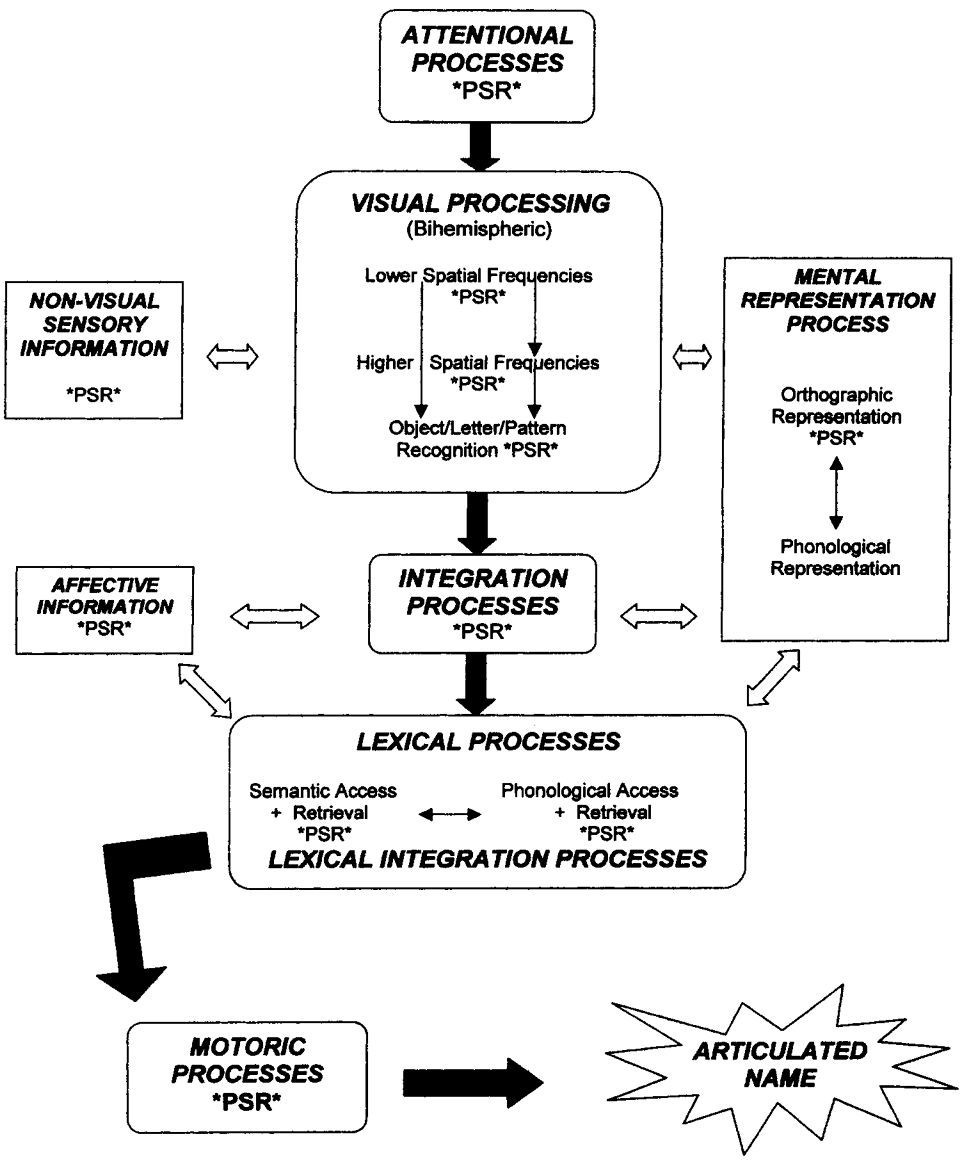

Figure 2. Model of visual naming for letter(s) stimulus. PSR = processing speed requirements.

naming. Many of the same components would also be depicted for other stimulus sets, particularly numbers. Briefly (for other descriptions, see Wolf, 1982, 1991a; Wolf, Bowers, & Biddle, in press), rapid letter naming requires (a) attention to the letter stimulus; (b) bihemispheric, visual processes that are responsible for initial feature detection, visual discrimination, and letter and letter–pattern identification; (c) integration of visual feature and pattern information with stored orthographic representations; (d) integration of visual information with stored phonological representations; (e) access and retrieval of phonological labels; (f) activation and integration of semantic and conceptual information; and (g) motoric activation leading to articulation. Precise rapid timing is critical both for the efficiency of operations within individual subprocesses and for integrating across them (for broader discussions of general naming, see Johnson, Paivio, & Clark, 1996; for discussions of efficiency, see Perfetti, 1985).

Demands for rapidity differ according to the specific characteristics of the stimulus. For example, in the previously given case of serial letter-naming tasks and for serial digit-naming tasks, alphanumeric stimuli are typically processed more rapidly than other stimuli (e.g., colors or objects) because they constitute a highly constrained category and are capable of being processed relatively "automatically." (See discussions of automatic processing as a continuum in Logan, 1988; Wolf, 1991a; see also Cattell, 1886.)

Within the model's description, the phonological process' role in naming-speed tasks is essential—activating stored phonological representations and the access and retrieval of phonological labels. It is equally the case that other verbal tasks (e.g., semantic fluency and expressive vocabulary) require these same phonological processes yet are rarely categorized as phonological tasks. The greater emphasis on other operations in these tasks has led them to be categorized as semantic and vocabulary tasks, rather than as part of the phonological family of tasks. Similarly, we argue that naming speed's particular emphases on both processing speed and the integration of an ensemble of lower level visual perceptual processes and higher level cognitive and linguistic subprocesses dictate a separate categorization of their own. The particular subprocesses in serial naming, we argue further, are also utilized in reading at a more complex level of integration with comprehension processes. As discussed by Denckla (1998), naming-speed tasks represent a microcosm of reading, a window on how rapid visual–verbal connections—essential to reading—are made in the developing child's system. Thus, early deficits in the basic naming-speed system alert researchers to future weaknesses in the later developing reading system and may also play a causal role (see Bowers, Golden, Kennedy, & Young, 1994), elaborated on a topic in the Discussion section.

To understand more fully which aspects of tasks typically used to tap the naming-speed deficit are reflected in poor reading, decomposing serial naming-speed tasks is helpful. Two related questions about the serial naming task have been studied: (a) What role does the task's serial format play in the relationship to reading? (b) What role is played by the necessity to articulate the symbol's name?

Serial format. Typically, the naming of symbols on a serial list (as in Denckla and Rudel's, 1976a, 1976b, task mentioned previously) has higher correlations with various reading measures than does the naming of items in a discrete (or isolated) format (Perfetti, Finger, & Hogaboam, 1978; Wagner et al., 1994; Wolff et al., 1990a). This pattern of results may be indicative of the greater demands for rapidity placed on the system during serial naming. Indeed, the processes tapped by serial and discrete naming tasks form separate factors in several studies with dyslexic readers (Olson, 1994; Wagner et al., 1994). (Interestingly, Jackson, Donaldson, and Mills, 1993, found that both formats loaded onto the same reading-related factor in nonreading-disabled, precocious readers.)

As Blachman (1984) has suggested, the rapid serial naming format provides a far better approximation of the requirements in reading running text than does the discrete naming format. Indeed, Scarborough and Domgaard (1998) have recently suggested that these tasks be called *rapid serial naming tasks* to emphasize the serial nature of the requirements. Nevertheless, in several studies, group differences were also found for discrete trial naming. Fawcett and Nicolson (1994) found significant differences in discrete trial naming speed between dyslexic and average children; 17-year-old dyslexic participants were closest in naming latency compared with normal 8-year-old controls (see also Bowers & Swanson, 1991). It may well be that poor readers who have more general lexical retrieval problems (e.g., as indexed by confrontation naming tasks) also have discrete trial-naming speed differences, an area that requires more investigation.

Articulation. Requirements for articulation speed and end-of-line scanning have also been cited as accounting for serial naming speed's stronger correlation to reading. Most researchers report that general articulatory speed does not account for differences between dyslexic readers and controls on serial naming tasks (Ackerman & Dykman, 1993; Ellis, 1985; Stanovich, Nathan, & Zolman, 1988), despite the significant relationships among measures of articulation speed, naming speed, and reading accuracy and speed (Scarborough & Domgaard, 1998).

In a study in our lab to investigate various hypotheses about the source of naming-speed differences, particularly articulation, Obregón (1994) designed a computerized program to digitize the speech stream of children while they performed serial naming tasks. Each articulated name was represented as a discrete "island" of sound with discrete spaces of time between sounds. Obregón demonstrated that the source of differences between dyslexic and average readers on these tasks was neither the time to articulate names of stimuli nor the time to scan the ends of lines. Rather, significant differences were found in the time taken in the interstimulus intervals (ISIs); that is, the time between the names. Such differences presumably reflect the extra time taken by dyslexic participants to relinquish processing the previous stimulus and to move on to processing the present one. Scarborough and Domgaard (1998) recently reported that a participant's yes/no decision about the names of letters in upper- and lowercase and different fonts on a serial list did not correlate with reading, although repeating the item names from this complex serial list and reading them were related. The decision task reduces the demand to locate a new name because one name is always kept in mind as decisions are made. We hypothesized that the time taken inhibiting the connection between the previous symbol and its name and then processing the visual and lexical information about the new symbol may well be what accounts for Scarborough and Domgaard's finding. J. K. Torgesen (personal communication, October 15, 1998) recently noted in an unpublished study a similar finding concerning the importance of the ISIs between stimuli on the coding task of the Wechsler Intelligence Scale for Children—Revised (Wechsler, 1974).

