

Current Status of Treatments for Dyslexia: Critical Review

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ABSTRACT

The acquisition of reading is a complex neurobiologic process. Identifying the most effective instruction and remedial intervention methods for children at risk of developing reading problems and for those who are already struggling is equally complex. This article aims to provide the clinician with a review of more current findings on the prevention and remediation of reading problems in children, along with an approach to considering the diagnosis and treatment of a child with dyslexia. The first part of the review describes interventions targeted at preventing reading difficulties in the at-risk younger child. The second part of the review discusses the efficacy of approaches to treat the older, reading-disabled child (“intervention studies”). Factors that impact the response to treatment are also discussed, as are neuroimaging studies that offer insight into how the brain responds to treatment interventions. With appropriate instruction, at-risk readers can become both accurate and fluent readers. In contrast, although intensive, evidence-based remedial interventions can markedly improve reading accuracy in older, reading-disabled children, they have been significantly less effective in closing the fluency gap. Owing to the dynamic course of language development and the changes in language demands over time, even after a child has demonstrated a substantial response to treatment interventions, his or her subsequent progress should be carefully tracked to ensure optimal progress toward the development of functional reading and written language skills. (*J Child Neurol* 2004;19:744–758).

Over the last 15 to 20 years, there has been a great deal of research focused on finding the most effective methods for treating reading disability (dyslexia). We have had the opportunity to evaluate not only the effect of specific interventions on reading skill but also to devise technologies that make it possible to study the way in which the brain responds to these interventions. This body of knowledge is complex, in part because although all individuals with dyslexia have a similar problem, namely, difficulty reading, they have heterogeneous characteristics, and depending on the child's developmental level, the demands of reading and the required skills are quite different. As Torgesen pointed out, even the definition of a good reader varies: Is it being able to orally decode accurately and fluently? Is it simply being able to get the gist of what is read? Or is it being able to analyze, synthesize, and convert information from multiple sources into a meaningful whole?¹ Torgesen noted that all of these factors have contributed to the challenge of designing intervention studies, interpreting the outcomes of treatment, and answering the following crucial questions:

1. What types of prevention or intervention treatment will be most effective? The answer depends on what children need to know to read at a given grade level and the reading level expected for their developmental stage (eg, mechanics of word reading, fluency, or text reading and comprehension of reading).
2. What level of intensity is most effective? There are two types of intensity: one referring to the frequency of the intervention (daily, two to three times per week, once per week) and the other referring to the instructor to student ratio (1:1, small group, classroom).
3. How many hours are needed to complete the intervention? What is the optimal duration of treatment?
4. How well are gains and skills maintained after the intervention has ended?
5. What therapist or teacher skills are needed?
6. What child characteristics contribute to the success or failure of the intervention (type of language involvement, severity, age, and comorbidity)?
7. In what educational context can these interventions be implemented?

To address some of these questions, the National Research Council, the research arm of the National Academy of Science, published a report in 1998 summarizing available research findings that could be used to prevent reading difficulties in young children.² The report emphasized the importance of early childhood language and literacy experience as the foundation on which systematic phonologic decoding should be taught. To explore how reading research could be more specifically applied to classroom implementation, the National Institute for Child Health and Human Development

and the Department of Education convened the National Reading Panel to conduct a meta-analysis of reading research since 1990 in the areas of alphabets, fluency, comprehension, teacher education, and the effects of computer technology. Only studies meeting rigorous research methodologic criteria were analyzed. Although much of the research in the field did not meet these criteria, and in some instances there were too few studies to conduct a meta-analysis, the National Reading Panel did find robust evidence in the areas of alphabets (phonologic awareness, reading and spelling skills).³

Specifically, direct and systematic phonologic awareness and phonics instruction produced significant effects for at-risk readers (ie, young children in kindergarten or first grade who have had minimal exposure to reading and are deficient in phonologic awareness and letter knowledge—precursors for the acquisition of phonologic decoding), as well as disabled readers (those who have had exposure to adequate reading instruction and have not learned to read). The panel noted that there were differences in the type of instruction and the response of these two groups of children to instruction:

One type of instruction involved the prevention of reading disability in the young, at-risk child:

1. The younger the child (kindergarten through first grade), the better the outcome.
2. The at-risk child responds best to small-group instruction (2:1 or 3:1), with phonologic awareness training being combined with letter knowledge and explicit phonics instruction.
3. Trained teachers achieved good results.
4. More frequent instruction (4–5 days/week) was more effective.
5. Gains were maintained in most of the children at long-term follow-up.
6. The following characteristics of the child were associated with poor outcome in reading and spelling: poor rapid naming, poor verbal ability, and attention or behavior overall. Low socioeconomic status was also associated with poor spelling achievement. Computer programs were helpful aids.

The second type of instruction, remediation, was directed at the older, reading-disabled child (second to sixth grade):

1. Although the older, reading-disabled children responded with improved word reading to similar intensive, direct, and explicit instruction, they were less responsive, and gains were not as marked.
2. They did better with one-to-one or small-group instruction.
3. More intensive work for a longer duration was required.
4. Spelling and fluency did not respond well, but there was some improvement in reading comprehension.
5. Gains were maintained in most children at follow-up.
6. Characteristics that impeded reading and spelling gains included poor attention and behavior control, rapid naming deficits, and weak verbal ability. Low socioeconomic status affected reading gains; trained teachers achieved good results, but they were typically not as robust as the results when working with researchers. Computer instruction served as an effective aid but was not effective by itself.

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The skills needed for normal reading development were found to encompass five essential domains:

1. Phonemic awareness: awareness of the sound structure of spoken language and the basic units of speech (phonemes)
2. Phonics: knowledge of relationships between letters and sounds and spelling-sound correspondences; allows fluent phonologic decoding
3. Sight word acquisition: automaticity of reading words by sight without having to decode sound by sound; leads to orthographic decoding fluency
4. Vocabulary: the storage of word meanings and the ability to fluently access that information
5. Comprehension of text: the ability to think about and extract the information provided in text while reading, a fluent integration of multiple processes.

Although the National Reading Panel's review of the research literature answered some of the questions about word reading instruction, there were not enough data to draw firm conclusions about the best way to teach fluency, vocabulary, and text comprehension or to train teachers, illustrating the need for more stringent research in the field. Nonetheless, preliminary findings suggested that:

1. Fluency is better achieved by repeated guided oral reading than by silent reading practice.
2. Vocabulary instruction should be taught by both direct and indirect methods, with computer programs as adjuncts.
3. Comprehension is developed by fluent word reading, vocabulary strength, and a combination of strategies for helping the child connect with and think about the text.

The most rigorous methodologic studies resulted in very robust effect sizes for reading gains; however, even the studies with the weakest methodology also yielded significant gains in phonologic awareness. With the impetus to improve the quality of the experimental studies to arrive at more definitive answers to our questions, research has continued to advance our understanding of how children develop skilled reading and to learn more about the factors that hinder that development.⁴ More recent findings are summarized below.

