Note. Although it is conceptualized as the summary article, readers with little background in this area may find it helpful to read this article immediately following the introductory article.

Naming-Speed Processes, Timing, and Reading: A Conceptual Review

Maryanne Wolf, Patricia Greig Bowers, and Kathleen Biddle

Abstract

This article integrates the findings in the special issue with a comprehensive review of the evidence for seven central questions about the role of naming-speed deficits in developmental reading disabilities. Cross-sectional, longitudinal, and cross-linguistic research on naming-speed processes, timing processes, and reading is presented. An evolving model of visual naming illustrates areas of difference and areas of overlap between naming speed and phonology in their underlying requirements. Work in the cognitive neurosciences is used to explore two nonexclusive hypotheses about the putative links between naming speed and reading processes and about the sources of disruption that may cause subtypes of reading disabilities predicted by the double-deficit hypothesis. Finally, the implications of the work in this special issue for diagnosis and intervention are elaborated.

As noted in the introductory article (Wolf & Bowers, this issue), the double-deficit hypothesis represents an evolving, alternative conceptualization of reading disabilities that integrates previous work on phonological deficits with research on naming-speed deficits. Three subtypes of impaired readers are presently categorized under this hypothesis, characterized respectively by phonological deficits, naming-speed deficits, and a combination of both. The latter, double deficit, appears to accompany the most serious forms of reading disability.

It is important to note from the outset that at no point do we suggest that phonological skills and processes underlying naming speed represent the only deficits that can disrupt reading development. Rather, we believe that a more refined understanding of the unique and combined contributions of both sets of processes will prove essential for an ultimately more differentiated view of reading failure and, very important, a more comprehensive approach to reading intervention, which will be the subject of the last question in this review.

Question 1

What are naming-speed deficits, how are they measured, and how extensive are they among children and adults with reading disabilities? Are they found among dyslexic readers in other languages? Almost 3 decades of research now demonstrate that the vast majority of children and adults with reading disabilities have pronounced difficulties when asked to name rapidly the most familiar visual symbols and stimuli in the language: letters, numbers, colors, and simple objects. Many of these children and adults do not have blatant word-finding difficulties but are nevertheless significantly slower than their average-reading peers on continuous naming or naming-speed tasks, in which they are required to retrieve names for common, serially presented stimuli under conditions requiring time (see Figure 1).
FIGURE 1. Example of most commonly used naming-speed task, the Rapid Automatized Naming (RAN) test.

The research in this area is based originally on work in the neurosciences, stemming from a hypothesis about color naming by Geschwind (1965). Geschwind (1965) suggested that the cognitive components involved in color naming—that is, those components involved in attaching a verbal label to an abstract, visual stimulus—would make a good early predictor of later reading performance, which poses similar cognitive requirements. This hypothesis was investigated and developed by Denckla (1972) who, in collaboration with Rudel (Denckla & Rudel, 1974, 1976a, 1976b), found that the speed with which names were retrieved, rather than the accuracy in color naming or the naming itself, differentiated dyslexic readers from others. These researchers were the first to design a rapid automatized naming (RAN) task to measure continuous, serial naming-speed performance on common visual stimuli. The RAN tasks measure the speed with which children can verbally name a serial array of the most basic visual symbols (see Figure 1) and are the prototypical tasks used in most of the cited research (for task variations that do not rely on alphanumeric symbols with language-impaired children, see Wiig, Zureich, & Chan, in this issue). The cumulative cross-sectional, longitudinal, and cross-linguistic research on RAN or RAN-like tasks has demonstrated that processes underlying naming speed differentiate dyslexic readers from

1. average readers (Berninger, in press; Berninger et al., 1995; Bowers, Steffy, & Tate, 1988; Denckla & Rudel, 1976a, 1976b; Grigorenko et al., 1997; Snyder & Downey, 1995; Spring & Capps, 1974; Spring & Davis, 1988; Wolf, 1982; Wolf, Bally, & Morris, 1986; Wolff, Michel, & Ovrut, 1990a, 1990b, 1990c);
2. nondiscrepancy or “garden-variety” poor readers (described by Gough and Tunmer, 1986, as readers whose low reading level is not discrepant with their IQ or achievement scores; Ackerman & Dykman, 1993, 1995; Badian, 1994, 1995, 1996a, 1996b; Wolf & Obregon, 1992); and

There are mixed results concerning the question whether naming speed differentiates dyslexic readers from reading-age–matched readers. This method employs comparisons with younger, average readers who read at the same level as the older dyslexic group. Ackerman and Dykman (1993), Biddle (1996), Segal and Wolf (1993), and Wolf (1991; Wolf & Segal, 1997) found that children with dyslexia performed significantly slower than reading-age–matched children, but Badian (1996a) and Olson (1995) reported no differences. A more comprehensive summary of the research on naming speed with more detailed information on specific populations and findings is provided in Table 1.