Another question pertinent to discovering what aspect of serial naming speed relates to reading is whether its effect appears mediated by other processes correlated with reading or whether it has a direct relationship. To date, no evidence of a mediated relationship has been found. The naming-speed deficit appears unrelated to IQ (Bowers et al., 1988; Meyer et al., 1998b; Spring & Davis, 1988) and memory (Bowers et al., 1988; Wagner et al., 1993; Wimmer, 1993). In a study of average readers across a wide age range, Kail and Hall (1994) found naming speed to be highly related to global changes in speed of processing (measured by symbol search, coding, and cross-out tasks) rather than directly related to age. (See also Carver's, 1991, 1997, view that letter-naming speed is a cognitive speed index.) In a replication of Kail and Hall's study in an impaired reader sample, Marcus (1997) found this pattern of relationships only for dyslexic readers and not for nondiscrepant poor readers, whose speed-of-processing variables were minimally related to naming speed.

Cutting, Carlisle, and Denckla (1998) used path analysis models to examine various relationships between the RAN task and other predictors of reading, including articulation, orthographic awareness, phonological processing, and memory span. Although orthographic awareness was related to naming speed, neither it nor the other variables explained the contribution of naming speed to reading. Instead, rapid naming contributed directly to word reading, not indirectly by some factor such as articulation or phonological skill. Further work such as the Cutting et al. and the Scarborough and Domgaard (1998) studies in decomposing the naming-speed task and investigating the paths by which it relates to reading are essential if researchers are to tease apart and understand the underlying sources of disruption in naming-speed findings.

Data From Diverse Populations

Since the mid-1970s, researchers in cognitive neuropsychology have found that most dyslexic children have exhibited naming-speed deficits when measured by continuous naming-speed tasks such as the RAN measures (Denckla & Rudel, 1974, 1976a, 1976b). Moreover, the deficit characterizes dyslexic readers across years of development: from prereading stages in kindergarten (Wolf et al., 1986) to adulthood (Felton, 1994; Felton & Brown, 1990; Flowers, 1993; Lombardino et al., 1998; Pennington, Van Orden, Smith, Green, & Haith, 1990; Wolff et al., 1990a).

Most dyslexic children are significantly slower in naming speed (particularly for letters and digits) than are average peers (Bowers et al., 1988; Denckla & Rudel, 1976a, 1976b; Snyder & Downey, 1995; Spring & Capps, 1974; Spring & Davis, 1988; Wolf, 1982) and other learning-disabled children without reading disabilities (Ackerman & Dykman, 1993, 1995; Denckla & Rudel, 1976a, 1976b; Felton & Wood, 1992; Felton, Wood, Brown, & Campbell, 1987; Wood & Felton, 1994). Discrepancy-based dyslexic readers (i.e., children whose poor reading achievement is discrepant from a reading level expected on the basis of their general intellectual development) are often compared with nondiscrepant or garden-variety reading-impaired children. Gough and Tunmer (1986) used the latter term to describe poor readers whose reading performance was similar to dyslexic readers but whose reading achievement was commensurate with their general intellectual ability. Thus, it is noteworthy that naming speed in this nondiscrepant group of poor readers was reported to be significantly faster than naming speed for dyslexic children and was closer to average readers' latencies (Ackerman & Dykman, 1993; Badian, 1994, 1995, 1996a, 1996b; Biddle, 1996; Wolf & Obregón, 1992); further work on this question is important. In dyslexic reader samples (as opposed to nondiscrepant poor readers), the relation between naming speed and reading was stronger for those severely impaired dyslexic readers with greater discrepancies between IQ and achievement (Badian, 1996a, 1996b).

Additional factors that may contribute to the suspected group differences between discrepant and nondiscrepant readers are the effects of a particular stimuli's potential for automatic processing. Scarborough and Domgaard (1998) recently found that nondiscrepant readers did not show letter- or number-naming deficits but did show slower naming-speed for objects, which was, in turn, correlated with their poorer performance on receptive and expressive vocabulary. This latter set of distinctions may prove particularly important in understanding some divergent research findings to be reported in a later section. To the extent that a sample includes greater numbers of nondiscrepant readers, there may be less pronounced naming-speed differences for the more automatic letter-and-number stimuli typically used in many studies.

Gidney et al., (1998), Sankaranarayanan (1998), and Scarborough and Domgaard (1998) have demonstrated comparable findings in African American children with severe reading disabilities. Sankaranarayanan found similar results in English-speaking children with reading disabilities in India; interestingly, she found faster naming-speed latencies among young, able Indian readers when compared with American able readers.

The evidence regarding differences in naming speed between dyslexic readers and younger normal readers matched on reading age is supportive of deficit specificity, but mixed. The fact that there may be a purely age-related component to naming speed makes the interpretation of reading-age comparisons more complex (see Carver, 1991, 1997). Many researchers have found dyslexic individuals to be slower in naming symbols than are reading-age matched peers (Ackerman & Dykman, 1993; Biddle, 1996; Segal & Wolf, 1993; Wolf, 1991a, 1991b), whereas others have not (Badian, 1996a; Olson, 1994). The relative severity of reading difficulties in samples may explain some differences between studies on this question. In a sample of profoundly impaired readers taken from a residential school for dyslexic children, Wolf and Segal (1999) found that 13-year-old dyslexic readers were significantly slower than reading-age-matched 10-year-old average readers. In longitudinal investigations of these issues, Wolf (1997) and Biddle (1996) reported that fourth-grade dyslexic readers were slower than their average peers' performance in second grade.

In summary, the deficit in serial naming speed appears specific to dyslexic children (i.e., not found in other learning-disabled children) and experimentally robust across different ages and dyslexic reader populations. Results from reading-age-matched comparisons are less consistent, and further work is needed concerning distinctions between discrepant and nondiscrepant poor readers.

Data From Other Language Systems

Naming-speed deficits have been demonstrated in impaired readers across several language systems; that is, German (Näslund & Schneider, 1991; Wimmer, 1993; Wimmer & Hummer, 1990; Wolf, Pfeil, Lotz, & Biddle, 1994), Dutch (Van den Bos, 1998; Yap & Van der Leij, 1993, 1994), Finnish (Korhonen, 1995), and Spanish (Novoa, 1988; Novoa & Wolf, 1984). These languages represent varying degrees of orthographic regularity; they present, therefore, an opportunity to disentangle, in part, the effects of naming-speed problems from the effects of phonological problems on reading disability. The question becomes the following: In more regular languages in which phonological demands are decreased, will naming-speed deficits appear as a stronger characteristic of disabled readers?

Wimmer (1993) showed that young German dyslexic readers (Grades 2 to 4) have less pronounced difficulties in standard phonemic segmentation tasks, scoring "high in absolute terms" on these tests and on tests of recognition accuracy for words and pseudowords. By contrast, they have significant problems in naming-speed measures and a "pervasive speed deficit for all types of reading tasks" (Wimmer, 1993, p. 2). Furthermore, digit-naming speed was the best predictor of reading differences among German normal achieving and dyslexic children.

Wolf et al. (1994) replicated and extended these findings with a larger sample of Grade 2–Grade 4 German children and with a more extensive battery of naming-speed and phonological awareness measures. In contrast to English-speaking children, many at-risk German prereaders who possess limited phonological awareness skills may be able to master the less stringent demands for phonemic analysis and synthesis imposed by the regular German orthography and, in turn, increase their decoding skills. However, in Wolf et al., adequate phonological awareness and blending skills did not predict reading speed and fluency, if a naming-speed problem was indeed present. Children with naming-speed deficits had difficulties mastering reading in German, as did a small group of children with both pronounced phonological awareness deficits and naming-speed deficits—who were the most impaired German readers.

Similarly, in the Dutch language, Yap and Van der Leij (1993, 1994) and Van den Bos (1998) found that dyslexic readers exhibit both speed and phonological awareness deficits. Yap and Van der Leij (1993) showed that Dutch dyslexic readers differed most strikingly from controls on accuracy scores when task demands were high for both phonological and speeded processing; there was evidence for the partial independence of these deficits. Van den Bos (1998) demonstrated that phonological and naming-speed tasks loaded onto separate factors, with naming speed as the most consistent and strongest predictor of word-identification measures in Dutch.

We interpret the cross-linguistic data as partial evidence that the particular role forced on phonological-based processes by English orthography has obscured the critical, differential role played by processes underlying naming-speed performance. When phonological analysis demands placed on young readers are reduced in languages with a more regular orthography, the naming-speed deficit appears as the dominant diagnostic indicator for at-risk readers (see a fuller discussion of cross-linguistic issues in Wolf et al., 1994).

Independent Contribution of Naming Speed to Reading

In this section, we consider two types of evidence that support the hypothesized independence of naming-speed processes from phonological awareness processes in the prediction of reading. First, there are generally modest rather than strong interrelationships between naming speed and the broad group of phonological-based tasks. Phonemic awareness tasks have relatively weak correlations with naming speed; whereas phonological (nonword) decoding accuracy and latency have stronger relationships. (The nonword decoding variables have contributions from both phonemic awareness and naming speed.) Second, there are independent, differential contributions of both phoneme awareness and naming-speed tasks to the variance in word identification (accuracy and latency), orthographic skill, fluent text reading, and comprehension.

Interrelationships. Blachman (1984) and Mann (1984) found modest relationships between early phonemic awareness and rapid naming tasks in kindergarten and Grade 1 students (e.g., $r = .09$; Mann, 1984). In a study designed in part to evaluate the presence of a large, general, phonological factor in a reading-risk population, Felton and Brown (1990) found no significant correlations between naming speed and all measures of phonological processes tested (i.e., four phonological awareness tasks, one phonetic recoding in memory task, and one other task classified as phonological recoding). Cornwall (1992) reported a modest relationship ($r = .35$, $p < .05$) between naming speed and one measure of phonological awareness (phoneme deletion) in a reading-impaired population and differential prediction capacities for both. She concluded that "these abilities may represent unique aspects of the reading process, as opposed to an overall phonological ability" (Cornwall, 1992, p. 537). Olson, Hulsander, and Castles (1998) also found no significant relationship between naming speed and the residual nonword decoding variance after controlling for age and word recognition accuracy. Recently, Goldberg, Wolf, Cirino, Morris, and Lovett (1998) found no significant relationships between phoneme elision and blending tasks and serial naming ($r = .12$) in a selected sample of profoundly impaired readers (standard scores of 62 and 64 in decoding and comprehension).