CURRENT RESEARCH

This article focuses on research studies that compare treatment efficacy for prevention (ie, working with young children who are "at risk") and the efficacy of various approaches to remediation (ie, treating older children who have already been identified as reading disabled). Pre- and post-treatment functional brain imaging studies have been conducted in some of these studies, and these are discussed. Behavioral studies in combination with neuroimaging studies allow us to develop an understanding of the neurobiologic correlates of behavioral responses to treatment. Finally, development of computational models, computer simulations of how reading is acquired, has not only provided additional insight into the process of reading acquisition but has also offered explanations for specific intervention outcomes.⁴

Prevention Studies

Torgesen, in an overview of research on the effectiveness of interventions with at-risk children, in the classroom and with small groups, noted that two programs providing relatively direct, systematic instruction in phonemic decoding skills, "Direct Instruction" and "Success for All," were effective for this at-risk group but not for already impaired readers.¹ Tunmer and Chapman conducted a longitudinal study using the Reading Recovery Method, which has been a popular early intervention program in the schools.^{5,6} It offers one-to-one, daily, pull-out tutoring for 12 to 20 weeks for 6-year-old children performing at or below the 30th percentile in reading. Although it has been reported to be helpful for struggling readers, its effectiveness has not been documented by rigorous research. Tunmer and Chapman found that 30% of the children were referred out of the program because they were not responding.⁵ These children were found to have significant phonologic deficits, which probably accounts in part for their lack of response. When the children who did show a good response to the intervention at the end of the treatment were tested 1 year later, their performance was no better than that of the controls. These findings indicate that intensive treatment alone is not enough; despite one-to-one instruction, the at-risk children did not respond as well as those receiving appropriate classroom intervention. This study illustrates that the content or method of intervention is itself a critical factor in treatment efficacy. The Reading Recovery Method is a top-down, more whole-language approach using semantic or syntactic clues for word reading and does not contain the explicit phonics or phonologic awareness instruction needed by these younger at-risk children.

Denton and Mathes reported the effectiveness of four primary classroom treatment projects that followed the National Reading Panel recommendations.⁷ The study targeted at-risk children who fell between the 18th and 25th percentiles in phonologic and letter knowledge skills. After intervention, 18 to 31% of the children still had not reached the benchmark of the 30th percentile for word-level reading and would require a higher level of intervention. Denton and Mathes also evaluated the effectiveness of five interventions that involved a more intensive approach (one to one, small group with more hours of instruction) with students who were more impaired (12–18th percentile). They found that 4 to 30% remained below the 30th percentile benchmark after this treatment. On extrapolating their findings to the general population for both groups, they noted that only 0.7 to 4.5% of the more severely impaired group and 5 to 6% of the mild to moderately impaired group remained in the impaired range, a significant difference from the 15 to 20% rate currently reported. Both types of intervention yielded significant results, with the more intensive administration moving even the more severely at-risk children into the average range.

Torgesen and colleagues conducted a study of kindergartners who were severely at risk (10th percentile for prereading skills).⁸ The study compared the effect of three types of intensive interventions that were delivered: one on one, 20 minutes/day, and 4 days/week through the end of second grade. There was also a no-treatment control group. The interventions were (1) a regular classroom reading curriculum, which was more whole language in nature; (2) embedded phonics training, which provided

more implicit, nonsequential phonics instruction when the opportunity presented itself in text; text reading and writing instruction were the predominant component; and (3) an explicit, sequential direct teaching of phonemic awareness using a multisensory approach, which brought in the motor perception of speech sounds (the Lindamood Auditory Discrimination in Depth program)⁹ to facilitate the development of fine-grained phonemic representations. Decoding and encoding of words with direct phonics instruction comprised most of the instruction, with little emphasis on text reading. This approach was a predominantly bottom-up, sensory approach for the development of more distinct phoneme representations, in contrast to the more top-down orthographic-semantic approach of the other interventions. It also offered more explicit phonics instruction.

The bottom-up, sensory, more explicit approach was significantly superior to all of the other groups at the end of the intervention period. The more top-down interventions resulted in outcomes similar to those of the no-treatment controls. Long-term follow-up revealed that the more explicitly trained group (those receiving the Lindamood Auditory Discrimination in Depth program) was performing solidly in the average range for accuracy and fluency at the end of the fourth grade. These findings suggest that these young, impaired children required much more salient intervention to improve their phoneme maps, combined with explicit instruction for letter and sound mapping. The more implicit phonics approach that taught phonics rules was ineffective. Perhaps this was due to the more abstract, top-down nature of teaching the phonics rules, without establishing fine-grained phonemic representations. With deficient phonologic processing, less explicit instruction would place greater demands on executive function. Because neither executive function nor abstract thinking ability is fully developed at this younger age, a more concrete intervention program would be expected to be most effective for the struggling reader.

Denton and Mathes also addressed the question of which criteria are most useful for predicting success with future reading acquisition following early intervention.⁷ They found that fluency (or words read per minute) was more significantly related to future outcome than other reading measures, and the rate of response to intervention was also a predictor of future reading development—the slower the learning curve, the more difficult it was for the child to become an adequate reader.

Vellutino and colleagues also found the rate of response to treatment to be a significant predictor of outcome. Their 6-year longitudinal study of at-risk first-graders revealed that the children in the “limited response to intervention” group (treatment resisters) differed from the children who were readily remediable.¹⁰ Although all of the subjects had significant difficulty with phonologic skills such as phoneme awareness and with letter and number naming, there were differences between the readily remediated readers and the most difficult-to-remediate readers in their cognitive and language-based abilities: rapid naming, confrontational naming, verbal working memory (syntactic word order, nonword repetition), short-term verbal memory (digit span), and articulation speed. The readily remediated group performed more like the normal reading group on these measures. These children were more likely to have had limitations in their early language experiences and/or instruction. Thus, although all of the children had phonologically

based deficits, there were two different types of deficient phonologic sensitivity. One group lacked the environmental exposure necessary for the development of a strong phonologic system (an “experiential reading disability”); the other group of children had been exposed to appropriate environmental stimulation but had atypical development of the neural systems underlying phonologic sensitivity (characteristic of the typical individual with dyslexia). With the appropriate input, the former group could develop the brain maps of the normal reader. The cognitive and linguistic deficits of the individual with dyslexia suggest a more pervasive difficulty, which is constitutional in nature and presents a distinct therapeutic challenge.

Intervention Studies

Intervention studies have demonstrated that intensive (daily, one on one, and small group), phonologically based treatments can close the gap for reading accuracy, even in those children falling as low as the 2nd percentile in word-level reading skills. In his intervention study, Torgesen and colleagues contrasted the two treatment approaches described in the prevention study above: (1) a multisensory, bottom-up, explicit approach for developing phonemic awareness and phonemic decoding and encoding skills with minimal text instruction (the Lindamood program, described above) and (2) the embedded phonics instruction approach in which only 20% of the time was spent on single-word phonemic decoding activities and the rest on text reading and sight word training.^{9,11,12} The children were 8 to 11 years old and fell in the 2nd percentile for word-level reading ability and the 10th percentile on a broad reading measure, combining word reading with comprehension (Broad Reading Score, Woodcock Johnson Tests of Achievement, Revised).¹³ Intensive remediation was delivered on a one-to-one basis, 5 days a week for 100 minutes a day for 8 weeks, and the children then returned to their special education classrooms.