Naming-speed differences have been demonstrated among dyslexic readers across languages of varying degrees of orthographic regularity, including German (Näslund & Schneider, 1991; Wimmer, 1993; Wolf, Pfeil, Lotz, & Biddle, 1994), Finnish (Korhonen, 1995), Dutch (Van den Bos, 1998; Yap & Van der Leij, 1993), and Spanish (Novoa, 1988; Novoa & Wolf, 1984). In both German (Wimmer, 1993) and Dutch (Van den Bos, 1998)—two languages with a more transparent or regular orthography than English—naming speed appears a more robust predictor of reading performance than phonological awareness measures. The importance of these cross-linguistic findings is that they eliminate the irregularity of English orthography as a possible explanatory factor in the naming-speed findings. Moreover, they suggest that, in languages where a regular structure can be decoded using relatively lower
<table>
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<th>Age/Grade</th>
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<th>Results</th>
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<tr>
<td>Ackerman &amp; Dykman, 1993</td>
<td>$n = 42$ dyslexic $n = 56$ ADD $n = 21$ slower learner</td>
<td>7.5–12 years</td>
<td>RAN</td>
<td>• Dyslexics slower than ADD readers and slower learners on RAN and RAS</td>
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<td></td>
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<td>RAS</td>
<td>• Continuous naming robust correlate of reading skill</td>
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<td>Badian, 1993</td>
<td>$N = 86$</td>
<td>6–8 years</td>
<td>RAN colors, objects, numbers, letters</td>
<td>• RAN letters, objects, numbers differentiated average from poor readers</td>
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<td></td>
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<td></td>
<td>• RAN letters, objects, and numbers correlate with later reading achievement</td>
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<tr>
<td>Badian, 1994</td>
<td>$N = 118$</td>
<td>4.5–5.5 years</td>
<td>RAN objects</td>
<td>• RAN objects' latency contributes to first-grade reading outcome</td>
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<td>• RAN objects' latency strong predictor of first-grade reading outcome</td>
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<tr>
<td>Berninger et al., 1997</td>
<td>$n = 20$ a tutorial study</td>
<td>end 1st grade</td>
<td>RAN</td>
<td>• 75% had RAN/RAS deficit</td>
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<td>RAS</td>
<td>• 50% had double deficit or RAN/RAS and orthographic coding deficit</td>
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<td>• Letter RAN and letter/number RAS improved after 12 months of reading/writing tutorial, but letter/number RAS (not letter RAN) was still in at-risk range.</td>
</tr>
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<td>Berninger, 1998</td>
<td>$n = 32$ first probands in family/genetics study</td>
<td>Grades 1–6</td>
<td>RAN/RAS</td>
<td>• All had RAN/RAS deficit</td>
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<td></td>
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<td>• None had a pure phonological deficit in phoneme segmentation</td>
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<td></td>
<td>• 53% had triple deficit in RAN/RAS, phonological coding, and orthographic coding</td>
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<tr>
<td>Berninger et al., 1999, in press</td>
<td>$n = 48$ in prevention study</td>
<td>Grade 1</td>
<td>RAN/RAS</td>
<td>• Combination of RAN/RAS and verbal IQ best predictor of real-word reading (Woodcock Reading Mastery Tests–Revised Word Identification) after intervention</td>
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<td></td>
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<td></td>
<td>• RAN/RAS only variable that consistently differentiated treatment responders and treatment nonresponders in growth curve analysis</td>
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<tr>
<td>Blachman, 1984</td>
<td>$n = 34$</td>
<td>Kindergarten</td>
<td>RAN objects/colors, letters (Grade 1 only)</td>
<td>• Kindergarten naming speed for color predicts Grade 1 reading achievement</td>
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<td></td>
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<td>Grade 1</td>
<td></td>
<td>• Colors and letters each contribute to prediction of reading</td>
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<tr>
<td>Bowers &amp; Kennedy, 1993</td>
<td>$N = 37$</td>
<td>Grade 2, 3, 4</td>
<td>RAN numbers</td>
<td>• Digit-naming speed contributes unique variance to reading speed</td>
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<td>• Digit-naming speed predicted fourth-grade reading speed</td>
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<tr>
<td>Bowers &amp; Swanson, 1991</td>
<td>$n = 24$ poor readers $n = 19$ average readers</td>
<td>Grade 2</td>
<td>Letters, numbers, continuous list, and discrete trials</td>
<td>• Both conditions differentiate poor/average readers</td>
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<td>• Continuous list latency relates to word identification (ID) accuracy</td>
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<td>• Continuous list latency relates to word attack accuracy</td>
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<td>• Both conditions relate to comprehension and word ID latency</td>
</tr>
<tr>
<td>Cornwall, 1992</td>
<td>$N = 54$ severe reading and spelling disability</td>
<td>7; 5–12; 3 years</td>
<td>RAN Other</td>
<td>• RAN unique share in variance of reading achievement</td>
</tr>
<tr>
<td>Denckla, 1972</td>
<td>$n = 5$ dyslexic</td>
<td>7; 5–10; 7 years</td>
<td>RAN color</td>
<td>• Dyslexics more than 1 SD below norm for kindergarten on RAN colors</td>
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<td>Study</td>
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<td>Age/Grade</td>
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<tr>
<td>Denckla &amp; Rudel, 1974</td>
<td>N = 180 controls</td>
<td>5; 10–11; 11 years</td>
<td>RAN color, number, letter, animal, object</td>
<td>• Age differences for all tasks</td>
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<td>n = 120 controls</td>
<td>7; 0–10; 11 years</td>
<td>RAN colors, numbers, letters, objects</td>
<td>• Greatest rate of change between 5 and 7 years, letters and numbers &gt; colors and objects</td>
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<td>n = 72 dyslexic</td>
<td>7; 0–12; 11 years</td>
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<td>• Main effects age, group, test</td>
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<td></td>
<td>n = 56 LD</td>
<td>7; 0–12; 11 years</td>
<td></td>
<td>Controls &gt; LD &gt; dyslexic on speed</td>
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<tr>
<td>Fawcett &amp; Nicolson, 1994</td>
<td>n = 35 dyslexic</td>
<td>$\overline{X} = 8, 13, 17$ discrete trial for objects, colors, numbers, letters CA and RA match</td>
<td>• Dyslexics slower than CA match on all tasks</td>
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<td></td>
<td>n = 32 controls</td>
<td>$\overline{X} = 8, 13, 17$</td>
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<td>• Dyslexics slower than RA match on objects</td>
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<td></td>
<td>n = 10 slow learners</td>
<td>$\overline{X} = 10$</td>
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<td>• Dyslexics slower than RA match on all tasks</td>
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<td>• 17 years dyslexic performs at level of 8 years on objects and letters; 10 years slow learners perform equivalent to 8 years dyslexic</td>
</tr>
<tr>
<td>Felton &amp; Brown, 1990</td>
<td>N = 81 at-risk</td>
<td>$\overline{X} = 6.2$ kindergartners measured in Grade 1</td>
<td>RAN Other</td>
<td>• RAN predicted reading ability</td>
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<td>• Word ID predicted by RAN</td>
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<td>• No correlation between RAN and phonological measures</td>
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<td>• Phonological measures not predictive of reading ability</td>
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<tr>
<td>Felton, Naylor, &amp; Wood, 1990</td>
<td>n = 115 adults RD</td>
<td>$\overline{X} = 33; 1 year$</td>
<td>RAN RAS Other</td>
<td>• RAN was one task that most clearly differentiated RD from NRD</td>
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<td>n = 23 controls NRD</td>
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<td>• Childhood reading status predicted differences on neuropsychological tasks</td>
</tr>
<tr>
<td>Katz, Curtiss, &amp; Taillal, 1992</td>
<td>n = 61 LI</td>
<td>$\overline{X} = 9; 3 years$</td>
<td>RAN</td>
<td>• RAN distinguished LI from controls</td>
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<td>n = 54 controls</td>
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<td>• Correlations between RAN and reading increase with age for LI students</td>
</tr>
<tr>
<td>Korhonen, 1995</td>
<td>n = 9 RD; measured twice</td>
<td>9 years; 18 years</td>
<td>RAN RAS</td>
<td>• at 9 years and 18 years RAN differentiates RD from controls RAS differentiates RD from controls</td>
</tr>
<tr>
<td>Manis &amp; Doi, 1995</td>
<td>n = 85 full range of reading ability</td>
<td>Grade 2</td>
<td>Serial naming letters, digits, objects</td>
<td>• Naming speed (letters and digits) contributes uniquely to reading ability</td>
</tr>
<tr>
<td></td>
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<td>$\overline{X} = 7; 10 years$</td>
<td></td>
<td>• Naming speed contributes strongly to orthographic skill</td>
</tr>
<tr>
<td>Mann &amp; Ditunno, 1990</td>
<td>N = 70</td>
<td>Kindergarten and Grade 1</td>
<td>Serial naming letters</td>
<td>• Kindergarten RAN predicts Grade 1 reading achievement</td>
</tr>
<tr>
<td>McBride-Chang &amp; Manis, 1996</td>
<td>n = 51 poor readers</td>
<td>Grades 3 and 4</td>
<td>Serial naming rhyming letters, nonrhyning letters, digits</td>
<td>• Naming speed correlates significantly with word reading for poor readers.</td>
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<tr>
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<td>n = 74 good readers</td>
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<tr>
<td>Obregón, 1994</td>
<td>n = 6 dyslexics</td>
<td>12–17; 9 years</td>
<td>RAN letters, colors, objects</td>
<td>• Dyslexics slower than controls</td>
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<td></td>
<td>n = 6 controls</td>
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<tr>
<td>Spring &amp; Capps, 1974</td>
<td>n = 24 dyslexic boys</td>
<td>7; 6–13; 4 years</td>
<td>Serial naming digits, colors</td>
<td>• Dyslexics slower than controls</td>
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<tr>
<td></td>
<td>n = 24 controls</td>
<td></td>
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<tr>
<td>Spring &amp; Davis, 1988</td>
<td>N = 30</td>
<td>Grades 1–3</td>
<td>Serial naming digits</td>
<td>• Naming speed correlates with irregular word accuracy</td>
</tr>
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<td>N = 92</td>
<td>Grades 4–10</td>
<td>Serial naming digits</td>
<td>• Naming speed correlates with nonsense word accuracy</td>
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<td>• Naming speed correlates with word recognition</td>
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<td>• Naming speed correlates with reading comprehension</td>
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(continued)
levels of phonological skill than needed in English, the speed-of-processing variable emerges as a stronger predictor of reading performance than phonological awareness tasks.