As is often the case, results from full classroom samples, unselected for reading achievement, differ somewhat from samples selected for a preponderance of reading-disabled children. In samples from Grade 3 classrooms unselected for reading skill, Bowers, Sunseth, and Newby-Clark (1998) found that RAN digits and phoneme deletion correlated .40 while still maintaining independent relationships to various reading skills. Wagner et al., (1993), using data from randomly selected children from regular classrooms, reported somewhat lower correlations in Grade 2, with correlations of latent variables for serial naming and phonological analysis at .35. Wagner et al. (1994) reported higher correlations in their Grade 2 sample. In all three studies, there were data consistent with an earlier confirmatory factor analysis, in which Wagner et al. described a model consisting of "two underlying abilities" in phonological awareness working memory and in code retrieval (naming speed) as best representing their 1987 and 1993 databases. Wagner et al. stated,

> A surprising finding emerged: a single underlying source of individual differences accounted for performance on the phonological awareness tasks and the phonological coding in working memory tasks. . . . A different underlying source of individual differences was found for the phonological code retrieval tasks. (1993, p. 85)

We interpret the combined results from both selected and unselected populations of severely impaired readers as one indication of the basic differences between the underlying requirements of naming-speed and phonological awareness tasks and also the differences between reading-disabled populations. We differ from Wagner et al.'s (1993) model only in the greater centrality we have placed on the retrieval-speed dimension.

Cross-linguistic results are supportive. In the German language, Wimmer found little interrelationship in Grade 2–Grade 4 participants between naming-speed and three measures of phonological awareness processes. Näslund and Schneider (1991) found a modest but significant ($r = .37$) relationship between naming-speed and phonological awareness tasks in a study of younger German readers.

As suggested by the German data, a more developmental perspective on these relationships may prove critical to researchers' ultimate understanding of phonological and naming-speed processes. Wagner et al. (1993) found in their cross-sectional samples of Kindergarten and Grade 2 children a change in the relationships between seven carefully defined phonological measures and serial naming speed for letters. In kindergarten, the correlations were relatively strong; whereas by Grade 2, most of these correlations failed to reach significance or diminished to modest relationships only (correlations were generally .1–.3). However, Wagner et al. (1994) reported a pattern of relationships different from the predominant pattern. They found consistent and moderately strong relationships in kindergarten and Grades 1 and 2.

With the exception of Wagner et al. (1994), the bulk of reported findings across (a) average and impaired readers, (b) several age groups, and (c) three languages (English, German, and Dutch) is consistent with only modest interrelationships between naming speed and a variety of early phonological awareness measures. In correlations ranging between .1 and .4, it is important to understand the large amount of variance unexplained by these relationships.

Differential contributions to specific aspects of word recognition. Findings in English, Dutch, and German indicate the partial independence of naming-speed measures from phonological awareness measures in predicting word-recognition performance (e.g., Berninger et al., 1995; Blachman, 1984; Bowers, 1995; Bowers & Swanson, 1991; Felton & Brown, 1990; Mann, 1984; Meyer et al., 1998b; Näslund, 1990; Näslund & Schneider, 1991; Van den Bos, 1998; Wimmer, 1993). Differing patterns in the relationships of phonemic awareness and of naming speed to the varying reading subskills (accuracy and latency) are found in a series of studies by Bowers and her colleagues (Bowers, 1993, 1995; Bowers et al., 1988; Bowers & Swanson, 1991). These researchers found phonological awareness tasks strongly predictive of word and nonword identification, but not of word and text reading speed. Phonological awareness uniquely predicted word attack (nonword reading), with naming speed's smaller contribution overlapping with phonemic skill. Naming speed was independently related to word identification (accuracy and latency) for moderate and high word frequency. Young and Bowers (1995) found only naming speed to be uniquely related to expressiveness and the speed of reading text passages. This finding may reflect the prosodic qualities in text reading that emerge when words in passages are read more fluently "by sight," a condition that may push the allocation of attention to meaning, rather than to decoding. Naming speed and reading comprehension are significantly but indirectly related because of the shared variance of comprehension with word-identification accuracy and speed (Bowers & Swanson, 1991; Kail & Hall, 1994; Spring & Davis, 1988).

Cornwall (1992) found a pattern of results similar to Bowers and Swanson's (1991). Phonological awareness added significantly to the variance in word attack and comprehension, and naming-speed measures added significantly to the variance in word identification, prose passage speed, and prose passage accuracy. Manis and Doi (1995) conducted a regression analysis with a clinical sample by using word-reading speed and nonsense word decoding as predictor variables of six reading measures. They replicated and extended findings that both variables predict significant, independent variance in the reading measures. In addition, Manis and Doi showed an independent variance associated with each variable for two orthographic measures. Doi and Manis (1996) extended these results to show the same pattern when symbol naming speed, rather than word-reading speed, was used as a predictor of orthographic ability (orthographic choice task).

Torgesen, Wagner, Rashotte, Burgess, and Hecht (1997) reported a longitudinal study in which Grades 4 and 5 varied reading skill measures were correlated with Grades 2 and 3 vocabulary, phonemic awareness, and rapid naming measures. They also found the expected pattern of greater unique contributions by phonemic awareness than rapid naming to later word analysis and greater contributions by rapid naming than phonemic awareness to orthographic accuracy and speed, as well as to Grade 5 reading speed. (The effect of controlling for earlier reading skills on these results is discussed in the following section.)

Predicting growth in reading over differing periods: Why do studies differ? One of the most complex issues related to understanding the differentiated relationships among phonological awareness tasks, naming speed, and specific reading skills concerns the development of these relationships over time in both able and dyslexic readers. Two recent reading predictor analyses by Torgesen et al. (1997) and by Meyer et al. (1998b) have provided conflicting views of the ability of phonological awareness and naming speed to predict later word recognition after earlier word recognition is controlled. In both of the studies, a method was used in which a reading measure taken at two ages is used as an *autoregressive variable.* For example, Torgesen et al. controlled for the effect of Grade 2 word recognition in their prediction of Grade 4 word recognition. Specifically, Torgesen et al. found that Grade 2 phonemic awareness, but not naming speed, continued to contribute significant (albeit small) variance to Grade 4 word recognition in both the full sample and in an impaired reader subgroup, after controlling for vocabulary and the variance contributed by Grade 2 word recognition.

It should be noted that when a predictor variable is not significant in an autoregression analysis, the interpretation that the variable no longer has effects is only one possibility among several. For example, in the present case, the effects of naming speed may continue over time, affecting later word recognition in a manner indistinguishable from the effects on earlier reading.

Meyer et al. (1998b) examined the differential power of rapid naming, phonological segmentation (Lindamood & Lindamood, 1979), and nonword reading to predict growth in word identification for average readers and impaired readers in Grades 5 and 8. In contrast to Torgesen et al. (1997), Meyer et al. found that naming speed was the only variable that significantly predicted later word identification for impaired readers (not for average readers) when the autoregressive variable—Grade 3 word identification—and IQ and socioeconomic status (SES) were controlled.

The divergent results of Torgesen et al. (1997) and Meyer et al. (1998) reveal how complex the relationships may be because of differences across populations. Thus, in addition to the discussed distinction between different prediction patterns for word attack and word identification, four population variables must be understood when interpreting results: (a) IQ and SES; (b) differences in variability in predictors (e.g., reliability across time periods), which in turn may be affected by the following two variables; (c) quality and type of reading instruction in this time period (see discussion in Torgesen et al., 1997); and (d) different rates of change of predictors at different ages (Torgesen et al., 1994), as well as subtype-specific rates of change for different variables.

This fourth variable requires some elaboration. Torgesen et al. (1994) reported that naming speed had the greatest growth rate between kindergarten and Grade 2, whereas phonemic analysis had a more moderate rate. McBride-Chang and Manis's (1996) related finding indicated that naming speed is most critical as a factor in the earliest stages of word recognition. In addition to the early growth of naming speed, researchers should recognize and understand the developmental course of it and the phonological analysis skills in each of the concerned populations (e.g., normally achieving, dyslexic, and nondiscrepant poor readers). In our lab, Biddle (1996) found that reading disability subtypes show differing patterns of growth. Using growth curve analyses, Biddle reported that the largest gains in naming speed were completed by Grade 1 or Grade 2 by most reading disability subtypes, similar to findings by Torgesen et al. (1997), Carver (1991), Meyer et al. (1998b), and McBride-Chang and Manis (1996). The subtype of children without phonological awareness and decoding problems but with naming-speed deficits was the single exception to this finding; these children increased their speed very gradually and showed no significant gains in any one year during this time period.

These differing rates of change may affect results of the previously described autoregressive analyses in particular because it appears that unexpected growth in reading (e.g., that which is not predicted by or reflected in the same, but earlier, reading measure) is predicted by these autoregressive analyses. Thus, Meyer et al.'s (1998b) prediction of later word identification by naming speed could be based on differences in naming speed rate of growth at different periods of time for normal and severely dyslexic readers.

McBride-Chang and Manis (1996) have provided a direct test for several of the issues involved. Examining concurrent associations of naming speed, phonological awareness, and verbal reasoning skills among carefully selected poor readers, McBride-Chang and Manis found that although phonological awareness tasks were associated with word identification for both groups, naming speed was strongly associated with word identification for poor readers only. These authors found significantly more variability for naming speed among poor readers than among average readers. McBride-Chang and Manis suggested that

> in an unselected sample such as the one used by Wagner et al. (1994; in press), there probably were not enough children on the low end of the reading continuum . . . to produce the

distinct association of naming speed to word reading. (1996, p. 335)

Inspecting the different characteristics of the impaired readers in these studies suggests the possibility that nondiscrepant (or garden-variety) poor readers might be more prevalent in the Torgesen et al. (1997) sample. It should be underscored that to date, Wolf (1997) and others have shown no significant naming-speed deficits for nondiscrepant poor readers (although, as stated previously, further research is required in this area). To the extent that the Torgesen et al. (1997) sample had high proportions of such readers, their pattern of results might be more similar to that of average readers in these studies (Biddle, 1996; Wolf, 1997). A similar, alternative possibility raised by Torgesen et al. is that their results were affected by the quality of reading instruction provided to their sample during this time period. Poor reading methods might result in disabled readers with a "curricular disability," whose cognitive profiles differ from the population studied by Meyer et al. (1998b) and McBride-Chang and Manis (1996).