Figure 1 provides a snapshot of the findings. The growth of the children’s reading skills in both conditions was measured on a broad measure combining word reading accuracy and passage comprehension into a single standard score (mean 100, SD 15; thus, a value from 85 to 115 is in the average range).

For the 16 months before the intervention, the children were in special education classes, where the instruction maintained their level but did not close the gap. The intensive intervention produced a steep rate of reading growth, regardless of the intervention, and gains continued over the 2 years, with the children reaching mean standard scores above 90, approximately the 30th percentile, which was also their mean Wechsler Verbal IQ. Even the children with the lowest verbal short-term memory (standard score 70–85) as measured by the Digit Span subtest of the Wechsler Intelligence Scale for Children-Revised (WISC-R)¹⁴ made gains in phonemic decoding similar to those of the group as a whole (mean standard score 70.2 to 93.5). At follow-up, 40% of the children had been staffed out of the special education classrooms, a considerably higher percentage than the county’s record of less than 5%.

Whereas almost all of the children made significant gains during the intervention period, only a little more than half sustained or increased their gains during follow-up. Furthermore, about a fourth of the children lost most of the gains made during the intervention during the 2-year follow-up period. The variables predict-

GROWTH IN TOTAL READING SKILL BEFORE, DURING, AND FOLLOWING INTENSIVE INTERVENTION

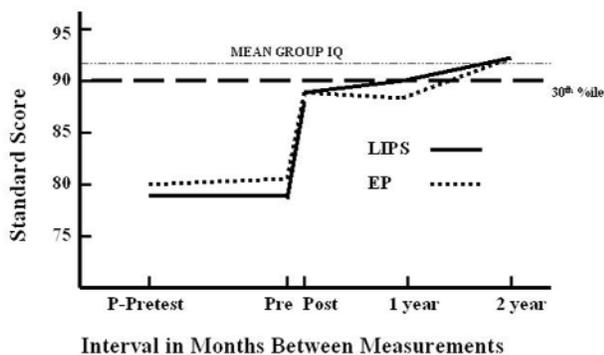


Figure 1. Treatment effects: broad reading skill measures (Woodcock Johnson Test of Achievement, Third Edition, standard score mean 100, $SD \pm 15$) before 16 months of special education (P-Pretest), before 9 weeks of intensive remediation (Pre), immediately after 9 weeks of remediation (Post), and at 1- and 2-year follow-up. The dotted horizontal line represents the group mean IQ. EP = embedded phonics; LIPS = Lindamood Phoneme Sequencing.

ing growth during the follow-up were attention, receptive language ability, and socioeconomic status. Of note, the more implicit top-down approach was as effective as the multisensory bottom-up approach, suggesting that the children could harness the phonics rules despite having weak phonologic representations. This would suggest that they now had the executive function and abstract thinking abilities to compensate.

Unfortunately, the fluency gap could not be narrowed with this intensive intervention, and the children remained severely impaired in reading rate (2nd percentile). To explore this further, Torgesen and colleagues conducted small-group intervention studies with older (11–12 years) reading-disabled children.¹⁵ All children were severely impaired in word reading fluency (2nd percentile), but one group was mildly impaired (30th percentile) and the other moderately impaired (10th percentile) for word reading skills. The intervention used the Spell, Read Phonological Auditory Training,¹⁶ which provided systematic instruction in phonemic awareness and phonemic decoding combined with fluency-oriented practice from the start. The mildly impaired group evidenced significant gains in both accuracy and fluency, with fluency improving from the 2nd percentile to approximately the 50th percentile after only 60 hours of treatment. The moderately impaired readers were further subdivided into two groups, which received different durations of treatment. One group received 50 hours of treatment, and the other received 100 hours. Although the gains in text reading accuracy and fluency on the Gray Oral Reading Test, Third Edition,¹⁷ were significant in both groups, the longer instruction period produced greater gains in accuracy (19 vs 8 standard score point improvement) and fluency. The group exposed to the longer duration of treatment improved in fluency from a mean standard score of 65 to 79 (14 standard score points—nearly 1 SD), whereas the group exposed to a shorter duration of treatment showed a 9 standard score point improvement (68 to 78). Clearly, fluency remained a significant problem for both groups.

Figure 2 illustrates the results from the prevention study of the young at-risk children as well as the remediation study of the older, reading-disabled children.¹⁵ Treatment of the young at-risk children in the prevention study resulted in normal accuracy and fluency at the end of fourth grade, emphasizing the importance of early identification and treatment.⁸ Although the mildly impaired readers (30th percentile) experienced very significant growth after treatment, they still evidenced a gap between accuracy and fluency. The more severely impaired readers (10th percentile) made significant gains in accuracy but remained impaired in fluency. The longer duration of treatment in the moderately impaired readers resulted in more gains but was still inadequate. The most severely impaired (2nd percentile) readers from Torgesen et al's intervention study also made significant gains in accuracy but no gains in fluency.¹¹

Torgesen and colleagues conducted a subsequent intervention study with two groups of severely impaired (2nd percentile) 9- to 11-year-old children using two interventions: (1) the Lindamood Phoneme Sequencing program¹² for 67.5 hours, followed by 67.5 hours of fluency instruction (repeated reading and word drills) and comprehension instruction, and (2) an accuracy-only group, which received only the Lindamood Phoneme Sequencing instruction, with equal time in comprehension instruction.¹⁵ Preliminary findings based on 45 of the 60 children who finished the study reveal similar accuracy and fluency outcomes for both groups, with significant gains in accuracy but none in fluency. Neither fluency instruction nor a longer duration could close the gap.

The studies by Torgesen et al support the need for early intervention for the development of fluent word reading. Torgesen proposed that because the acquisition of sight words occurs with repeated exposure to words in print, individuals with dyslexia do not read, and the fluency gap widens.¹ Those older children who are remediated and acquire the phonologic decoding ability for accurate reading would have to read more than other children to close the sight word gap. Other factors contributing to poor automatic word reading and text reading fluency can be child characteristics such as rapid naming, attention deficit, executive function deficits, or receptive language ability. In their 2001 study, Torgesen et al found that attention, receptive language ability, and socioeconomic status were predictive factors in this population.¹¹ Indeed, the children in the 2001 study were found to have significant language impairment as measured by the Clinical Evaluation of Language Fundamentals, Third Revision,¹⁸ with a mean total language standard score of 76.3 (+ 9.0) for the group receiving the Lindamood Phoneme Sequencing, and of 81 (+ 12) in the embedded phonics group. Interestingly, these language-impaired children showed a significant improvement in the total language standard score at 1-year follow-up: the Lindamood Phoneme Sequencing group standard score improved to 89.7 (+ 14), and the embedded phonics group standard score improved to 89.9 (+ 19.3). Both the explicit and the more implicit phonologic interventions were effective in significantly enhancing spoken language processing and written language.