Efforts to understand the sources of naming-speed deficits have indicated that naming speed's differentiation of dyslexic readers from controls cannot easily be ascribed to differences in articulation rate (Ackerman & Dykman, 1993; Ellis, 1985; Obregón, 1994; Stanovich, Nathan, & Zolman, 1988; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993; Wimmer, 1993), short-term memory difficulties (Bowers et al., 1988; Wimmer, 1993), or visual scanning problems that might result from the continuous naming format. (See, however, differences for dyslexics in articulation rate for non-naming tasks in Nicolson & Fawcett, 1995; Snyder & Downey, 1995; Wolff et al., 1990b.) To investigate these articulatory and end-of-line visual scanning hypotheses, Obregón (1994) in our lab designed a highly sophisticated computer program to digitize the speech stream of children during RAN tasks. He found no differences between reader groups in isolated time to articulate the verbal labels, nor for time to scan from the end of one line to the beginning of the next line. Significant differences were found, however, for children with dyslexia in the interstimulus intervals (ISI)—that is, the time it takes dyslexic readers to disinhibit from the previous stimulus, perceive and recognize the present stimulus, activate lexical access and retrieval processes for its verbal label, and move to the next stimulus. The locus of reader differences for naming speed in the ISI is an important finding with potential links to similar findings in timed visual and auditory tasks. This is discussed in more detail under Question 5.

To summarize, naming-speed deficits are consistently found in children and adults with reading disabilities across all languages tested, alongside the better understood phonological awareness-based deficits. These deficits cannot be attributed to English orthography, articulation, or short-term memory, although more work is needed with regard to rate of articulation.

Question 2

Can children with developmental dyslexia be categorized in subtypes according to the presence or absence of phonological and naming-speed deficits? The extensive literature on phonological disabilities in children with reading disabilities represents one of the most well-known areas of research in reading disabilities and is not reviewed here (see, e.g., Blachman, 1997; Catts, 1996; Lyon, 1995; Stanovich & Siegel, 1994; Torgesen, Wagner, & Rashotte, 1994). A parallel body of research on naming-speed deficits is summarized in Table 1 and discussed in Wolf and Bowers (1999). Until recently, there have been few efforts to discuss the ramifications of the co-occurrence of these deficits in the same child (see Blachman, 1994). Lovett (1984) may have been the first to address this convergence in her subtype descriptions of accuracy-disabled and rate-disabled readers. As discussed in the introductory article, Lovett’s rate-disabled readers showed poor naming speed but age-appropriate word
identification scores. The accuracy-disabled readers were more severely impaired than average or rate-disabled readers on both accuracy and rate for all reading and naming-speed measures.

In both the school-based and the clinically-referred samples included in this special issue, the reanalysis of participants along the lines of the double-deficit hypothesis resulted in four subgroups of readers whose differences were clear-cut. These included a group of children with no deficit, two groups with a deficit in one but not in the other process, and a group with deficits in both processes. In the school-based samples, readers in the age-appropriate range on phonological and naming-speed dimensions differed significantly from those with combined deficits on all aspects of reading tested, including word attack, word identification accuracy and latency for concrete words and for exception words, oral reading, and reading comprehension. Either deficit could appear singly in a child with reading disabilities. The vast majority of single-deficit children in the school-referred databases (see Bowers, 1995; Manis, Doi, & Bhadha, in this issue; Wolf & Bowers, 1999) would be described as having modest reading impairments, with the phonological-deficit subtype somewhat more impaired than the subtype with naming-speed deficits.

It is important to note that in the clinically-referred populations, Lovett (1995; Lovett, Steinbach, & Frijters, in this issue) has shown that single deficits can also be implicated in more serious cases of reading disability. It was unknown until this time whether single-deficit subtypes would appear in these very impaired children. As would be predicted, however, the majority of Lovett et al.'s population were classified as children with a double deficit: “The most striking finding from diagnostic comparisons of the three subgroups was the extent to which the two deficits in combination depressed all aspects of written language acquisition for affected children” (Lovett, Steinbach, & Frijters, in this issue). In Wolf and Bowers' (1999) school-based population, double-deficit readers were approximately 2.5 to 3 years below grade-level expectations on six aspects of reading (see similar findings in Krug, 1996). Across both clinical and school populations, therefore, the double-deficit subtype was the most impaired of all subtypes on all measures of reading. With few exceptions, double-deficit readers performed worse than single-deficit readers in the phonological and naming-speed subtypes on both rate and phonological measures.

Research on these subtypes is rapidly increasing. Several emerging databases by Badian (1996a, 1996b), Berninger et al. (1995), Biddle (1996), Krug (1996), and Meyer, Wood, Hart, and Felton (1998) have shown findings consistent with those reported in this issue. Furthermore, cross-linguistic studies that indicate similar subtypes have begun in Dutch (Van den Bos, 1998), German (Wolf et al., 1994), and Hebrew (Breznitz, personal communication, June 1999). Recently, Morris et al. (1998) applied clustering techniques to classify reading disability subgroups in their large study. Consistent with their original theoretical predictions, phonological deficits played a central role in the classification of their subtypes. Less predicted in their original hypotheses, naming-speed deficits also played a major role in their classifications and, when occurring with phonological deficits, characterized their two most profoundly impaired subtypes. According to Morris et al., these findings “attest to the primary impairments of phonological processes and serial naming speed—as opposed to IQ scores—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” (1998, p. 24).

Earlier data reports of combined deficits are also supportive of double-deficit hypothesis subtypes. Blachman (1994) quoted Wood in questioning whether the early co-occurrence of phonemic awareness and naming-speed deficits is a better marker for the most impaired readers than simply phonemic awareness alone: “Poor phonemic awareness may get the child into a remedial reading program, but having a naming rate deficit may be what keeps the child in the program” (Wood, cited in Blachman, 1994, p. 290).

The results in this section indicate that naming-speed deficits and phonological deficits can be found independently and in combined forms. They underscore the importance of including rapid naming criteria in our identification of subgroups. Very important, if future research consistently demonstrates that single-deficit readers are more frequently modestly impaired and that double-deficit readers are the most profoundly impaired, then critical studies about possible compensatory skills can be pursued. Furthermore, longitudinal research from kindergarten to middle grades will be important to understand cognitive-developmental differences between double-deficit readers who continue to have both deficits over time and those who resolved their deficits in early grades. We are particularly interested in double-deficit readers whose phonological decoding problems are resolved with intervention, reclassifying them into a naming-speed deficit subtype with more discrete fluency and comprehension problems.

To summarize the evidence for the second question, naming-speed deficits or phonological deficits can occur independently in cases of modest or serious reading disability. The co-occurrence of both deficits—the double-deficit subtype—characterizes the most difficult forms of reading disability. Current research on subtypes increasingly reflects both dimensions.

**Question 3**

Should naming-speed processes be subsumed under phonological pro-
cesses, as is current practice in most research on reading disabilities? If not, what are the distinctive properties of naming-speed processes that separate them from phonology? Researchers who work within a phonological core deficit framework regularly acknowledge the independent contributions of naming speed to reading, but they tend to categorize naming speed as “part of the phonological family” (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997, p. 84). Depicted as the retrieval of phonological codes in earlier characterizations (Wagner et al., 1993), naming speed was conceptualized with good reason as a phonological process, including some shared variance (to be described) between the two variables. Naming speed, like any linguistic task (e.g., semantic generation, expressive vocabulary), involves accessing a phonological code; however, we believe this to be insufficient reason to categorize and subsume naming speed under phonology.

Cognitive Requirements

The rationale for emphasizing the differences between naming speed and phonology is embedded in the complex cognitive structure of naming and also in the importance of timing within and across each of naming's multiple subprocesses. A brief examination of this structure in a model of letter naming illustrates how naming and serial naming speed’s internal complexity go beyond phonological processes (see Figure 2).

As depicted in Figure 2, visual naming represents a demanding array of attentional, perceptual, conceptual, memory, lexical, and articulatory processes (see earlier model in Wolf, 1982; see detailed discussion of this model’s components in Wolf & Bowers, 1999). The model begins with the activation of attentional processes that, in turn, activate bihemispheric visual processing at multiple levels. For example, components responsible for lower spatial frequencies provide information about the global shape of the stimulus and are operating within 60 to 80 ms of stimulus presentation (Chase, 1996; Legge, 1978). Visual components responsible for higher spatial frequencies operate somewhat more slowly, within 150 to 200 ms, and provide information about the finer details of the stimulus. This, in turn, allows for identification or recognition processes that integrate information about the present stimulus with known mental representations, the quality of which will influence the speed of the processing (see Perfetti, 1992). Additional components that may influence the integration of the cumulative visual and representational information are affective factors and associative input from other sensory modalities (see concept of cumulative modality threshold in Wolf, 1982). Lexical processes—including semantic, phonological access, and retrieval processes—are integrated with the cumulative information. Motor commands translate this phonological information into an articulated name. The entire process occurs within 500 ms (Wingfield, 1968).