Much remains to be understood by researchers in this domain. A developmental understanding of cognitive variables that involve speed of processing (see Carver, 1990, 1991, 1997; Kail & Hall, 1994; Marcus, 1997; Scarborough & Domgaard, 1998) appears important for future research. For example, Carver (1991) suggested that letter-naming speed is a developmental proxy for cognitive speed, which he describes as follows:

> An aptitude factor that purportedly limits how fast a person can read and accurately comprehend relatively easy material. He [Carver] has posited a learning curve for word recognition that asymptotes at a level that reflects individual difference in cognitive speed. Since letter-naming speed should be at asymptote for almost all children in Grade 2, it follows that individual differences in letter-naming speed should be good indicators of individual differences in the time required to process words during reading. (Carver, 1991, p. 34)

If, as Carver (1990, 1991, 1997) and others believe, naming speed has a steep slope until quite early in most children and thereafter more modest growth (Biddle, 1996; McBride-Chang & Manis, 1996; Meyer et al., 1998a; Torgesen et al., 1997), this may explain the robust naming-speed relation to early word recognition and why little additional significant variance is explained in later word recognition when Grade 2 or Grade 3 word recognition is regressed. The major "action" for naming speed is earlier and incorporated largely in the early word recognition of most average and nondiscrepant readers by Grade 2 or Grade 3. The findings appear to differ for subtypes of more impaired dyslexic readers, particularly when word identification is the outcome variable (Meyer et al., 1998b).

In summary, the independent contributions of naming speed and phonological awareness variables to reading are better understood when reading outcome variables (e.g., word identification and word attack), participant characteristics (including IQ and SES), reading instruction quality, and developmental cognitive variables are carefully specified. There are strong relationships between naming speed and word- and text-reading fluency and between phonological awareness and word attack (i.e., nonword decoding). When naming speed and phonemic awareness both contribute to one reading skill (e.g., word-identification accuracy), each variable contributes uniquely to that skill and has some variance in common. There appear to be reader-group differences in predictor–outcome relationships after Grades 2 and 3, when average readers are approaching asymptotic performance on symbol–speed measures. Good readers are close to "automatic" performances early, and naming speed is a poor predictor of their later reading abilities. The most impaired poor readers rarely become fully automatic in the naming of symbols; naming speed appears to be a strong predictor of later reading for this group, well into Grade 8.

Subtype Distinctions and the Double-Deficit Hypothesis

The fifth piece of evidence supporting the independence of the two deficits involves an examination of previous and present classifications of reading disability subtypes. If subtypes of children have been found to have rate or processing-speed problems without phonological-related problems, then this constitutes one form of evidence for the independence of the two sources of reading breakdown. The section begins with past taxonomies and a description of the subtypes outlined in the double-deficit hypothesis and ends with a discussion of recent studies that either replicate subtypes described here or provide corroborative evidence.

Reader classifications that include rate dimensions have been proposed for many years (see Doehring, Trites, Patel, & Fiedorwicz, 1981; and Morris et al., 1998, for important discussions of subtype classification). Reading speed differences have long been used as individual difference indices among poor readers (e.g., Aaron, Joshi, & Williams, in press; Barron, 1986; Bowers & Swanson, 1991; Carver, 1990, 1991, 1997; Curtis, 1980; Stanovich, 1980). One of the better known typologies using this dimension is Lovett's (1984) classification, which includes rate-disabled and accuracy-disabled readers, in which the latter group might equally well be classified as both accuracy and rate disabled (Lovett, 1987, 1992). Lovett's rate-disabled subgroup exhibited slow naming speed, accurate but slow word recognition, good phonemic-analysis and spelling-to-dictation skills, and problems in reading comprehension. The accuracy subgroup exhibited problems in phonemic analysis, word-recognition accuracy and speed, naming speed (more impaired than in rate subgroups), and reading comprehension.

Lovett's (1987) rate-disabled group demonstrated that naming-speed deficits can exist in poor readers without the typical phonological deficits described in most dyslexia research. In the first conceptualization of the double-deficit hypothesis, we asked whether the converse would also be true. In addition to poor readers with naming-speed deficits but without phonological awareness issues, are there poor readers characterized only by phonological-based problems? Furthermore, we questioned whether children with deficits in both areas would represent the most intractable forms of reading disabilities across various populations. Our thinking was the following: If single-deficit readers were found to have different profiles of reading breakdown that followed the differential relationships between the two variables and specific aspects of reading (e.g., between naming speed and word-identification fluency; between phonological processes and word attack), then children with both or double deficits would have multiple impediments to reading development, with few compensatory routes available.

To pursue evidence supporting these questions, we conducted a series of reanalyses of cross-sectional and longitudinal samples of school-aged children between kindergarten and Grade 4 in the United States and Canada. Bowers (1995) divided her Canadian sample into four subgroups by using a 35-percentile cutoff on a phoneme awareness measure, the Auditory Analysis Test (Rosner & Simon, 1971), and on digit-naming speed. Wolf (1997) reanalyzed a larger sample, using stricter cutoff criteria (i.e., one standard deviation for each variable) and classifying participants according to letter or digit-naming speed and a variation of the phonological measure—phonological nonsense word decoding (see discussion of terminology for this variable in Foorman, 1994). The latter variable was used because it is the most consistent indicator of phonological-based reading disabilities (Rack et al., 1992) and because ceiling effects begin to appear in some phoneme awareness tests in Grade 4.

There were four convergent findings in both studies. First, multiple regressions using continuous scores revealed that there were significant, independent contributions of both naming speed and phonological nonsense decoding variables to oral reading and word-identification accuracy for regular and exception words. Second, naming speed contributed to word reading speed in text and in isolation (however, when data were log transformed in the Wolf, 1997, study, both variables were significant). Third, only nonsense decoding variables contributed significantly to reading comprehension in both studies (see also Spring & Davis, 1988).

The fourth convergent finding was that despite using two levels of cutoff criteria and two measures of phonological-related processes, four subtypes of average and poor readers were consistently distinguished in both Canadian and U.S. school-based samples. A subtype of average-reading children had no deficit. Two subgroups with either naming-speed deficits or phonological-based deficits were modestly impaired poor readers. Children in subtypes with single deficits did not differ significantly from each other on any reading variable other than the criterion variables (i.e., phonological decoding of nonsense words). Nevertheless, the phonological-deficit group scored consistently lower (albeit not significantly so) on all measures except latency-based ones. Children with double deficits were the most profoundly impaired readers in both samples; in the Wolf sample, double-deficit children performed at least 2½ years below their age peers in all aspects of reading. These children had the lowest scores on all phonological, naming speed, and reading variables; only their receptive vocabulary performance was not impaired.

The next series of questions involved the replication of these subtypes in other samples, particularly in samples composed of clinically referred, profoundly disabled readers. Lovett (1995) reported a replication of the double-deficit subgroups in a large clinical sample of 76 children, most of whom were reading at the bottom five percentiles on standardized measures. Using one standard deviation below the mean on naming speed and nonsense word decoding as criteria variables (the criteria used in Wolf, 1997), Lovett found that 79% of her 76 participants could be characterized as members of the deficit subtypes proposed by the double-deficit hypothesis. Although the majority of children ($n = 41$) fell into the double-deficit category, as would be predicted in such an impaired population, 17 phonological-deficit readers and 18 naming-speed deficit readers were identified. The earlier reported patterns in reading performance by subtype were replicated and extended in this clinical population: (a) Double-deficit readers were significantly more impaired than single-deficit groups on every measure; (b) phonological-deficit readers were significantly more impaired than were naming-speed deficit readers on all word-identification accuracy measures; and (c) naming-speed deficit readers were significantly more impaired than were phonological-deficit readers on word-identification latencies.

In a study of 83 profoundly disabled readers, Goldberg et al., (1998) used phoneme elision and phoneme blending as the phonological variable and letter-naming speed as the naming-speed variable and found a similar breakdown: 49% in the double-deficit category, 29% in naming-speed deficit, 14% phonological deficit, and 8% nonclassifiable.

Berninger et al. (1995) and Badian (1996a, 1997) have isolated groups of single-, double-, and triple-deficit readers (the latter have naming-speed and phonological deficits and orthographic problems, which we did not test for) similar to those reported here. Children with double and triple deficits always had naming-speed and phonological deficits and were the most impaired readers. V. W. Berninger (personal communication, March 16, 1997) has suggested that a question for future studies is whether the most impaired participants across various subtype classifications must always include a combination of phonological and naming-speed deficits (see Morris et al., 1998).

Krug (1996) found a clear replication of our subtypes in an elementary school population of fifth graders, with double-deficit readers approximately four years below the reading level of average readers. Krug provided one of the few investigations of the lesser known cognitive characteristics of the three subgroups. Of particular interest, Krug showed that the double-deficit readers were superior to average readers and the other two single-deficit subgroups in visuospatial analysis on matrix completion tasks. The presence of strengths in this area is a matter of increasing debate and interest in dyslexia research (West, 1998).

Several phonological priming studies shed indirect light on the double-deficit hypothesis subtypes. In priming studies, participants attend to one word (e.g., by reading or hearing modalities) and are then asked to judge whether the next stimulus word is a real word. The time taken to make this judgment is directly related to whether there is a particular relationship between the two words. The first word primes the activation of the second word. Priming can be based on different aspects of the word (e.g., phonological or orthographic properties). Evoked potential studies that use this priming paradigm investigate which areas in the brain are activated during various lexical processes. An evoked potential study of phonological priming in dyslexic adolescents provided an unexpected glimpse of potential underlying neurophysiological differences between subgroups. McPherson, Ackerman, Oglesby, and Dykman (1996) divided readers into two groups: those with phonological deficits, and those without phonological deficit; all of the second group possessed naming-speed deficits. The phonological deficit group (which would potentially include both our phonological deficit and double-deficit subtypes) showed a virtual absence of phonological priming in the left hemisphere; whereas the nonphonological deficit readers with naming-speed deficits showed an overabundance of activity over the left hemisphere site, which is normally evoked during phonological priming. The latter readers demonstrated a priming effect that was larger and endured longer than in the controls, especially in parietal regions. (Wood, 1995, reported a similar finding in an evoked potential study with dyslexic participants.)