Pokorni et al reported minimal gains in language and reading-related skills in a group of 18 younger, language-impaired, poor readers, aged 7.5 to 9 years.¹⁹ Their scores on the Clinical Evaluation of Language Fundamentals, Third Edition,¹⁸ fell more than 1.5 SD below the mean, and they were moderately reading impaired

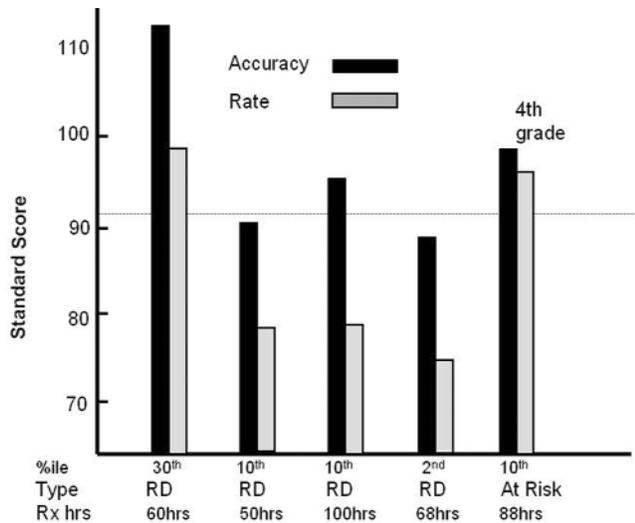


Figure 2. The fluency gap: a comparison of word-level fluency gains immediately after intensive, phonologically based treatment in groups of reading disabled (RD) children, with varying severity of difficulty prior to treatment. The two groups of RD children in the 10th percentile illustrate that longer treatment duration (Rx hrs) yielded greater gains in accuracy but no response with fluency. A contrast group of at-risk children, who had received intensive intervention through second grade, illustrates maintenance of gains through fourth grade, with normal fluency. The horizontal line represents the 30th percentile benchmark.

(18–25th percentile). These children received the Lindamood Phoneme Sequencing intervention for approximately the same number of hours of daily treatment, but in a small group (four children to one instructor). Two other groups also received equal time and intensity of treatment using either Earobics Step II²⁰ or Fast-ForWord,²¹ computer programs designed to remediate auditory temporal processing deficits. The Lindamood Phoneme Sequencing group alone made significant gains in phonologic awareness, as well as segmenting and blending after 60 hours of intervention. However, no gains in reading were observed. This would suggest that the more intensive, one-on-one intervention is more effective, particularly for children with both oral and written language impairments. Moreover, Lindamood Phoneme Sequencing is a complex program, and considerable training is required to work effectively with very impaired children. It is possible that the training and experience of the therapists, which were not specified in this study, might not have been as extensive as reported in Torgesen et al's 2001 study,¹¹ and might have been a contributing factor. The authors cautioned that the study was limited by a small sample size, a heterogeneous group, and an absence of IQ scores.

In addressing the comprehensive and multidimensional needs of children with dyslexia, especially in the areas of oral (rapid naming) and reading fluency, Wolf et al reported the preliminary findings of their longitudinal intervention study with reading-disabled children.²² Interventions contrasted three different treatment strategies. All subjects were trained using an evidence-based phonologic treatment (Phonological Awareness and Blending/Direct Instruction, developed by Lovett et al²³) followed by three different protocols: (1) RAVE-O (Retrieval, Automaticity, Vocabulary Elaboration, Orthography), developed by Wolf et al "to simultaneously address the need for automaticity in phonological, ortho-

graphic, semantic, syntactic, and morphological systems and the importance of training explicit connections between these linguistic system"²⁴; the comprehensive interventions with emphasis on the semantic aspects of language (vocabulary and retrieval) set it apart from other linguistic intervention studies; (2) Word Identification Strategy Training (teaching other strategies for analyzing words)²³; and (3) Teaching Classroom Survival Strategies.²² Subjects were second- and third-graders. They received 70 sessions of small-group, daily interventions. Preliminary findings reported by Wolf et al on the children with low average vocabulary scores revealed that the Phonological Awareness and Blending/Direct Instruction plus RAVE-O group improved more than the Phonological Awareness and Blending/Direct Instruction plus Word Identification Strategy Training group.²² On the Gray Oral Reading Test, Third Edition, Reading Quotient (a combined measure of rate, accuracy, and comprehension subtests), the Phonological Awareness and Blending/Direct Instruction + RAVE-O group showed a 10-point standard score gain (74 to 84) compared with the Phonological Awareness and Blending/Direct Instruction plus Word Identification Strategy Training group, which showed only a 4-point standard score improvement (74 to 78). However, at the 1-year follow-up, both groups were performing similarly, in the low 80s (Lovett M, personal communication, 2004). The Phonological Awareness and Blending/Direct Instruction plus Classroom Survival Strategies group scores showed a nonsignificant decline from a standard score of 76 to a standard score of 74. The final results of this comprehensive multidimensional study should yield helpful information about the response of the children's various cognitive and linguistic characteristics, including rapid naming, to differing linguistic interventions (semantic, morphologic, orthographic) with a core phonologic component.

In summary, these phonologically driven linguistic treatment studies indicate that the younger the child, the more explicit the intervention must be; the older the child and the more severe the impairment, the more intensive the treatment, and the longer its duration must be. A systematic phonics approach results in robust results in word reading accuracy but is not effective in developing fluency in the older, more impaired reader. Further research is needed to establish more effective interventions that will enable these children to become skilled readers.

NEUROIMAGING STUDIES AND RESPONSE TO TREATMENT

Neuroimaging studies have demonstrated the impact of intensive and explicit phonologically based remedial interventions on cortical activation. Simos and colleagues used magnetic source imaging to evaluate changes in spatiotemporal brain activation profiles while children performed a pseudoword reading task before and after treatment.²⁵ Treatment consisted of 8 weeks of intensive (one on one, 1 to 2 hours/day), phonologically based interventions in eight children aged 7 to 17 years (mean age 11.4 years) with dyslexia. Six of the eight children scored below the 4th percentile, and two scored at or below the 18th percentile on reading measures (the Basic Reading Skills cluster of the Woodcock-Johnson Test of Achievement, Third Edition.)¹³ Intelligence was in the average range (mean IQ 102 ± 4.5 on the Wechsler Intelligence Scale

for Children, Third Edition [WISC-III]).¹⁴ Six of the eight were diagnosed with attention-deficit disorder and were treated with psychostimulant medication throughout the study period. The comparison group consisted of eight children aged 8 to 14.2 years old (mean age 10.3 years) with reading scores above the 50th percentile and a mean IQ score of 107 (+ 10.5). One of the eight was diagnosed with attention-deficit disorder and was treated with medication. All 16 subjects were right-handed, native English speakers. Following intervention, reading accuracy in all subjects was above the 37th percentile. On the imaging studies prior to intervention, the subjects with dyslexia displayed the characteristic cortical activation profile of the individual with dyslexia: little to no activation in the left temporoparietal areas and strong activation in the homotopic right hemisphere. In contrast, the controls had little activation on the right and strongly activated the temporoparietal areas on the left, believed to be involved in phonologic processing. After treatment, the cortical activation patterns of the subjects with dyslexia resembled much more closely those of the normal controls. A dramatic increase was noted on the left, most pronounced in the left superior temporal gyrus, and increased activation in the inferior parietal areas approached significance. There was a moderate decrease in homotopic right hemisphere activation. The cortical activation patterns of the normal controls did not change. Of note, the imaging study also revealed that the subjects with dyslexia engaged the left superior temporal gyrus more slowly than did the controls, despite remediation, suggesting that the new circuitry might not be as efficient, and fluency would remain a problem. The authors stated that the small sample size calls for caution in interpreting the results. However, with the significant improvement noted both behaviorally and physiologically, they suggested that these findings indicate a "normalization" of functional brain organization following intensive intervention.