One purpose of this evolving model is to give a visual heuristic for understanding the complexity of naming’s structural requirements (see also models of naming in Johnson, Paivio, & Clark, 1996; Seymour, 1973; Wolf, 1982). It exemplifies both the importance of access to the phonological code in naming and the fact that phonological processes represent only one subset of the multiple processes involved in naming.

The second purpose of the model is to demonstrate the extent of processing-speed requirements (PSRs) that accompany each of the components in naming. Continuous naming-speed tasks add to the visual naming model the extra demands of rapidity and serial processing to the ordinary PSRs found in each subprocess. The complexity of this underlying structure, the extent of ordinary processing speed demands, and the addition of rapid rate and seriation to PSRs make naming speed a different cognitive task from phonology.

By the same token, this particular combination of requirements makes naming speed a significant predictor of reading. This is because naming speed (particularly serial naming speed) provides an early, simpler approximation of the reading process (see Blachman, 1984), with reading’s similar combination of rapid, serial processing and integration of attentional, perceptual, conceptual, lexical, and motoric subprocesses. The demands in reading for higher-level comprehension processes go far beyond those in naming speed. Nevertheless, it is the intrinsic cognitive complexity of naming speed and reading that we wish to emphasize in our arguments here—a complexity that is obscured by referring to naming speed as a phonological process. Furthermore, just as in reading, the multiple underlying component structure of naming speed obviates unitary explanations for its breakdown. These explanations include phonological processing problems for both naming speed and reading; there are, however, other potential causes for failure in naming speed and reading that are based on the complexity described. Thus, throughout this work the emphasis is not so much on naming speed but rather on the multiple processes underlying it.

Independent Prediction

In addition to the cognitive—structural differences modeled above, several other types of evidence support the differentiation between naming speed and phonology. First, the interrelationships found between phonological measures and rapid naming tasks are modest (Blachman, 1984; Bowers, 1995; Cornwall, 1992; Felton & Brown, 1990; Wimmer, 1993) or sometimes insignificant (Mann, 1984). There is variability in this finding, as described in two studies by Wagner and Torgesen. In one study, Wagner et al. (1993) found that by Grade 2 the relationship between phonological and naming-speed measures was small; in a subsequent,
Letter Stimulus to be Named

**ATTENTIONAL PROCESSES**

*PSR*

**VISUAL PROCESSING**
(Bihemispheric)

Lower Spatial Frequencies

*PSR*

Higher Spatial Frequencies

*PSR*

Object/Letter/Pattern Recognition *PSR*

**MENTAL REPRESENTATION PROCESSES**

Orthographic Representation *PSR*

Phonological Representation

**INTEGRATION PROCESSES**

*PSR*

**LEXICAL PROCESSES**

Semantic Access

+ Retrieval

*PSR*

Phonological Access

+ Retrieval

*PSR*

**LEXICAL INTEGRATION PROCESSES**

**MOTORIC PROCESSES**

*PSR*

**ARTICULATED NAME**

*PSR* - Processing Speed Requirements

**FIGURE 2.** Model of visual naming.
both variables. Naming speed alone unique aspects of the reading process, reading subskills and concluded that speed and phonological tasks with potential patterns of relationships for naming- Cornwall (1992) found similar differences, whereas phonological decoding contributed solely to comprehension. Naming speed alone contributed to speed on reading measures, whereas phonological decoding contributed solely to comprehension. Cornwall (1992) found similar differential patterns of relationships for naming-speed and phonological tasks with reading subskills and concluded that naming-speed abilities “may represent unique aspects of the reading process, as opposed to an overall phonological ability” (1992, p. 537).

In this issue, Manis, Doi, and Bhadha (see their Tables 2 and 3) conducted commonality analyses to determine the amount of shared and unique variance of phonemic awareness and naming speed with various reading tasks. These analyses consistently indicated that both naming-speed and phonological variables predict unique, independent variance in every reading measure in addition to significant common variance. In orthographic variables, naming speed accounted for more variance in the “puruer” orthographic tasks than the phonological variable and a similar amount of variance in tasks that included both orthographic and phonological components (e.g., word identification).

A third and related type of evidence is a matter of ongoing debate in the literature. Controlling for the effects of Grade 2 word identification on later reading skills, Torgesen et al. (1997) found that phonological measures—but not naming speed—predicted small but significant variance in later reading beyond the contribution of Grade 2 reading variables. Meyer et al. (1998) in a similar analysis found that only naming speed predicted later reading in a severely impaired population when controlling for Grade 4 word identification.

Most recently, Manis (personal communication, August 15, 1998) conducted a study with participants more similar in age to Torgesen et al.’s (1997) sample, and more similar in severity of impairment to Meyer et al.’s (1998) population. Unlike Torgesen et al. (1997), Manis and his colleagues (in this issue) found significant variance in Grade 2 orthographic skill explained by both naming-speed and phonological awareness measures after controlling for the autoregressive effects of Grade 2 reading skills. Although the complex factors in this area of research are beyond the scope of this article (see discussions in Torgesen et al., 1997; Wolf & Bowers, 1999), this literature indicates that it is critical to take into account the following:

1. the severity of reading impairment and sample characteristics (including, as noted by Torgesen et al., 1997, the quality of reading instruction);
2. the distinctions among word identification, word attack, word recognition, and reading speed variables; and
3. the developmental factors that incorporate information about when various processes approach automatic levels (Biddle, 1996; Carver, 1991; Cronin & Carver, 1998; Kail & Hall, 1994; McBride-Chang & Manis, 1996).

To summarize the arguments in this area, naming speed is conceptualized as a complex ensemble of attentional, perceptual, conceptual, memory, phonological, semantic, and motoric subprocesses that places heavy emphasis on precise timing requirements within each component and across all components. Phonological processes play an ineluctably important role in naming speed, but represent only one component area among many. There seem to be strong relationships between naming speed and word and text fluency and between phonological awareness and word attack (real word and nonword). Both variables contribute uniquely to word identification and also have some variance in common. There appear to be strong developmental trends with average readers, who approach levels of automaticity (see Note 1) on symbol–speed measures by Grade 2, significantly earlier than dyslexic readers. Nondiscrepant or garden-variety poor readers appear to be much closer to average readers in their development of automaticity for symbols, but further work is necessary to understand the effects of IQ. Naming speed is a weaker predictor of later reading for nondiscrepant poor readers and average reader groups after Grade 2. For severely impaired dys-
lexic readers, naming speed appears to be a powerful—and sometimes the strongest—predictor of later reading well into Grade 8 (Meyer et al., 1998). Given this evidence, continuing to subsume naming speed under phonology obscures its separate role in reading failure.

**Question 4**

What links naming-speed processes to reading? Although the phonological core deficit perspective rests on an extensive research tradition and good common sense (e.g., learning grapheme-phoneme correspondence rules requires an awareness of and an ability to analyze and blend the sounds within words), no such straightforward conceptualization exists to explain how the processes underlying naming speed affect word identification and word attack. Toward that end, in the next two sections we briefly summarize two nonexclusive hypotheses on the possible roles of orthography or general timing processes in explaining the relationships between naming-speed deficits and reading breakdown. The arguments in these sections are highly speculative and represent work in progress (see more elaborate discussions in Bowers & Wolf, 1993; Wolf & Bowers, 1999). Considerable further work from a variety of perspectives is needed before these relationships will be sufficiently clarified.