It may be that this excess activity in the readers with naming-speed deficits is indicative of their being less prepared to move on to the next stages of processing, a description that would be compatible with Obregón's (1994) finding of longer ISIs between stimuli on RAN tasks. The significant differences in location, duration, and amplitude of evoked potentials between the two subgroups represent the first, preliminary electrophysiological evidence of subgroup distinctions according to the double-deficit hypothesis, but considerable research is still required.

Another type of evidence comes from highly sophisticated cluster-analysis-based subtypes described by Morris et al. (1998). Supporting Morris et al.'s predictions, phonological deficits were central in most of their subtypes. Unpredicted by Morris et al., but consistent with a double-deficit hypothesis framework, rate-based deficits also played a central role in the classification both of a specific rate subtype without phonological awareness problems and in the phonological short-term-memory rate and global subtypes, which represented Morris et al.'s most impaired reader subtypes. Their findings

> attest to the primary impairments of phonological processes and serial naming speed in explaining variability within groups of disabled readers. These results suggest that serial naming deficits and more general rate-based factors must be considered in examining reading outcomes for children with reading disabilities." (Morris et al., 1998, pp. 55, 57)

Recent genetic research on dyslexia buttresses Morris et al.'s (1998) subtype conclusions and our own. Grigorenko et al.'s (1997) findings supported the centrality of phonological processing weaknesses in one phenotype. In addition, they found a single-word reading phenotype that was not explained by phonological measures but that was moderately correlated ($r = .46$, $p < .01$) with rapid naming for colors and objects. Because color and object naming have been less robust in prediction and group differentiation of dyslexic readers than the more automaticity-driven letters and digits (Wolf et al., 1986), whether the results of the single word-reading phenotype would be stronger with the use of RAN letters and digits remains to be answered. Pennington (1997) summarized Grigorenko et al.'s (1997) data as pointing to "a genetic, double dissociation between genes influencing two phenotypes" (p. 15). Grigorenko et al. concluded "that a theoretically driven fractionation of the overall dyslexic deficit into more precise defining attributes, partly overlapping but partly distinct, is the necessary prerequisite for an informative genetic analysis of this complex phenotype" (p. 37). We believe that these results provide important new directions for future research in the dyslexias.

In summary, there is increasing direct and indirect evidence in support of discrete subtypes characterized by phonological deficits, naming-speed deficits, or the double-deficit combination in both school-based and clinical populations. The phonological-deficit readers depicted in Bowers and Wolf's (1993) school-based samples would more than likely be identified early as reading-disabled children on the basis of their poor phonological decoding. The naming-speed deficit poor readers would not be so easily identified because of early, adequate phonological awareness and decoding skills. Despite these skills, the naming-speed subtype consistently fails to achieve automatic levels of basic symbol and word recognition, and by Grade 4 these disabled readers fall further behind their average cohort in comprehension—a profile similar to Lovett's (1984) rate-disabled group descriptions. Rudel (1988) pinpointed this group of poor readers as the one that researchers know least about; neither most current diagnostic batteries nor the most successful remediation programs are well suited for this group—points elaborated on in the Discussion section.

Discussion

Our review of these recent findings suggests that there are two largely independent reading-deficit sources. The focus in this article has been on a separate core deficit in processes underlying naming speed for dyslexic readers. Such a deficit raises significant theoretical and applied questions. Current theories of reading development and reading failure require some revision to accommodate the separable influences of naming-speed processes and phonology on various aspects of reading. The empirical finding of separable deficits does not reveal how naming-speed deficits affect reading progress. Previous research of phonological deficits amply supports the commonsense conclusion that learning to use grapheme–phoneme correspondence rules in decoding words rests on the more basic ability to analyze the sounds within a word. No similar a priori conceptualization about the processes underlying naming speed exists to explain how these processes affect word identification, word attack, and other reading skills. In the first section of this discussion, we discuss two nonexclusive hypotheses concerning the nature of the relationships among processes underlying naming speed and reading. In the second section, we discuss implications of the double-deficit hypothesis for intervention.

The Relationships Between Processes Underlying Naming-Speed Deficits and Reading Failure

Perhaps the most perplexing theoretical questions about naming-speed deficits revolve around the domain-specific versus domain-general nature of the deficit; that is, does a deficit in naming speed represent a specific deficit, or is it the linguistic manifestation of a range of processing speed deficits that occur across various modalities, particularly when the rapid integration of multiple subcomponents is required? Or can it be either, depending on the individual child? In the following two subsections we outline two nonexclusive hypotheses concerning the potential effects of naming-speed deficits on reading breakdown.

Hypothesis 1: Contributions to Speed of Orthographic Pattern Recognition

Bowers and Wolf (1993) constructed a hypothesis whereby naming speed was related to the rate at which children can induce orthographic patterns from exposure to print. According to this hypothesis, processes underlying slow, visual naming speed may contribute to reading failure in three ways: (a) by impeding the appropriate amalgamation of connections between phonemes and orthographic patterns at subword and word levels of representation, (b) by limiting the quality of orthographic codes in memory, and (c) by increasing the amount of repeated practice needed to unitize codes before representations of adequate quality are achieved.

Neurophysiological work by Chase (1996) and Livingstone, Rosen, Drislane, and Galaburda (1991) has provided one possible explanation for how these impediments might originate at the visual perceptual level. When an individual looks at a visual stimulus (e.g., letters, words, or objects), there is an automatic analysis of the stimuli's constituent features. Chase has shown that this analysis of features requires the processing of low spatial-frequency components, which are the responsibility of the magnocellular system. The latter system of cells represents the fast processing or transient pathways that are involved in various perceptual areas. The magnocellular system in the visual area includes regions from the retina through subcortical visual areas in the thalamus. Livingstone et al., Rosen (1998), and Sherman (1998) have demonstrated that the magnocellular system is aberrant in these subcortical visual areas, specifically in the lateral geniculate nucleus (LGN) in a small sample of dyslexic brains (see Greatrex & Drasdo, 1995, for review of magnocellular deficits in dyslexia). The LGN is responsible for coordinating visual processing in both subcortical and cortical areas. Galaburda and his associates (Livingstone, 1998; Rosen, 1998) argued that the specific deficits found in the LGN (i.e., reduced cell and axon size and decreased cell number) would affect the speed with which similarly affected dyslexic individuals process visual information throughout the system.

Chase (1996) connected these cytoarchitectonic-based findings to his visual flicker fusion studies. In the study tasks, participants are shown two images on a screen with systematically altered ISIs between the stimuli. Depending on the size of the ISI, the images appear either to fuse or to be two separate stimuli. Dyslexic children require significantly longer ISIs than do other children to see two separate stimuli. Because these tasks emphasize low spatial-frequency processing (a magnocellular function), these results would be predicted in dyslexia. Chase further argued that if speed and quality of visual information for low spatial-frequency components are weakened in dyslexic readers, "then the degraded signal may be insufficient to establish and selectively activate the matching grapheme clusters within the child's lexicon" (1996, p. 10). The child who requires more time on flicker fusion tasks also cannot make fast enough visual discriminations to establish basic orthographic representations.

Our first hypothesis, Livingstone et al.'s (1991) findings, and Chase's (1996) arguments intersect in the following ways: If the magnocellular system in the LGN is aberrant in development, then the processing of lower spatial-frequency components will be slowed, leading to slower visual discriminations as well as letter and letter pattern identification. Slowed visual letter identification, in turn, would have varied initial consequences; for example, (a) serial naming speed, particularly for more "automatic" letters and digits, would be impaired, and (b) the links or connections between letters that co-occur frequently in words (Seidenberg & McClelland, 1989) would not be forged as easily. The final consequences of this cycle are twofold: (a) A full repertoire of orthographic patterns (which contributes to reading fluency) will not accrue, and (b) much more practice identifying words would be needed before representations of adequate quality are achieved. Figure 3 depicts what would occur in Hypothesis 1 within the earlier presented model of visual letter naming.

Connecting this position to reading literature, Bowers et al. (1994) used Adam's (1981) orthographic redundancy model to stress the importance in orthographic development of the learned associations between letters. Able readers learn associations between letters that have occurred in sequence on several occasions; thus, they recognize orthographic patterns rather than continue to treat letters as isolated units. Bowers et al. speculated that

> if a beginning reader is slow in identifying individual letters (as indexed by rapid naming tests), then single letters in a word will not be activated in *sufficiently close temporal proximity* to allow the child to become sensitive to letter patterns that frequently co-occur in print. (1994, p. 203, emphasis added)

See Spring and Davis (1988) for a somewhat different position regarding a dyslexic reader's inability to overlap different stages of processing visual information.