These findings have been replicated in a methodologically rigorous longitudinal study by Shaywitz and colleagues.²⁶ A large cohort (77 6- to 9-year-old children) with reading disabilities received 86 to 115 hours of daily, individual, and evidence-based phonologically mediated reading intervention at school. There were two control groups: a group of reading-disabled children who received the typical interventions of the school and private tutoring and a group of normal readers. The children were assessed before, following, and 1 year after treatment ended. Behavioral gains on the Gray Oral Reading Test, Third Edition, were found to be significant in comparison with the control reading-disabled group and the normal readers immediately post-treatment. The scale score improved from 5.4 to 7.0 for the treatment group; the scale score decreased from 5.4 to 4.9 for the reading-disabled control group on the passage score, a combination of accuracy and rate (mean 7, SD \pm 3). There could be no comparison at 1 year because only two of the reading-disabled control group and two of the normal reading group returned. The treatment group evidenced a decline in performance from a standard score of 7.0 to 6.4. However, an effect size calculation of the group's gains during treatment and of gains maintained from pretreatment to 1-year follow-up revealed an effect for both periods (effect size 0.52 and 0.43, respectively). Effect size in the 0.5 to 0.79 range is considered moderate.²⁷ Of note, the mean reading comprehension as measured by the Gray Oral Reading Test, Third Edition, improved during

the treatment and at the 1-year follow-up, moving into and staying in the average range (pretest mean standard score 5.7; post-test mean standard score 8.0; standard score at 1-year follow-up 8.5). Other studies have demonstrated a greater ability with text comprehension than with word-level reading before treatment¹¹ and that, following treatment, comprehension exceeds the 30th percentile, although word reading ability still lags behind in the 13th to 22nd percentile. This suggests that enhanced phonologic decoding allows the person with dyslexia to better use other top-down processing strategies, which can be strengths.

Physiologic measures also revealed significant changes. Using functional magnetic resonance imaging (MRI) during a letter identification task, Shaywitz et al also demonstrated the shift from right hemisphere to increased left hemisphere activation reported by Simos et al.^{25,26} Interestingly, although the treatment subjects remained in the impaired range on reading measures (Gray Oral Reading Test, Third Edition, passage score: 5.4 preintervention, 7.0 immediately postintervention, and 6.4 1 year later) in contrast to the normal readers, both groups demonstrated similar brain activation patterns, with increased activation in the left inferior gyrus and posterior middle temporal gyrus immediately after treatment. At the 1-year follow-up, only the treatment group underwent a repeated imaging study, which revealed that these children activated the fast-paced occipitotemporal word form area serving skilled reading, the bilateral inferior frontal gyri, and left superior temporal regions.

Richards et al used magnetic resonance spectroscopy (specifically, proton echo-planar spectroscopy) to evaluate the response to a less intensive but phonologically based intervention on brain lactate metabolism during "reading-related tasks" in eight boys with dyslexia and seven control boys between the ages of 10 and 13 years.²⁸ After the 3-week intervention period, which consisted of 15 2-hour group sessions, performance on behavioral measures of phonologic processing improved. Prior to intervention, the dyslexic participants manifested significantly greater lactate metabolism in the anterior quadrant of the left hemisphere during a reading task compared with controls, suggesting that they had greater difficulty with the task that necessitated increased use of the frontal cortex. One year after intervention, repeat magnetic resonance spectroscopy revealed a metabolic pattern similar to that of controls during the phonologic task.

To evaluate the effects of treatment using two different linguistic interventions, phonologic and morphologic, Berninger et al conducted a study with children in fourth to sixth grade who were part of a family genetics study and were found to be dyslexic.²⁹ The children were of normal intelligence (mean Wechsler Verbal IQ was 110.6 \pm 11), and although they did not have oral language problems or attention deficit, rapid naming deficits were present. The subjects were randomly assigned to a phonologic awareness or a morphologic awareness treatment group. They received daily treatment amounting to 28 hours over a period of 3 weeks. The behavioral results revealed significant gains in phonemic decoding skill and the rate from pretest to post-test for both groups. Phonologic decoding (the Woodcock-Johnson Reading Mastery Test Word Attack subtest) improved significantly for both groups. Interestingly, the morphology treatment group showed a significantly greater level of improvement than the phonology treatment group in phonologic decoding efficiency, as measured by the Pseudoword

Reading Efficiency subtest of the Test of Word Reading Efficiency.³⁰ Berninger et al suggested that the efficiency of phonologic decoding depends on an interaction between phonologic, morphologic, and orthographic representations, as described by Harm and Seidenberg's computer simulation studies below.³¹ Moreover, following morphology treatment, magnetic resonance spectroscopy revealed decreased lactate activation in the left frontal region during a rhyming task in all but one child with dyslexia, and the activation pattern resembled that of normal readers. However, in the phonologic treatment group, the pattern of activation remained the same or increased in all of the subjects. A reduction in lactate activation might reflect increased efficiency of mental processing. Good readers have less activation in the left frontal region during this phonologic judgment task, indicating less need to enlist prefrontal executive resources. A second imaging study using functional MRI revealed that normally reading controls showed different patterns of activation when performing phonologic and morphologic judgment tasks that were stable over time. In contrast, the pretreatment activation patterns of the subjects with dyslexia differed from those of the controls but resembled them after treatment.

The study groups were small, and the intervention was brief; therefore, the interpretation of these results merits caution. Berninger et al suggested that morphologic awareness training can help children develop the coordination for all of the language codes needed for word learning.²⁹ If this is so, they suggest that morphology provides a built-in executive function to do so. They recommend that future treatment design not only be aimed at orthographic and phonologic awareness but should also include training in morphologic awareness and the interrelationship of the three word forms: phonologic, morphologic, and orthographic.