**Orthographic Pattern Recognition**

In our first hypothesis, we consider whether naming speed and reading are connected through orthographic processes. (The second hypothesis is the subject of Question 5.) In an earlier article (Bowers & Wolf, 1993), we hypothesized that processes underlying slow naming speed could contribute to reading failure in three related ways:

1. by preventing the appropriate amalgamation (see Ehri, 1992) of the connections between phonemes and orthographic patterns at subword and word levels of representation;
2. by limiting the quality of orthographic representations in long-term memory (see Perfetti, 1992); and
3. by increasing the amount of repeated practice needed before an orthographic code is learned as a lexical or sublexical unit and before representations of sufficient quality are achieved.

For some time, we have each attempted to examine this question at different levels of analysis. Based in part on Adams' (1981) orthographic redundancy model, Bowers, Golden, Kennedy, and Young (1994) have emphasized the importance of the learned associations between letters in the development of orthographic representations: "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 [italics added] to allow the child to become sensitive to letter patterns that frequently co-occur in print" (p. 203).

**Neurophysiological Evidence**

Based on work in the cognitive neurosciences, Wolf (1991; Wolf & Obregón, 1992) studied potential connections between slow visual naming speed and aberrant neurological development at the cellular level. For example, Livingstone, Rosen, Drislane, and Galaburda (1991) found, in a small study of dyslexic brains, aberrant development in the lateral geniculate nucleus (LGN), an area in the thalamus responsible for the cortical and subcortical coordination of visual information. Important to arguments involving timing, the specific area of aberrant development in the LGN was the magnocellular system—that is, those cells responsible for fast and transient processing of information. Livingstone et al. found a reduction in cell number and cell size in the magnocellular system, as well as abnormalities in neural migration. Although the database was necessarily very limited, these data provided some of the first evidence for a neurophysiological basis for some naming-speed deficits, albeit at the level of visual input only (see visual processes in model of visual naming in Figure 2).

More recently, we (Wolf & Bowers, 1999) have begun the task of connecting all three areas: naming speed, neurophysiological evidence, and orthographic recognition. For example, Chase (1996) stressed the importance of low spatial frequency components in the visual analysis of the constituent features of letters, words, and so forth (see also Breitmeyer, 1993; Lovegrove & Williams, 1993). As discussed in the model's description under Question 3, low spatial frequency information involves very rapid processes that extract the more global shapes of objects, letters, or words within 60 to 80 ms (Legge, 1978). These frequencies are processed at the cellular level in the visual areas by the magnocellular system. Chase (1996) connected the previously discussed cytoarchitectonic data on the LGN by Galaburda (Livingstone et al., 1991) to his studies of visual flicker fusion in dyslexic children. In these studies, two very brief visual images are presented in rapid succession with varying ISIs; children with reading disabilities require far greater time in the ISI to be able to see two images rather than a single fusion of the two stimuli. On the basis of his own and Galaburda's findings at the neuronal level, Chase argued that the speed and quality of visual information for low spatial frequency components is weakened in impaired readers, preventing them in higher level tasks from making sufficiently rapid visual discriminations and high-quality orthographic representations.

Reflecting previously discussed work and our earlier study (Bowers & Wolf, 1993), our first hypothesis about the relationship between naming speed and reading leads to the following argument. If the speed and quality...
of visual information at the level of low spatial frequencies are compromised (based, potentially, on underlying aberrations at the cellular level), then letter identification proceeds too slowly both for making high-quality letter representations and for forging the necessary links between frequently co-occurring letters to store them as patterns (Seidenberg & McClelland, 1989). The consequences for reading are as follows: The quality of orthographic representations will be affected, the number of common orthographic patterns (a key factor in fluent reading) will be restricted, and considerably more exposures (practice) will be needed for word identification. The work of Manis et al. (in this issue), Berninger (1994), and their colleagues provides increasing evidence supportive of this connection between naming speed and specific aspects of orthography (see, however, important contrasting arguments in Torgesen et al., 1997). Also supportive is the reading skill profile of children who make up the single naming-speed deficit subgroup. These children are characterized by problems with fluency, word identification, and comprehension.

**Question 5**

Do naming-speed deficits reflect a larger, systemic timing deficit? Embedded in this question are two highly complex and unresolved issues. First, does naming speed represent the linguistic analogue of a larger, potentially domain-general timing deficit that goes beyond language? Second, how would such a broadened conceptualization of processing-speed deficits relate to reading processes? These issues will be initially decoupled in this section and then brought together in a description of our second hypothesis about the relationship of naming speed to reading failure. Three types of evidence will be brought to bear regarding the breadth of the timing deficit: reaction time data, neurophysiological findings, and developmental data.

**The Nature of the Timing Deficit and the Question of Domain Specificity**

**Reaction Time Data.** In order to understand how extensive temporal-related deficits are in dyslexic populations, we examined the growing literature on reader group differences in timing at the behavioral level across visual, auditory, and motoric areas (see reviews in Breznitz, 1996; Farmer & Klein, 1995). In an attempt to add clarity to this research, we have provided a set of charts that depict examples of the range of behavioral findings for visual, auditory, and motoric domains (see Tables 2, 3, and 4, respectively).

Several key points become apparent in this overview of the varied sensory and motoric findings. The first involves the sheer range of findings that affect reading processes.

### TABLE 2

**Behavioral Findings for Visual Tasks**

<table>
<thead>
<tr>
<th>Task</th>
<th>Study</th>
<th>Stimuli</th>
<th>Age</th>
<th>Reader Group Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic detection³</td>
<td>Blackwell, McIntyre, &amp; Murray, 1983</td>
<td>Single letter detection at 150 ms</td>
<td>8–12</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Klein, Berry, Briand, D'Entremont, &amp; Farmer, 1990</td>
<td>Single letter detection at 17 ms</td>
<td>13–18</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Blank, Berenzweig, &amp; Brüder, 1975</td>
<td>Flash of light Complex cartoon</td>
<td>9</td>
<td>Yes</td>
</tr>
<tr>
<td>Gap detection²</td>
<td>Slaghuis &amp; Lovegrove, 1985</td>
<td>Sequenced wave gratings</td>
<td>9</td>
<td>Yes—Dyslexics need longer ISI to detect at low spatial frequencies</td>
</tr>
<tr>
<td></td>
<td>DiLollo, Hanson, &amp; McIntyre, 1983</td>
<td>Varied vertical lines</td>
<td>8–14</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Chase, 1996</td>
<td>Varied flicker fusion tasks</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Visual discrimination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow rate</td>
<td>Bryden, 1972</td>
<td>Dot patterns at 500–750 ms</td>
<td>9–10</td>
<td>No</td>
</tr>
<tr>
<td>Simultaneous presentation</td>
<td>Farmer &amp; Bryson, 1989</td>
<td>4 letters simultaneous and slow</td>
<td>12–18</td>
<td>No</td>
</tr>
<tr>
<td>Fast rate and sequenced</td>
<td>Farmer &amp; Bryson, 1989</td>
<td>4 letters simultaneous and fast;</td>
<td>12–18</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sequenced and fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal order judgment</td>
<td>Reed, 1989</td>
<td>2 symbols at slow speeds</td>
<td>7–10</td>
<td>No</td>
</tr>
<tr>
<td>Slow rate</td>
<td>Brannan &amp; Williams, 1988</td>
<td>3 letters at 20–70 ms</td>
<td>8–12</td>
<td>Yes</td>
</tr>
<tr>
<td>Fast rate speeds</td>
<td>Kinsbourne, Rufo, Gamzu, Palmer, &amp; Berliner, 1991</td>
<td>Light flashes at 20 msec</td>
<td>adult</td>
<td>Yes</td>
</tr>
</tbody>
</table>

³Significant differences favoring average readers. ⁴Requires simple judgment about presence/absence of stimulus. ⁵Requires more complex detection of 2 stimuli; e.g., flicker fusion tasks.
across the perceptual and motoric areas and an explanation for this breadth. As noted by Wolff (1993) and by Nicolson and Fawcett (1994), the range of these findings invites but cannot be explained by a simple, across-the-board reaction time (RT) explanation. As denoted on the tables for visual and auditory processes, no RT differences appear on single-task conditions at the most basic level of perceptual detection; rather, perceptual timing differences in dyslexic readers seem to occur when some aspect of choice and integration of more than one set of subprocesses are required (see also Farmer & Klein, 1995). This finding reinforces earlier conclusions in studies by Blank, Berenzweig, and Bridger (1975) and by Moore, Kagan, Sahl, and Grant (1982). Blank et al. examined the effects of stimulus complexity in intra- and crossmodal performance for dyslexic and average readers and found that the demands of stimulus complexity in the visual modality differentiated dyslexic readers: “Difficulties in processing complex, meaningful, visual information—and possibly in processing any complex meaningful information—do seem to represent a pivotal source of difficulty” (Blank et al., 1975, p. 139). Moore et al. investigated the differences between average and dyslexic readers on an extensive array of cognitive, perceptual, and motor tasks that included 14 decision time tasks. They concluded that “when the task is very simple, decision times for retarded readers and normal readers tend to be very similar, but the differences between the two groups increase when the task is made more complex” (Moore et al., 1982, p. 91; see also lack of differentiation for reader groups on dot matrix tasks in Arnett & DiLollo, 1979).