We believe this general view is congruent with several other reading research perspectives such as Ehri's (1992) depictions of early reading; Perfetti's (1985) early emphasis on efficiency and his later (1992) emphasis on precise, redundant word representations; and Levy and Bourassa's (1998) work on practice effects. This view contributes to these perspectives an individual-difference factor in rate of processing (tapped by naming speed) that influences how quickly a child achieves good-quality orthographic represen-

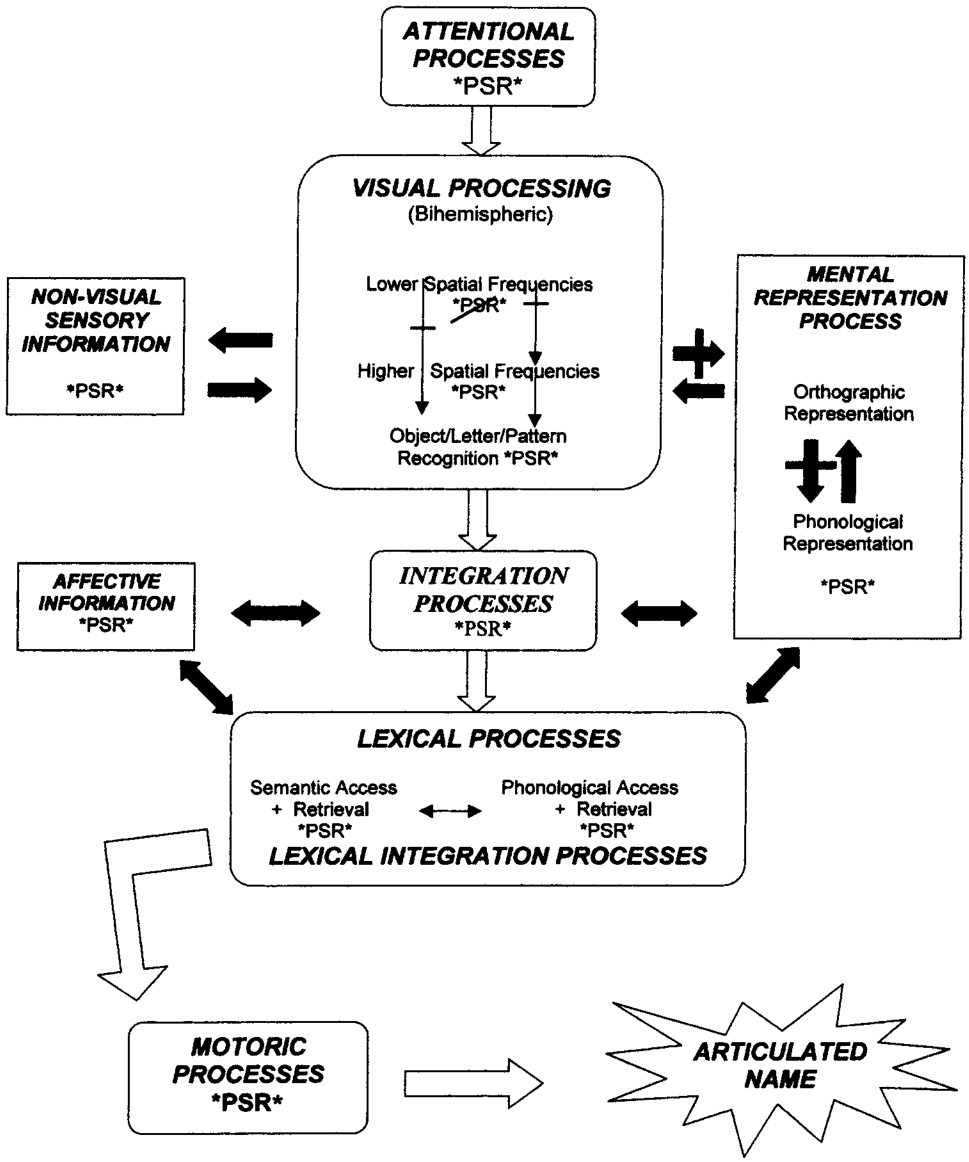

Figure 3. Model of letter naming in Hypothesis 1, depicting effects of lower level, processing-speed deficits. Slash across the PSR indicates slowed or impeded processing and flow of information. PSR = processing speed requirements.

tations. (See also Carver's, 1997, related arguments about the effect of cognitive speed, as indexed by naming speed, on reading.) Ehri argued that phonological recoding is the foundation for early reading, a foundation that is then replaced when specific connections link a letter sequence with its pronunciation and meaning. The final step of this early development is when fully amalgamated orthographic representations are made. Ehri's view assumes a well-functioning, rapid system for access and retrieval of the name and posits that weak recoding skills are the basis for failure to achieve orthographic images. Our view makes no such assumption but rather asserts that either weak recoding skills or slow retrieval of letter identities could derail orthographic development. Slow retrieval of letter information could be based on earlier visual perceptual processes, lexical retrieval difficulties, or both, as discussed in Hypothesis 2.

Perfetti (1992) asserted that "the heart of lexical access is the activation of a phonologically referenced name code" (pp. 164–165). Perfetti, like Ehri (1995), emphasized the phonological underpinnings of lexical knowledge; we further add that processing efficiency underlying the speed of activation plays no less important role in lexical access.

Although children with fast naming speed respond more quickly to relatively practiced orthographic patterns than to comparable, previously unseen patterns, slow naming-speed children may show no such difference until many exposures are encountered. This insensitivity to previously practiced patterns for dyslexic participants has been observed by many researchers, particularly Lemoine, Levy, and Hutchinson (1993), Reitsma (1983), and Ehri (1995). A limited store of sight words would be predicted from such insensitivity-to-practice effects, as well as from phonological problems. Some support for a naming speed connection to insensitivity-to-practice effects has been provided by Bowers and Kennedy (1993), who reported that naming speed affected the reading speed increase of isolated words or text, given a set amount of practice. Levy and Bourassa (1998) divided poor readers according to their naming-speed performance in an intervention program. Relevant to Hypothesis 1, they found across 20 sessions of repeated segmented or unsegmented practice with a set of words that "slow namers show a particular deficit with whole word units, consistent with the Bowers and Wolf position" (1998, p. 2).

This hypothesis's major problem is that researchers' knowledge of orthographic processing deficits is much less developed than the present understanding of phonological deficits. Vellutino et al.'s (1995) critique of orthographic skill tests, which often measure reading or spelling ability rather than specific orthographic components of reading, must be considered in any account of orthographic processing deficits. Berninger and Abbot (1994) have expanded the literature in this area by differentiating types of orthographic skills. Attending to the particulars of the measurement of orthographic skill is critical in future research and may clarify why some researchers find strong relationships between naming speed and orthographic skill while others do not.

An increased understanding of the links among slow naming speed, reduced impact of practice, insufficient orthographic pattern knowledge, and impoverished store of sight words is of particular importance for the design of new forms of intervention. For example, if the links between naming speed and specific orthographic areas are confirmed, then intervention programs that emphasize orthographic fluency are particularly needed. One example of such a program—the fluency-based, retrieval, automaticity, vocabulary elaboration-orthography (RAVE-O) program (Wolf, Miller, & Donnelly, in press)—is discussed in the final section.

Hypothesis 2: Naming Speed as the Lexical Midpoint in a Cascading System of Processing-Speed Effects

A more speculative line of reasoning about the connections between deficits in naming speed and dyslexia is based on the evolving literature that connects dyslexia and processing rate in varied cognitive functions (see, for example, Breznitz, 1996; Farmer & Klein, 1995; Lovett, 1992; Patel, 1995). These authors raise the question of whether deficits in the speed of naming are the linguistic analogue of the consistent speed of processing differences among dyslexic children across several perceptual, motoric, and linguistic domains (Breitmeyer, 1993; Chase, 1996; Farmer & Klein, 1995; Lovegrove & Williams, 1993; Tallal, Miller, & Fitch, 1993; Willows, Kruk, & Corcos, 1993; Wolf et al., in press; Wolff, 1993). In this section, we briefly examine perceptual, motoric, and neurophysiological findings and then connect them to naming speed.

Perceptual findings. In the visual domain, in addition to the flicker fusion tasks cited earlier, there are a growing number of studies on contrast sensitivity, object superiority effect tasks, and visual persistence indicating that dyslexic readers cannot process lower level visual information at the same speed as do average reading children (Breitmeyer, 1993; Chase & Jenner, 1993; Farmer & Klein, 1995; Greatrex & Drasdo, 1995; Lehmkuhle, 1993; Lovegrove, 1993). There are several processing requirement levels in perceptual tasks that need to be teased apart, however, before any general statements about processing speed can be discussed (Farmer & Klein, 1995). For example, in both the visual and auditory domains, there appear to be no differences in processing rate in the dyslexic reader's ability at the early feature detection level, in which children must detect only that a particular stimulus (e.g., a flash of light or tone) has occurred. Blackwell, McIntyre, and Murray (1983) found no reader group differences in detecting a letter presented in brief duration. Similarly, Tallal (1980) found no group differences in dyslexic readers in detecting briefly presented tones.

At the next level, however, the differences in processing speed occur. That is, differences appear when a participant must determine that a given stimulus is separate or individuated from an identical stimulus presented in rapid succession at different ISIs. Dyslexic children appear particularly weak in such stimulus individuation tasks in the visual domain (see review in Farmer & Klein, 1995). In the auditory domain, various researchers have shown that reading-disabled and other learning-disabled children require longer ISIs than do average readers in order to hear two separated brief tones (Farmer & Klein, 1993; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Nicolson & Fawcett, 1996; Tallal et al., 1993; Werker & Tees, 1987). Related to Obregón's (1994) findings, ISI elongations in some of the auditory tasks used in Tallal et al. brought language-impaired dyslexic readers into normal ranges (see discussion of ISI findings in other modalities in Biddle, 1996; Farmer & Klein, 1995; and Obregón, 1994).

There are unresolved issues surrounding the next level of complexity, *temporal order judgment,* in both visual and auditory domains. This test requires participants to judge whether two stimuli presented in rapid succession (with systematically varied ISIs) are the same or different. Further research appears necessary at this level of task complexity because of sample differences (e.g., some of the auditory data comes from language-impaired children who may vary in important ways from dyslexic readers) and the use of different stimulus characteristics in both modalities in different studies. (For visual studies, see Brannan & Williams, 1988; May, Williams, & Dunlap, 1988; Reed, 1989; for auditory studies, see Reed, 1989; Tallal, 1980.) Kinsbourne, Rufo, Gamzu, Palmer, and Berliner (1991) demonstrated temporal order judgment in deficits for both visual light flashes and auditory clicks in adult dyslexic readers, whose performances on these tasks were highly correlated with naming-speed performance.