RESEARCH RELATING TO LINGUISTICALLY BASED COMMERCIAL PROGRAMS

When classroom-based programs are not sufficient, clinicians and teachers can turn to commercial treatment programs. Many commercial programs (Alphabetic Phonics, Project Read, the Herman Approach, Slingerland Approach, the Spalding Approach, the Wilson Approach, LANGUAGE! [see Appendix]) are based on the Orton-Gillingham approach.³² This is a multisensory explicit phonics method with emphasis on visual and auditory feedback for sounds and the tactile-kinesthetic input of letter formation. This evidence-based treatment is the only method offering a complete intervention, including writing instruction, and has been the forerunner in the field. Unfortunately, there are few methodologically sound studies in peer-reviewed journals to validate its efficacy. Quasiexperimental studies were published by the International Multisensory Structured Language Education Council in 1995.³³ Many of the studies were hampered by either large, diverse groups of subjects or by inadequate numbers of subjects, by gains being reported in grade equivalents and not standard scores, by no long-term follow-up, and by the absence of control groups.

A study by Guyer and colleagues using the Wilson Reading System to treat the spelling deficits of college students is of interest, although the sample size was small.³⁴ There were three groups of 10 subjects: a no-treatment control group, a group receiving intervention via the Wilson Reading System spelling approach, and a third

group receiving treatment via a nonphonetic spelling approach. After 2 hours/week for 16 weeks, the students receiving the Wilson Reading System manifested significant gains in contrast to the other groups; spelling scores on the Wide Range Achievement Test-Revised³⁵ improved from a standard score of 76.7 to a score of 91, reaching the 30th percentile benchmark. The other groups did not show this level of improvement.

The results of Project Read interventions with young at-risk children and matched control groups in three school districts, using standard score gain measures to monitor gains, were described by Greene.³⁶ The treatment groups gained an annual mean of 12.7 standard score points (almost 1 SD) in 1 year, in contrast to the nonsignificant mean loss of 1.50 standard score points by matched-pair subjects in the control group. First-graders made the greatest gains in comparison with second- and third-graders.

In another study using the Orton-Gillingham method, Maskell and Felton evaluated the response of 230 older reading-disabled children (elementary through high school age) in a school for learning disabilities.³⁷ Subjects were instructed in small-group (3:1 or 4:1), daily (3 hours) sessions over 1 to 3 years, and the response was monitored over a 5-year period. The mean Wechsler Full-Scale IQ was 108. The subjects fell into the mildly impaired range: reading comprehension scores for all three groups were in the 100 to 104 range, and word reading skills were in the low 90s, based on the Woodcock Reading Mastery Test-Revised³⁸ and the Woodcock Johnson Tests of Achievement-Revised.¹³ Based on the Wide Range Achievement Test-Revised,³⁵ pretest spelling scores were in the mid- to upper 80s. Significant gains were noted for all groups in comprehension and word-level reading. The subjects who made the greatest gains were those who required only 1 or 2 years of treatment. Spelling gains were significant for all except the middle and high school students who required 2 years of intervention, even though their baseline spelling scores were in the 35th to 40th percentile. The students requiring 3 years of intervention did not achieve significant gains in word identification or spelling despite beginning with relatively mild impairments. Their resistance to treatment would suggest that other factors were involved in their lack of response, but no other measures were available in the study. There was no control group.

These studies support the use of the Orton-Gillingham method, but future research using methodologically sound designs is badly needed. Two Orton-Gillingham interventions have been reported in peer-reviewed journals. Oakland et al reported on a scientifically controlled study of the effectiveness of Alphabetic Phonics.^{39,40} Their study measured word identification and comprehension ability after 350 hours of small-group treatment. There were moderate gains in word reading (standard score 72 to 82) and comprehension (13th to 22nd percentile; no standard scores were given), but the 30th percentile benchmark was not achieved. A study by Hook et al revealed that an Orton-Gillingham approach resulted in significant gains in phonologic decoding after 6 weeks, in contrast to a group receiving FastForWord.⁴¹

The Lindamood Phoneme Sequencing program¹² has been described above and has been scientifically validated in a series of well-designed research studies.^{8,11} The Phono-Graphix program also involves a systematic and explicit phonologic intervention but has less multisensory mediation.⁴² It was used in the study by

Simos and colleagues described above and resulted in significant behavioral and physiologic gains in the six patients who were treated.²⁵ However, no other scientifically controlled studies on this program have been reported. A word of caution is necessary: the Simos et al study delivered the intervention in a one-to-one daily intensive manner using a trained teacher. However, the program was designed to be carried out by parents at home, with 1 to 2 hours per week of teacher support, making the intensity considerably less. No reliable study has validated this form of delivery. Intensity is a key ingredient to successful remediation, and the intensity needs to increase when the deficit is severe. Home programs in this day and age in families in which both parents are working are not realistic if intensity is required.

NONLINGUISTIC INTERVENTIONS

The remedial intervention studies discussed thus far have been linguistically driven. Individuals with dyslexia have been reported to have co-occurring nonlinguistic deficits as well. Heilman and Alexander summarized the most commonly reported and considered them to be deterrents to the efficient mapping of phonemic representations, which are essential as the building blocks for a strong phonologic system.⁴³ These nonlinguistic road blocks include: a) impaired temporal processing of rapidly presented brief auditory, visual, and somatosensory stimuli; b) a slowed response time across domains, which is thought to compromise working memory with its time-limited capacity; and c) an attention deficit compromising working memory as well as executive functions and sustained attention. Children with dyslexia can evidence poor sensorimotor coordination requiring bimanual and/or rhythmic output⁴⁴; poor postural stability and low tone in the upper body and labored acquisition of skilled motor tasks, such as shoe tying and handwriting⁴⁵; and difficulty with temporal sequential ordering in short-term auditory memory and working memory.⁴⁶ Subtle impairments in visual function include impaired binocular vergence control, with inefficient fixation on near targets and less accurate localization of small dots on a screen; difficulty recognizing several visual items presented simultaneously; trouble with letters or words "swimming" or jumping around on the page; and trouble with left-right discrimination.⁴⁷

TREATMENTS TARGETING AUDITORY PROCESSING

Intervention studies exploring auditory temporal processing deficits in children with reading problems and the impact of interventions designed to remediate these low-level perceptual processing deficits reported in some subsets of subjects with dyslexia have yielded interesting findings.^{4,48-50} There are few methodologically sound research studies on the efficacy of these nonlinguistic intervention strategies. Earobics²⁰ and FastForWord²¹ were used in some of the studies reviewed above. These programs are conducted using commercially developed computer programs to address the auditory processing deficit found in a subset of subjects with dyslexia. They use acoustically modified speech to remediate the auditory processing deficit but also tap phonologic skills. FastForWord was developed based on scientific evidence of the relationship

between auditory processing and language.⁴⁸ It is presented through the auditory channel but also trains syntactic and semantic comprehension. Earobics incorporates graphemes and written words into the program.

Hayes et al studied 27 children aged 8 to 12 years old with learning impairments (as defined by a discrepancy of at least 1 SD or more between measures of mental ability and reading, spelling, phonologic awareness, or auditory processing).⁵¹ The subjects, who received 8 weeks of auditory perceptual training with Earobics Step I and Step II, exhibited improvements in auditory processing skills and altered cortical responses to speech syllables, with a more mature pattern in quiet and increased resistance to degradation in background noise compared with normal controls and an untreated learning-disabled group. However, these changes did not result in improvement in performance on measures of reading and spelling ability. The possible implications of these results for children with dyslexia are unclear because the subjects included children with attention deficit alone.