### TABLE 3

<table>
<thead>
<tr>
<th>Task</th>
<th>Study</th>
<th>Stimuli</th>
<th>Age</th>
<th>Reader Group Differences*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic detection</td>
<td>Blank et al., 1975</td>
<td>Simple tone</td>
<td>9</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Tellal, 1980</td>
<td>Complex tone at 75 ms</td>
<td>8-12</td>
<td>No</td>
</tr>
<tr>
<td>Gap detection</td>
<td>Haggerty &amp; Stamm, 1978</td>
<td>Clicks at varied speeds</td>
<td>7-9</td>
<td>Yes</td>
</tr>
<tr>
<td>Auditory discrimination</td>
<td>Bryden, 1972</td>
<td>3-5 tones</td>
<td>9-10</td>
<td>Yes</td>
</tr>
<tr>
<td>Fast rate</td>
<td>Farmer &amp; Klein, 1993</td>
<td>500-750 ms</td>
<td></td>
<td>Adolescents—Dyslexics need longer ISI</td>
</tr>
<tr>
<td>Temporal order judgment</td>
<td>Tellal, 1980</td>
<td>Complex tones in 8-305 ms range</td>
<td>8-12</td>
<td>Yes—Dyslexics require longer ISI</td>
</tr>
<tr>
<td></td>
<td>Reed, 1989</td>
<td>2 tones</td>
<td>8-10</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 vowels</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Dyslexics require longer ISI for tones not vowels.</td>
</tr>
</tbody>
</table>

*Significant differences favoring average readers. **Requires simple judgment about the presence/absence of stimulus. †Requires more complex detection of 2 stimuli.

### TABLE 4

<table>
<thead>
<tr>
<th>Task</th>
<th>Study</th>
<th>Stimuli</th>
<th>Age</th>
<th>Reader Group Differences*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger tapping—Basic level</td>
<td>Wolff, Cohen, &amp; Drake, 1984</td>
<td>Synchronous tapping by single hand</td>
<td>Varied</td>
<td>No</td>
</tr>
<tr>
<td>Finger tapping and hand movements</td>
<td>Wolff, 1985</td>
<td>Asynchronous tapping</td>
<td>9-10</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Wolff, Michel, &amp; Ovrut, 1990c</td>
<td>Bi-manual</td>
<td>Adolescents</td>
<td>Yes—Dyslexics show subtle difficulty in sequenced motor movement, particularly when interlimb coordination required</td>
</tr>
<tr>
<td></td>
<td>Gardner, 1987</td>
<td>Unimanual—when another pattern is embedded</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Multiple requirement task</td>
<td>Nicolson &amp; Fawcett, 1990</td>
<td>Walking on a beam plus counting</td>
<td></td>
<td>Yes—May indicate difficulty in automatizing skills</td>
</tr>
</tbody>
</table>

*Significant differences favoring average readers.
In the motoric area, drawing on a long history of work on motoric problems in dyslexia (Klippka, Wolff, & Drake, 1981; Wolff et al., 1990a, 1990b, 1990c), Wolff (1993) asserted that motoric problems emerge in dyslexic readers when they are required to "assemble component units of behavior into temporally ordered larger ensembles" (p. 101). It would appear, therefore, that across both sensory and motor domains, processing-speed differences are found between reader groups, but not at the level of basic reaction time. The elements of choice and precise, temporal coordination—both of which contribute to the system's cognitive "load" (J. Holmes Bernstein, personal communication, June 1997)—appear necessary for the timing deficits to be evidenced.

The second, related point involves the combination of seriation and speed, particularly in the visual and auditory domains. As shown in Tables 2 and 3, when stimuli are presented at relatively longer intervals, differences between dyslexic and average readers do not appear; rather, they appear when faster levels of speed and serial requirements occur. Thus, it would appear that the requirements of rapidity and seriation present dyslexic readers with special difficulty. Both of these requirements are essential aspects of naming-speed tasks. (Note that Schwartz & Rengan, 1996, reached a similar conclusion for children with receptive language problems.)

Neurophysiological Evidence. Several bodies of research, some at the cellular level, have suggested specific cortical and subcortical mechanisms that may underlie the varied perceptual and motoric findings. In addition to the previously discussed magnocellular anomalies in the lateral geniculate nucleus (LGN), Galaburda and his colleagues have found similar magnocellular anomalies in the medial geniculate nucleus (MGN), the thalamic area responsible for coordinating auditory information (Galaburda, Menard, & Rosen, 1994). Because the MGN magnocellular pathways are intrinsically involved in the speed with which auditory information is processed, aberrant development in these auditory areas could affect a child's early ability to discriminate individual phonemes and to develop good quality phonemic representations. This, in turn, would potentially disrupt the development of various phonological processes, a position incorporated in the research of Merzenich, Tallal, and their colleagues with children with language impairments (Merzenich et al., 1996; Tallal et al., 1996). The directionality of the effects of cortical–subcortical anomalies, however, is not straightforward. Animal models of induced cortical pathology indicate that changes in the behavioral speed of auditory processing can have subcortical effects on underlying thalamic nuclei (see Herman, Galaburda, Fitch, Carter, & Rosen, 1997; and Sherman, reported in Galaburda, 1996).

In their studies of motoric timing differences, Wolff and his colleagues (Waber, 1999; Wolff, 1993; Wolff et al., 1990a, 1990b, 1990c) found that dyslexic readers are also affected by increased rate requirements, but particularly under certain conditions (e.g., alternating hand conditions that require bimanual input). Wolff et al. (1990c) included differences in the rate of interhemispheric transfer as one possible, more general explanation for their findings. In a recent MRI study of a small sample of dyslexic readers, Hynd et al. (1995) noted some morphological differences in the anterior and posterior regions of the corpus callosum, areas that would affect how rapidly the two hemispheres transfer information between homologous regions necessary for reading. Hynd et al. (Hynd et al., 1995; Hynd & Semrud-Clikeman, 1989; Hynd, Semrud-Clikeman, Lorys, Novey, & Eliopoulos, 1990) connected their MRI findings to previously demonstrated cellular level anomalies in the frontal areas of people with dyslexia (Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985; see Note 2).

There has been increased attention to the nature of timing in human behavior (see Rosenbaum & Collyer, 1998). Three major types of explanations for timing are frequently discussed (Cohen, 1999):

1. a central time-keeping mechanism;
2. multiple reference systems;
3. no mechanisms or systems, but rather the product of sequencing and memory processes.

With the first view, one central question is whether specific cortical or subcortical areas function as an oscillator-clock controlling the rate of oscillation in various processes. A precursor of this view is found in earlier work by Ojemann (1983, 1984). After demonstrating that naming, reading, and sequential, orofacial movements are all disturbed when the same anterior frontal lobe areas are blocked by electrical stimulation, Ojemann argued that the mechanism common to these particular language and motor functions might be a precise timing mechanism critical to both decoding and language production. Attempting to understand possible connections among naming, reading, and motoric problems, Wolf (1991) used work by Ojemann (1983, 1984) and by Tzeng and Wang (1984) to argue for the existence of a common precise timing mechanism employed in some linguistic, perceptual, and motor functions. In this earlier work, Wolf posited that a breakdown within such a mechanism could help explain both the breadth of timing deficits noted among dyslexic readers and one possible source of the connections between naming speed and reading breakdown.