Motoric findings. Evidence of processing speed deficits at the motoric level is similarly dependent on the level of complexity demanded. In two tests requiring balancing on a low beam, Nicolson and Fawcett (1990) showed no differences on a single balance task but found significant group differences when dyslexic children were asked to balance and perform a second task, such as counting or to balance while blindfolded. In recent efforts to replicate these results, however, Wimmer (1998) found little supportive evidence.

Wolff (1993) and Wolff et al. (1990a, 1990b) have found enduring problems for dyslexic readers in a number of finger-tapping tasks. In some of the tasks, participants listen to a metronome and try to reproduce a particular speed with their fingers in conditions that vary from simple tapping with one finger to more difficult asynchronous patterns by using both hands. Significant differences in dyslexic readers' ability on tasks that required rapid, alternating hand movements and finger tapping for asynchronous patterns were found (Wolff, 1993; Wolff et al., 1990a, 1990b; see also Fawcett & Nicolson, 1996; Nicolson & Fawcett, 1994). Wolff emphasized that motoric-processing-speed problems surface most clearly when dyslexic readers are required to "assemble component units of behavior into *temporally ordered larger ensembles*" (1993, p. 101, emphasis added), a conclusion also made by Gardiner (1987).

Cross-modality findings. Nicolson and Fawcett (1994; Fawcett & Nicolson, 1994) investigated whether a basic reaction time (RT) deficit in dyslexic readers exists that would explain the range of findings described previously. Similar to Blank, Berenzweig, and Bridger (1975), Nicolson and Fawcett found no RT differences between dyslexic and average readers for simple RT (e.g., detecting a tone) tasks but found quantitative rate deficits among dyslexic participants both when the complexity of choice or judgment was added (e.g., determining low or high tones) and in lexical-access decision tasks (e.g., judging whether a word is real). In a broad review of rate deficits across various modalities, Wolf et al. (in press) found similar distinctions: no rate deficits at the most basic levels of perceptual detection, but many processing-speed problems as task complexity was increased, with the concomitant demand for more efficiency in and across additional subprocesses.

Such findings in rate and processing speed invite conceptual linkage (see review of this literature in Farmer & Klein, 1995, and Wolf et al., in press), but the presence of rate deficits across each of the domains within the same population of dyslexic readers has yet to be demonstrated. To explore one aspect of this question, in two ongoing National Institute of Child Health and Human Development (NICHD) studies (see Morris, Lovett, & Wolf, 1995; Waber, 1995), a battery of rate-related tasks across visual, auditory, articulatory, and motoric domains is being administered, along with naming-speed tasks, to samples of average and impaired readers.

Neurophysiological findings. Evidence at the neuronal level includes a series of cytoarchitectonic studies by Galaburda and his colleagues (e.g., see Galaburda, Menard, & Rosen, 1994). Although this research remains preliminary due to the small sample, findings indicate significant differences in the thalamus in two magnocellular systems: in the lateral geniculate nuclei, as reported earlier (Livingstone, 1998; Livingstone et al., 1991; Rosen, 1998; Sherman, 1998), and in the medial geniculate nuclei responsible for auditory processing (Galaburda, Menard, & Rosen, 1994). No differences were detected in thalamic parvocellular systems, which subserve more sustained processing. In other words, there are preliminary neurophysiological data at the neuronal level implicating difficulties whenever the rapid processing of both visual information (central to orthographic processes) and auditory information (central to the phonological system) is required.

Another direction of work in the neurosciences involves increasing evidence that the organization of cortical receptive fields is based on the *temporal synchrony* of sensory input (Merzenich, Schreiner, Jenkins, & Wang, 1993); that is, the cortex builds representational maps by grouping together information from the senses that is temporally correlated—all within a narrow window of time. On the basis of work in thalamic and cerebellar areas, Llinas (1993, 1996) has hypothesized that there may be areas directly responsible for the regulation of timing within neurons: specifically, the inferior olive in the cerebellum and the intralaminar nucleus in the thalamus. According to Llinas, the latter area, in which the axons extend to and from every area of cerebral cortex, may be involved in coordinating the rate of oscillation in specific sensory areas.

Although highly speculative at this time, if future research supports the role of the intralaminar nucleus or some other set of specific brain structures in the more general regulation of rate of processing, deficits in such areas could produce the pattern of difficulties documented in dyslexic children across multiple domains. (See Llinas, 1993, for a discussion of dyslexia as dyschronia; see Johnson & Myklebust, 1967, for a discussion of dyslexia as dyschrometria.) In principle, such structures could be the subcortical analogue to what we have earlier hypothesized at a more abstract level as the failure of a precise timing mechanism in developmental dyslexic readers. (See discussions of a precise timing mechanism in Bowers & Wolf, 1993; Ojemann, 1983; Wolf, 1991a; see Kail & Hall, 1994, concerning a global mechanism responsible for change in speed of information processing; see Ivry, 1997, Fawcett & Nicolson, 1996, for cerebellar-based connections to timing deficits.)

The question posed by the convergence of the behavioral and neurophysiological findings for reading research is the following: What occurs in reading behaviors if there are basic problems in how fast both visual and auditory information can be processed, as would be the case if the magnocellular systems in both of the indicated subcortical regions are poorly developed (or, in Llinas's, 1993, 1996, account, poorly coordinated in time)? Chase (1996) suggested that the speed with which the visual system receives and processes information plays a critical role in how it organizes "cortical representational maps that define the global shape of the letters in text" (p. 25). In the scenario described by Chase and the conceptualized Hypothesis 1, the induction of orthographic information would adversely be affected with consequences, we hypothesized, for reading fluency and comprehension.

If, in addition, there are underlying deficits in the speed and efficiency with which auditory information is processed at the phonemic level, a position argued by Merzenich et al. (1996) and Tallal et al. (1996), there would be at least two potential areas of disruption that stem from underlying deficiencies at the neuronal level. Either of these failures to build visual and auditory representational maps would impede reading development; together, the effect could potentially cripple both developing orthographic and phonological systems and permit no compensatory alternative route from the other system.

Naming speed. Where does naming speed fit within Hypothesis 2? Depicted earlier in the model presented in Figure 2, we conceptualized naming speed as a temporally ordered ensemble of lower level perceptual and linguistic processes, each of which is also necessary for reading. More specifically, we conceptualized visual naming speed within tasks such as the RAN as the rapid integration of lexical access and retrieval processes with lower level visual, auditory, and motoric (articulatory) processes. We believe that this unique combination of (a) actual subprocesses used in reading and (b) similar efficiency or processing speed requirements needed in subprocess integration has made naming-speed tasks one of the two best predictors of reading achievement (along with phonemic awareness tasks) across all languages studied to date.

At the same time, the multicomponential nature of naming speed suggests that naming-speed deficits could result from multiple, underlying sources. Three major sources include the following: First, there can be disruption specific to lexical access and retrieval processes only (see Katz, 1986, for arguments that depict phonological deficits as the basis for retrieval and retrieval speed problems). Second, naming-speed deficits could be based on slower processing speed in one, a combination of several, or all of the lower level perceptual and motoric processes involved. (The emphasis of Hypothesis 1 on visual pattern recognition represents an example of one of these possibilities.) Third, whatever underlies the consistent perceptual and motoric timing deficits noted among dyslexic readers could also affect the speed of the lexical retrieval processes. Within the third scenario, naming-speed deficits would be a midlevel subset of deficits *within a cascading system of processing-speed effects;* that is, naming speed would represent at once both the effect of slowed lower level processes on lexical retrieval and also a cause of further disruption of fluent reading. This is shown in Figure 4, in which the reduced processing-speed requirements of each affected component are depicted.

In summary, Hypothesis 2 has the same structure as Hypothesis 1; that is, deficits in processes underlying naming-speed impede lower level perceptual requirements that, in turn, prevent increases in fluency in word identification, which impede comprehension. However, in Hypothesis 2, naming-speed difficulties can represent one manifestation of a broader cascading system of rate or efficiency-based difficulties that would affect not only orthographic but also phonological routes and representations.

These hypotheses are intentionally nonexclusive and indeed may ultimately help explain several subtypes of poor readers (see Lahey & Edwards, 1996, for a related discussion of timing deficits among subtypes of specific language-impaired children; see Moore, Kagan, Sahl, & Grant, 1982, for a discussion of unresolved rate questions in their most impaired subgroup). For example, children with a more isolated naming-speed deficit may have problems more specific to the lexical level. We predict that these children would have fairly adequate phonological decoding, but orthographic difficulties at the word level (e.g., poor recognition of irregular words) and possibly at the letter-cluster level (see Levy & Bourassa, 1998). We also predict that children with more systemic processing-speed deficits have underlying visual and auditory processing problems, resulting in concomitant naming-speed and phonological deficiencies. These children would represent the double-deficit subtype characterized by deficits at the lexical and sublexical levels and by the most profound reading disabilities in all reading skills. Within this view, the early appearing phonemic awareness difficulties of double-deficit children could result from auditory-processing-based problems (see Farmer & Klein, 1995), the reduced speed of activation for phonological processes, or both. Such a view does not exclude other possible sources of phonological deficits that have no relationship to processing-speed factors; rather, it includes domain-specific and domain-general efficiency problems as two possible sources or contributors to them.

Implications for Diagnosis and Intervention

As discussed earlier, the most important implications of the double-deficit hypothesis concern diagnosis and intervention. A major implication of the conceptualization described in this article is that phonological deficit readers will benefit most from current phonological-based interventions but that naming-speed deficit and double-deficit readers will be less comprehensively diagnosed and less fully remediated. Lovett (1995) began a test of this prediction using her clinical sample's treatment outcome data from highly successful phonologically based and strategy-based treatment programs (Lovett et al., 1994). On the basis of the double-deficit hypothesis subgroups described earlier, Lovett (1995; Lovett & Steinbach, in press) found (a) significant differences in treatment gains for every subgroup, and (b) differential outcome gains by phonological deficit readers on several posttreatment measures (e.g., more gains on letter–sound knowledge, nonword reading, and regular and exception word recognition). Although phonological intervention programs appear to contribute to all reading-impaired children, Lovett concluded that subgroups of naming-speed deficit and double-deficit impaired readers may need different or additional emphases to achieve maximal gains.