Agnew and colleagues studied the impact of a language remediation program using acoustically modified speech (FastForWord), designed to improve auditory temporal processing and language skills.⁵² Their primary aim was to assess its effect on the accuracy with which seven children (being seen in a private clinic for FastForWord treatment based on parental concern, clinician referral, or poor school performance) could judge relative durations of auditory and visual stimuli. Their second aim was to ascertain its effect on phonologic decoding. Following 4 to 6 weeks of intensive daily intervention, the subjects demonstrated improvements in the auditory, but not visual, modality on duration judgment tasks. This was interpreted as evidence that the program indeed improved auditory processing and that gains were not due to improved attention. This improvement in auditory temporal discrimination was not associated with improvement in phonologic awareness or nonword reading, results that Agnew and colleagues interpreted as "illustrating the need for further research to establish the relationship between reading and auditory temporal processing." They proposed that the auditory temporal processing difficulty that children with specific language impairment and dyslexia exhibit is the result of poor phonologic representations rather than an auditory temporal processing deficit or, as has been suggested by other researchers, a generalized nervous system deficit in the processing and integration of rapidly successive and transient signals.

In the study described above by Pokorni et al, Earobics Step II and FastForWord were compared with the Lindamood Phoneme Sequencing program.¹⁹ After approximately 60 hours of daily intervention delivered in a small-group setting, reading gains were not noted in either group. Children exposed to Lindamood Phoneme Sequencing were significantly better in improving phonologic awareness with gains in segmenting and blending, and the Earobics group also showed significant gains attributed to phonemic segmentation. No significant gains were found in the FastForWord group.

Temple and colleagues compared the cortical activation patterns of 20 children with dyslexia before and after 8 weeks of FastForWord remediation.⁵³ Left temporoparietal cortex and left inferior frontal gyrus activation increased following the interven-

tion. In contrast to other studies,^{19,52} Temple and colleagues demonstrated group improvement in both oral language and reading performance in association with these changes in cortical activity. Their subjects were moderately impaired in nonword reading (standard score 85.5, SD 7.9), average in oral language (receptive language standard score 92.5, SD 12.1), and severely impaired in rapid naming (standard score 79.1, SD 14.5). Significant gains were found in nonword reading, word identification and passage comprehension, receptive and expressive language, and rapid naming. Only nonword reading reached the 30th percentile benchmark, with a post-treatment score of 93.7 (range 82–109). Oral language already exceeded it before treatment. However, there were no significant gains in oral language for 10 (50%) of the subjects. Similarly, there were no significant reading gains for 9 (45%) of the subjects. Similar data for rapid naming are not reported. The amount of activation in the left temporoparietal area correlated with improvement in oral language ability. Increased activity in the right hemisphere frontal and temporal regions, as well as the bilateral anterior cingulate, was noted. Temple et al suggested that the cingulate might represent improved attention and that the homotopic right hemisphere areas might represent compensatory activity, which might decrease with improved function.

Whereas gains in auditory, phonologic, and language processing have been noted with these programs, the gains in reading skills have been, at best, inconsistent and have not matched the gains in reading reported by programs using systematic phonologic awareness and phonics interventions. Both programs have developed new software that includes phonics and language instruction. The efficacy of these additions has yet to be reported.

TREATMENTS INVOLVING THE VISUAL SYSTEM

Stein and Talcott showed that a subset of subjects with dyslexia might have abnormal magnocellular systems, causing decreased visual motion sensitivity, with poor visual guidance of the eye movements that result in inferior binocular vergence control.⁴⁷ This problem with vergence control results in difficulty fixating on near targets and might explain why the children reported trouble with letters moving around on the page. This visual motion sensitivity has been found to be a predictor of orthographic skill, accounting for more than 15% of the variance in the reading accuracy of irregular sight words.⁵⁴ Stein et al reported on a large intervention study (two groups of 70 children, average age 8 years, 9 months, of normal intelligence, with reading skills more than 2 SD below the mean).⁵⁵ The subjects met the criteria for severe dyslexia and unstable binocular vision and were randomly assigned to wear yellow-tinted glasses with or without occlusion of the left lens (because most of the children were right handed). Yellow tinting was chosen because the magnocellular system, felt to be deficient in these children, gets a boost in the yellow range. Stein et al reported that short-term monocular occlusion helped the children to overcome their binocular fixation instability, and, while using only one eye to read, visual inconsistency and confusion resolved. The children were seen every 3 months for 9 months and were assessed for binocular stability and reading ability. Both groups began treatment reading at the 6.8- to 6.10-year-old level. At the end of 9 months, the group with monocular occlusion had gained 16.1 months in reading ability but

still remained significantly behind (at the 8.1-year-old reading level at the age of 9.5 years). The children who made the greatest gains were those achieving binocular stability. In fact, when a child demonstrated inconsistent stability over time, the reading gains for the 3-month period of instability were 1.2 months per month, in contrast to an average of 2.1 months per month when stability was present. The group with tinted lenses alone manifested only an 8-month gain over the 9-month period. Stein et al noted that the group treated with tinted glasses alone achieved a greater than expected rate of binocular stability over the 9 months (54%, in contrast to a similar study using clear glasses, with a rate of 20 to 24%). They wondered if this difference could be due to the color giving a boost to the magnocellular system. They noted that most children with dyslexia have a core deficit in the phonologic system of language but proposed that in a subset of subjects with dyslexia, visual processing difficulties might account for orthographic mapping problems owing to the inconsistency of the visual input.

TREATMENTS RELATED TO THE CEREBELLAR OR MOTOR SYSTEM

Fawcett et al and Nicolson and Fawcett reported that many children with dyslexia perform poorly on tests assessing cerebellar processing.^{45,56} The cerebellum helps control eye movements that impact reading and might also have a role in phonologic processing (mentally sounding out the letters in a word).⁵⁷ This is supported by the connection between the right cerebellum and left temporoparietal areas. Structural MRI studies by Eckert and colleagues found a decreased right cerebellar volume in their dyslexic population.⁵⁸ Based on this hypothesis of the role of the cerebellum in phonologic and other reading-related processes, an intervention has been developed, the Dyslexia, Dyspraxia and Attention Deficit Treatment—an exercise-based approach to the remediation of dyslexia and related disorders. Reynolds et al conducted a study using this approach in a population of junior high school students (mean age 9 years, 4 months) identified as being at potential risk of dyslexia by the Dyslexia Screening Test.^{59,60} Although significant improvements in balance, dexterity, and eye movement control, along with reported improvements in reading, were described, methodologic flaws in the research design and problematic analysis and interpretation of the results rendered these findings of limited use in determining whether these interventions aimed at improving cerebellar function indeed result in improvement in the oral and written language skills of children with reading difficulties. The program is available commercially at the Dore Achievement Centers. It involves a home program administered daily by the parents, with supervision by the center. The International Dyslexia Association does not endorse it but encourages future methodologically sound studies to validate the efficacy of this intervention.