Another example of a more central time-keeping explanation for perceptual, linguistic, and motoric timing deficits in dyslexic readers is from the work of Llinas (1993, 1996). Llinas (1993) conceptualized dyslexia as a syndrome in which the disruption of temporal processes may underlie reading failure. Briefly, Llinas speculated that the intralaminar nucleus in the thalamus may function as a timing mechanism that coordinates the rate of oscillation in various sensory and motoric regions. If Llinas' hypothesis...
about the role of the intralaminar nucleus in timing is to be evaluated, one future direction in dyslexia research would be cytoarchitectonic investigations in this area of the thalamus, similar to previous work with the lateral and medial geniculate nuclei.

There is to date no resolution concerning what causes or connects the observed timing deficits across various linguistic, perceptual, and motoric domains. Wolf’s earlier hypothesis about the role of a precise timing mechanism in reading failure (Wolf, 1991) and Llinas’ hypothesis about the time-governing role of the intralaminar nucleus are examples of more unified oscillator–clock explanations for timing disruptions in some dyslexic readers. Researchers like Denckla (1998) and Wolff (1993) have eschewed the possibility of any single mechanism capable of explaining all the deficits noted. Recent work by Wood (personal communication, February 7, 2000) and Ivry and his colleagues (Mangels & Ivry, 1999) has suggested explanations that invoke multiple reference systems; for example, findings by Mangels and Ivry indicate that multiple pathways involving the cerebellum, prefrontal cortex, and thalamic areas are involved in various aspects of timing.

Another possible example of the effects of multiple reference systems involves a scenario where there are basic, simultaneous problems in the speed and quality of both visual and auditory information, as would be the case if both indicated subcortical areas (LGN and MGN) are poorly developed (Galaburda et al., 1994) or too slowly coordinated in time (Llinas, 1993, 1996). Although either of these failures to build high-quality visual and auditory representations would impede word identification and word attack skills, the combination of both would cripple the system by permitting no compensatory routes from the other system. The most intractable forms of reading disability, such as those seen in the double-deficit subtype, fit such a description and could be explained by either multiple system or central time-keeping explanations.

**Developmental Data.** A related set of scenarios about explanations for timing has been discussed by Kail and Hall with an emphasis on naming speed (Hale, 1990; Kail, 1991; Kail & Hall, 1994). They posited that there can be at least three possible sources for differences in the normal development of processing rates: a global speed-of-processing factor that affects all components; a local trends factor that is localized to particular components; and a task–strategy factor (e.g., the rate for the letter- and number-naming tasks will always be faster than the rate for color- or object-naming tasks, due to the automatized properties inherent in alphanumeric stimuli). Kail and Hall (1994) provided evidence for a more general or global processing-speed factor that underlies naming-speed changes in average-reading children and that is connected to the speed of word recognition in reading.

It remains, however, unknown whether differences in naming speed among dyslexic readers can be ascribed to global, task–strategic, or local factors. The cumulative timing deficits covered by Hypothesis 2 cross domains and point toward the breakdown either of multiple systems or of a more global processing factor, at least in many of the most impaired readers. The presence of single naming-speed deficits in some readers with disabilities, however, points to the possibility of a more local rate factor (e.g., in an individual, underlying component-like visual processing of letters).

Marcus (1997) in our lab conducted a replication of Kail and Hall’s (1994) work and investigated some of these complex issues in subgroups of impaired readers whose reading level was discrepant or nondiscrepant with general cognitive ability. Preliminary results indicated that timed visual perceptual tasks (i.e., the visual matching and cross-out tasks used by Kail and Hall) correlated with all naming-speed measures, word identification, and comprehension in the .50 to .91 range in children whose poor reading was discrepant with their high intellectual potential. None of the timed tasks, however, correlated even moderately with word attack or phonological blending, and the significant correlations between the timed tasks and reading measures were not found for nondiscrepant readers (see earlier similar findings under Question 1). The small sample sizes in this study prevent generalization, but point to the importance of examining the roles of both general and specific processing speeds’ contributions to reading failure in various reader subgroups (see new work by Kail, Hall, & Caskey, 1997). The more precise specification of what constitute the underlying components of naming speed and how disruption of each component in naming might affect specific reading skills is one of the most important future directions in this line of research (see ongoing work by Cutting, Carlisle, & Denckla, 1998; Marcus, 1997; Scarborough & Domgaard, 1998; also Manis & Seidenberg, personal communication, July, 1997).

In brief, far more evidence is needed before any conclusions can be drawn about whether naming-speed deficits reflect a more systematic failure in timing processes. Our own current emphasis has been on the multiple sources of breakdown in naming speed and reading that are possible in different readers (see also Denckla, 1998). The possibility of multiple sources, however, does not exclude the possibility that one source in some dyslexic readers could be found in an area that functions as a more central time-keeping mechanism for some perceptual and motoric areas. In addition to the need for further work on the underlying neurological explanations of naming-speed deficits, future investigations are critical to understand whether the range of naming-speed and timing deficits documented in Tables 2 through 4 across different samples can be demonstrated within the same sample of severely impaired read-
The Possible Relationships of Naming Speed to Reading Failure

There are many missing pieces in the conceptualizations concerning the variety of paths whereby deficits in naming speed could result. As noted frequently here, the direct implication of a multicomponential view of naming speed is that multiple sources of its breakdown are possible. Hypothesis 1 emphasized what occurs when the underlying rate of processing in visual areas is disrupted and argued that the effects of this disruption on forming orthographic representations are important in fluency and comprehension. In our second hypothesis, we examine the possible effects of broader, more generalized disruption in multiple processes with processing-speed requirements. In this second hypothesis, the extent to which any individual process is disrupted by processing-speed deficits is hypothesized to be dependent on the specific requirements for rapidity within that process or set of processes. For example, the same underlying source of processing-speed problems might dramatically compromise lower level visual and auditory components (that need to operate within a very narrow time window) but less obviously compromise articulatory processes, because of the larger time window employed in articulation processes.

Combining the multicomponential depiction of naming in the third section with the notion of more systemic or multiple timing deficits in dyslexic readers, an alternative account of naming speed’s relationship to reading failure emerges in Hypothesis 2. Within this hypothesized set of events, naming speed is conceptualized as a multicomponential process that is itself a mid-level subset of deficits within a cascading system of malfunctioning timing effects. In other words, if there are more general timing problems, naming speed could represent at once both the combined effects of slowed, lower level visual, auditory, conceptual, and motoric processes (any one combination of which may slow it) and a cause itself of further disruption of fluent reading. The causal effect is based on the working assumption that slower access to lexical and sublexical information may impede the development of fluency in reading, which, in turn, impedes comprehension (see model of these influences in Marcus, 1997).

To summarize Questions 4 and 5, these sections begin and end in speculation, evolving knowledge, and an intense need for further study. Our hypotheses are set within this context and within a broader context for looking at multiple etiologies of reading disability, discussed earlier by Wolf (1991). In this account, disruption in reading or naming speed can be caused by:

1. breakdown in any one specific component (e.g., phonological processing);
2. failure to integrate information across subprocesses; and
3. rate deficits either in a single component (Hypothesis 1) or across multiple components (Hypothesis 2).

The first hypothesis emphasizes the connections between processes underlying naming speed and automatic orthographic pattern recognition in word identification. In the second hypothesis, naming-speed deficits represent the potential linguistic manifestation of a broader, more extensive set of timing problems, with ramifications for word attack, word identification, and comprehension. These hypotheses are nonexclusive and, indeed, in conjunction with the better understood phonological deficit hypotheses, could help explain more of the heterogeneity of reading disabilities than currently possible. For example, single naming-speed deficit readers, who remain the least understood, may best be described by Hypothesis 1 or a variation of it; single phonological deficit readers would be aptly described by current phonological core deficit theories; and many double-deficit readers could be characterized by Hypothesis 2 or by a combination of these explanations.