Diagnosis. If we are better able to understand the additional dimensions represented by deficits in naming speed in impaired readers, especially the "treatment resisters" (Torgesen et al., 1994), we may be better prepared to

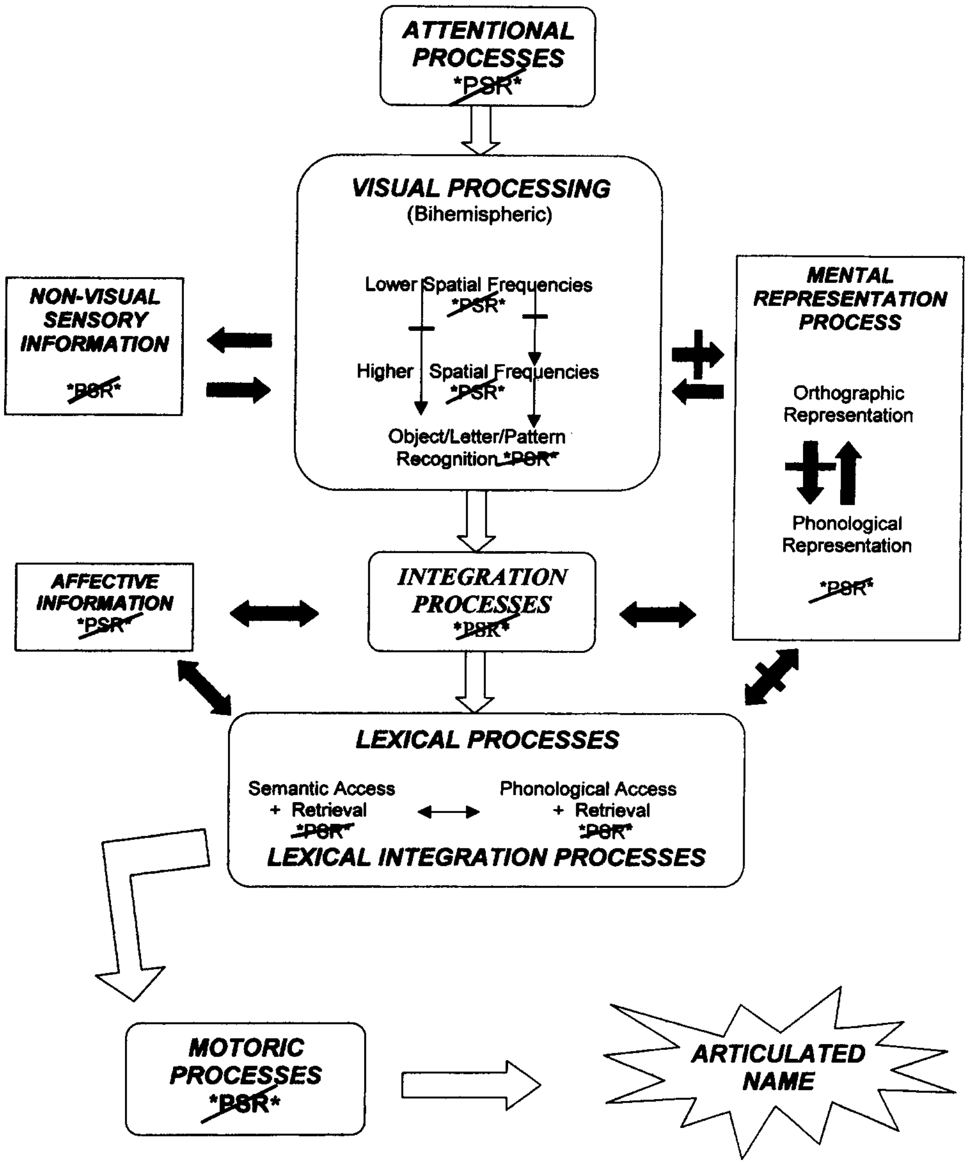

Figure 4. Model of letter naming in Hypothesis 2, depicting effects of more general, processing-speed deficits. Slashes across the PSRs indicate slowed or impeded processing and flow of information. PSR = processing speed requirements.

design better diagnostic batteries and treatments that correspond to the readers' needs (see Blachman, 1994; Lyon, 1985a, 1985b). To the extent that researchers' batteries do not include naming-speed-like measures, some reading-impaired, naming-speed deficit children will elude early diagnoses and miss potentially critical early services. Furthermore, the severity of the most impaired children, who consistently manifest early dual deficits in naming speed and phonological processing, will not be as quickly understood.

The use of similar batteries of tasks that allow researchers to examine correspondences between the deficit subtypes predicted within the double-deficit hypothesis and other subtype classifications is critical for future studies. For example, the naming-speed and double-deficit subtypes are directly analogous to Lovett's (1995) rate- and accuracy-deficit groups, but there may also be parallels with surface and phonological dyslexia that require further examination (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, & Peterson, 1996). Similarly, what are the correspondences between the three double-deficit hypothesis subtypes, Johnson and Myklebust's (1967) visual and auditory subtypes, Boder's (1971) original dyseidetic and dysphonetic groups, and Morris et al.'s (1998) multiple subtypes?

Intervention. Finally, intervention research that explicitly addresses the development of fluency in reading subskills is, to our minds, the most critical and complex implication of the present research (see Breznitz, 1997; Wolf & Obregón, 1997). One area of this research involves a more refined, theoretical understanding of orthographic skills than is currently the case (see Berninger & Abbot, 1994). A second area, as alluded to earlier, is the development of fluency-based reading programs. Differential treatment studies are critical in determining whether subtypes of children with processing-speed difficulties (with and without phoneme awareness problems) are benefited by the targeting of specific word recognition skills or by more comprehensive emphases on fluency across all underlying components.

As part of an ongoing National Institute of Child Health and Human Development (NICHD) study, Morris, Lovett, and Wolf (1995) are testing the differential treatment effects of a more comprehensive model of fluency-based reading intervention. The RAVE-O program (retrieval, automaticity, vocabulary-elaboration, and orthography; Wolf, Miller, & Donnelly, in press) is a direct outgrowth of the implications of the double-deficit hypothesis. It directly addresses the need for fluency and automaticity at two levels: in both overt reading behaviors—such as word identification, word attack, and comprehension—and in underlying component processes, including visual and auditory recognition, orthographic pattern recognition, lexical-retrieval, and semantic processes. For example, at the underlying component level, a special set of computerized games (Speed Wizards; Wolf & Goodman, 1996) has been designed to increase the speed of (a) visual scanning, (b) orthographic pattern recognition (i.e., onset and rime), (c) auditory discrimination at the phoneme and phoneme cluster levels, and (d) word identification. The word patterns used in Speed Wizards are first introduced and taught within a systematic phonological-based approach (see phonological analysis and blending program in Lovett et al., 1994). The goal is to connect phoneme analysis and blending skills with fluency training at the orthographic pattern and word level.

To address lexical retrieval, research teachers teach children a series of metacognitive strategies for word retrieval in RAVE-O, alongside a systematic approach to enriched semantic development (see earlier RAVE program in Wolf & Segal, 1999). Based on earlier work in vocabulary development by Beck, Perfetti, and McKeown (1982) and others, the principle is that one retrieves fastest what one knows best. Vocabulary growth is conceptualized as an essential aspect of both rapid retrieval (in oral and written language) and also of comprehension. A series of timed and untimed comprehension stories (e.g., "Minute Mysteries") accompanies each week of RAVE-O lessons. The vocabulary in the stories both incorporates known rime patterns and also emphasizes the multiple meanings and semantically related words of the week's vocabulary words. In summary, the RAVE-O program represents a first step toward a more comprehensive approach to fluency programs.

Summary

In this article, we have presented evidence for a second core deficit in the developmental dyslexias, indexed in the linguistic domain by naming speed. We have argued that this deficit can exist both independent from and in combination with phonological deficits; the latter combined form appears to characterize children with the most serious and pervasive impairments in reading across varying languages.

We have presented two nonexclusive hypotheses that attempt to explain the effects of naming-speed deficits on reading breakdown. In Hypothesis 1, findings by Galaburda et al. (1994), Livingstone et al. (1991), and Chase (1996) were integrated to argue the following: If the magnocellular system in the thalamic visual areas is aberrant, then the processing of lower spatial-frequency components will be slowed, potentially leading to slower visual discriminations, slower letter–pattern identification, slower naming speed for serially presented visual stimuli, and delayed induction of orthographic patterns. Slower naming speed in this scenario is viewed as an index of lower level problems that disrupt the smooth development of fluency in word identification and comprehension.

In Hypothesis 2, naming speed is both an index of dysfunction in lower level processes and is also a contributing factor to pervasive reading failure. In this scenario, deficits in naming speed are conceptualized as one manifestation of a cascading system of more general processing-speed deficits that may affect visual, auditory, and possibly motoric domains, as well as orthographic and phonological processing systems.

Whether either of our speculative hypotheses about the relationships connecting naming speed to reading will ultimately prove correct, the cumulative evidence in this article challenges researchers to create an understanding of reading disabilities that is no longer restricted to dyslexic readers who are defined largely by phonological deficits but that incorporates the dimensions of processing speed and fluency. Recognition of deficits in both phonology and the processes underlying naming speed leads, we believe, to a more comprehensive conceptualization of reading disabilities and their treatment. The RAVE-O reading intervention program represents one step in the direction of a new emphasis on fluency-based treatment.

A final cautionary note, however, is critical to restate. The history of dyslexia research, the well-known heterogeneity of dyslexic children, and the very complexity of the reading process argue against any single unifying explanation for reading breakdown. The double-deficit hypothesis has never been conceptualized as a total explanation of dyslexia but rather as a vehicle to push researchers' understanding of the heterogeneity of readers beyond unitary models and solely linguistic explanations toward more encompassing models of reading breakdown and reading intervention.

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