Question 6

What are the implications from this research for diagnosis and clinical and educational practice? The first major implication of the double-deficit hypothesis for diagnosis is that naming-speed measures should be added regularly to kindergarten and first-grade screening batteries. Their inclusion will aid the early identification process, particularly of the children whose decoding problems are apparently minor but whose naming-speed problems presage later delays in fluent reading and sometimes in reading comprehension. Biddle (1996) demonstrated that it is essential to test in both kindergarten and first grade because of the large variability in young readers before automaticity for symbol recognition is complete (see Note 1).

There are two other advantages regarding the inclusion of serial naming tests in predictive and diagnostic batteries. As demonstrated in a reading prediction study by Hurford et al. (1994), phonological awareness tasks do not consistently predict later reading as sufficiently as expected. Catts (1996) and Torgesen, Wagner, and their colleagues (Wagner et al., 1994) have convincingly demonstrated that the combination of serial naming tests with phonological awareness measures provides the strongest prediction
capabilities to date. Another advantage is purely pragmatic. The administration of the typical RAN and rapid alternating stimulus (RAS) tasks for letters, numbers, colors, and common objects (see Wolf, 1986) takes 5 to 8 minutes in total. The tests are simply constructed (see Wolf et al., 1986), quickly administered, and easily performed by most children.

An implication for clinical practice is that naming-speed measures make an important contribution to a wide variety of diagnostic batteries, well beyond reading prediction. This information is particularly relevant for poor readers or other children with learning disabilities who appear in the normal range for most phonological and decoding skills (see Blachman, 1994; Felton, 1993). Slow performances on continuous naming tasks can prompt a more in-depth examination of the underlying factors that may affect fluent reading.

**Question 7**

What are the implications of the double-deficit hypothesis for educational intervention? As mentioned in the introductory article, if the principal assumptions of the double-deficit hypothesis are correct, two important subgroups of impaired readers receive insufficient attention to skills involved in the development of fluency and automaticity in word recognition. Although Lovett, Steinbach, and Frijters (in this issue) clearly demonstrate that treatment for children with naming-speed deficits and double deficits should certainly include the phonemic awareness and phonological decoding training currently prescribed, intervention should also include explicit training toward establishing the automaticity of these skills. Furthermore, compared to children with single phonemic deficits, children with double deficits may well require extraordinary amounts of practice in reading and rereading text (Bowers & Kennedy, 1993; Young, Bowers, & MacKinnon, 1996). We have hypothesized that some of the treatment-resistant groups described by Torgesen et al. (1994) in their phonological awareness–based treatments may be composed of children who fall into either the single naming-speed deficit subgroup or the double deficit subgroup.

Lovett, Steinbach, and Frijters (in this issue) have made the first critical foray into investigations in this area by retrospectively subtyping participants in their intervention studies and examining the preferential response of these groups to their well-established, theoretically motivated phonological and metacognitive treatment programs. It is essential to note that all subtypes made substantial gains on phonological measures and word identification accuracy with their programs. The naming-speed deficit subtype showed no changes in RAN naming speed, but did improve in latencies for keywords. The phonological deficit group made most gains in nonword reading tasks. These are the first retrospective treatment data supporting some of the basic assumptions of the double-deficit hypothesis within existing phonological programs. However, as pointed out by Lovett et al., only when we have programs specifically addressing increased fluency in word recognition processes will we be able to test the utility of this hypothesis with regard to treatment response.

An ongoing NICHD research project by Morris, Lovett, and Wolf (1995) is directly investigating, among other goals, the preferential treatment response of double-deficit hypothesis subtypes to Lovett et al.’s (in this issue) phonological and metacognitive programs and to a new curriculum explicitly designed to address issues of rate and automaticity. Small groups of randomly assigned children are given an intensive pull-out intervention based on one of three different treatment packages or a control (math and study skills) program. A phonological base is essential to each treatment package. Thus, the first half of each package includes the systematic phonological analysis and blending (PHAB) program, used by Lovett et al. and shown to have strong generalization and transfer effects (Lovett et al., 1994). The PHAB program is based on the SRA Reading Mastery Fast Cycle program (Engelmann & Bruner, 1988). The second half of each treatment represents one of three approaches:

1. a control, study skills program that would allow phonological-treatment-only comparisons;
2. a metacognitive strategy program (adapted by Lovett from parts of the Benchmark School program; see Gaskins, Downer, & Gaskins, 1986); and
3. the RAVE-O (Retrieval, Automaticity, Vocabulary Elaboration, Orthography) curriculum designed by Wolf and her colleagues (Wolf, Miller, & Donnelly, in this issue).

The combined emphases of the RAVE-O program embody the philosophical principles of a connectionist approach to reading (see Adams, 1990; Foorman, 1994)—that is, that skillful word reading is the consequence of the rapid, "coordinated and highly interactive processing of the orthography of words, their meanings and pronunciations" (Adams, 1990, p. 107). As conceptualized here, the RAVE-O program represents the first comprehensive approach to fluency in outcome reading behaviors (i.e., word attack, word identification, and comprehension) and to automaticity in underlying component processes (e.g., visual and auditory discrimination, orthographic pattern recognition, vocabulary development, and lexical retrieval; see a review of fluency-related programs in Meyer & Felton, 1998). RAVE-O is the first of a series of efforts to address the implications of the double-deficit hypothesis—with its explicit emphasis on automaticity and fluency—in classroom intervention.
Summary

The research summarized in this article and special issue represents a shift in perspective from the direction of reading disabilities research over the last decade and a half. The double-deficit hypothesis represents an evolving conceptualization of reading disabilities that integrates previous work on phonological deficits with research on naming-speed deficits. The view that phonological processing deficits lie at the core of reading failure has been extended to incorporate a second major core deficit in the processes underlying naming speed. Three subtypes of impaired readers are presently categorized under this hypothesis, characterized, respectively, by phonological deficits, naming-speed deficits, and a combination of both. A range of evidence in several languages demonstrates that children with double deficits represent the most serious forms of reading disability.

Although naming-speed processes clearly include aspects of phonological processing, they are not reducible to a subset of phonological processes. Rather, naming speed is conceptualized as a complex ensemble of attentional, perceptual, conceptual, memory, phonological, semantic, and motoric subprocesses that have precise, rapid timing requirements within and across all components. The structural complexity of the naming-speed processes was the basis for two nonexclusive hypotheses about the nature of the link between naming speed and reading. The first hypothesis emphasized the connections among processes underlying naming speed, automatic orthographic pattern recognition, word identification, and reading fluency. The second hypothesis explored the possibility of multiple or domain-general timing problems and their effects on naming speed and reading failure.

In summary, the authors of this special issue believe that a more refined understanding of the unique and combined contributions of both phonological and naming-speed processes will prove essential for an ultimately more differentiated view of reading failure and, very important, a more comprehensive approach to reading intervention. It is, in fact, the implications for diagnosis and intervention that have propelled this change in our perspective and that demand our best efforts in future research.

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NOTES

1. Beyond the scope of this article are critical discussions about the nature of automaticity (see Logan, 1988; Stanovich, 1990; Wolf, 1991) and about comparisons between alphanumeric (letters and numbers) stimuli that achieve more automatic-like rates than colors or objects across all populations studied (see Wolf, 1991; Wolf et al., 1986). Also of importance in this discussion is the role of experience and familiarity. Clearly, some children whose environments provided them with less exposure to symbolic stimuli than other children will achieve automatic rates at later ages for reasons other than those described here for dyslexic readers (Sankaranarayanan, personal communication, May 1997).

2. It is important to note that individuals with dyslexia traditionally perform poorly on frontal lobe tests and that RAN tasks are increasingly categorized in neuropsychological batteries as frontal lobe tests. A promising direction in future imaging and evoked potential studies would be to explore the connections between naming speed and other timed tasks and areas of morphological differences in people with dyslexia, particularly in frontal and prefrontal regions (see Galaburda, 1996).

REFERENCES