QUESTIONS TO ASK IN EVALUATING TREATMENT PROGRAMS

Eden and Moats reviewed commercial programs that have been fueled by neuroscientific theories of dyslexia.⁶¹ Some are effective, whereas others are less so. It is important that the child undergo

a thorough evaluation to define what is likely to be the best treatment modality. Without such an evaluation and careful assessment of the child's needs and the nature of the program, parents might invest time and money in a program that is not appropriate for their child. The research available to the neuroscientist is also not readily available to the public. Parents should be encouraged to seek help from the International Dyslexia Association or their physician, psychologist, language therapist, or teacher. However, they should also ask the following questions when considering any specific intervention:

- What are the short- and long-term gains in accuracy, fluency, and comprehension of the intervention?
- Do they do baseline and post-treatment standardized assessments to measure outcome?
- Is it administered intensively?
- Is there support following the intensive treatment to ensure that the child practices and maintains gains?
- Is it a cost-effective solution?
- Has the intervention been rigorously evaluated with scientifically designed studies and reported in peer-reviewed studies in reputable journals? Do these studies use standard reading assessments? Eden and Moats noted that only two commercially available programs fell into that category, emphasizing the need for this research.⁶¹
- What are the training requirements to become a proficient therapist?
- Parents and professionals can also find reviews of reading programs offered in the schools by going to Torgesen's Center for Reading Research Web site, <www.fcrr.org>. The site also offers the presentations made by their professionals on the current research in reading, a very helpful source of information.

WHAT CAN BE LEARNED FROM STUDIES USING COMPUTER-MODELED NEURAL NETWORKS?

The connectionist models are not related to any specific treatment approach but rather serve to elucidate some of the neurologic factors involved in learning to read. The connectionist model of orthography-phonology mapping developed by Harm and Seidenberg demonstrated that phonologic knowledge could be pre-trained using phonologic forms of words.⁶² Subsequent training to map orthography to the pre-trained phonologic system changed its phonemic representations, making them more distinct. This change facilitated learning to read additional words, thus illustrating the reciprocity between the development of phonemic awareness and reading. They also found that if the model was made to have very subtle phonologic deficits, it had significant difficulty learning to read the word. Phonologic representations were ineffective, the neural maps were peculiar, and there was no evidence that the code for the alphabetic principle could be discerned. Rayner and colleagues suggested that these findings infer that constitutional differences in the capacity for encoding phonologic structure could result in the variable outcomes in learning to read, further supporting the phonologic deficit hypothesis for developmental dyslexia.⁴

Harm and Seidenberg also used a computer model to show that, when learning to read, the phonologic pathway predominates because orthographic-phonologic mapping is easier to learn.⁶² The orthographic-semantic (sight word reading) mapping pathway takes longer to learn because the code is less explicit. These representations develop with the repetition of the exposure. Once developed, the orthographic-semantic pathway plays a greater role in word reading. Of note, the most efficient decoding occurred when both pathways worked together on almost all words, further illustrating the need for the optimal development of both to prevent reading disabilities.

DIAGNOSIS AND TREATMENT OF THE CHILD WITH DYSLEXIA

As can be seen from the previous discussion, dyslexia is a complex neurobiologic process that involves a number of different components. The selection of the appropriate treatment approach is not a "one-size-fits-all" situation but rather is based on a detailed, multidisciplinary evaluation, which involves a thorough developmental neurologic assessment, evaluation of gross and fine motor skills, neuropsychological testing with a specific focus on phonologic skills, a speech-language and occupational therapy assessment, and a screening of the child's psychiatric status and the family milieu. All of these assessments play an important role in the selection and management of the treatment phase. As we attempt to identify and treat children at a very early developmental stage, the physician offers expertise in the assessment of these young prereaders, as well as assessing the older child with dyslexia to identify the multiple neurologic components that might be affecting the acquisition of normal reading. Visual schematics, although an oversimplification, can be helpful in the systematic consideration of all of these factors. The following schematics are designed to allow consideration of the components contributing to the development of the phonologic system and the acquisition of reading. They can be helpful in explaining treatment plans to therapists and parents as well.

Children develop their abilities from the bottom up, with the wiring together of sensory stimuli. Those that fire together are more likely to wire together into efficient neural representations.⁶³ This linkage is enhanced with repetition, and representations are mapped into functional modules in a distinct fine-grained fashion. The more perceptually salient, consistent, frequent, multisensory, and emotionally reinforcing the input, the stronger the map becomes. These factors are helpful to remember when analyzing the child's neurocognitive profile and learning environment. They are also essential for an effective treatment program.

Figure 3 includes the following, from the bottom up:

- The attention or arousal system, which is essential for the imprinting of sensory inputs
- Bidirectional arrows, which illustrate the neural networks interacting with each other
- Stoplights, which have been used to illustrate the neural flow from a representation or a sensory input. A green light represents flow as it should be for optimal, fine-grained mapping, yellow represents compromised flow that results in less precise

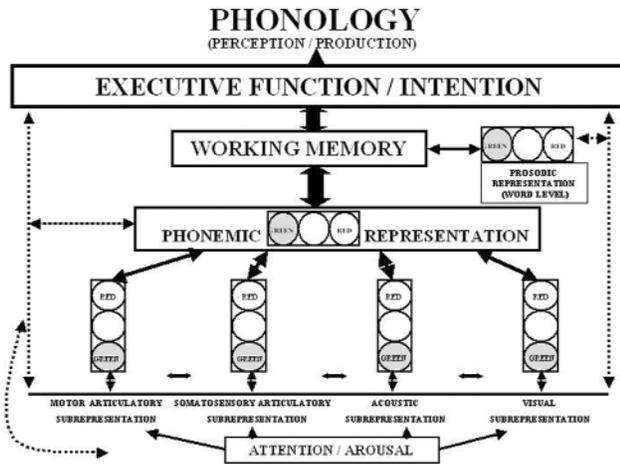


Figure 3. The development of the phonologic system: a visual schematic illustrating the neural substrates and networks needed for the optimal development of the phonologic system. The stoplights serve to illustrate whether the neural substrates allow for efficient networking (green), as is shown here. The stoplights can be used to explain treatment plans, illustrating when substrates are suboptimal, resulting in a “bottleneck” (yellow), or are nonexistent, requiring a “detour.”

mapping, and red represents a lack of input from that neural component, requiring the overreliance on other components and the wiring of atypical networks. With impaired inputs, bottlenecks or “roadblocks” to learning occur. The more distinct components of sensory input or cortical representations must be relied on more frequently for skill acquisition; the less distinct are ignored. It is hypothesized that a type of “Matthew effect” occurs: the strong become stronger, and the weak become weaker.^{64,65} Thus, children with phonologic weakness do not choose to engage in activities that use this system. They must be immersed in it in an explicit and systematic fashion, as noted above, to develop the necessary neural networks. Therefore, an analytic approach as to which pathways are well developed and which are not is essential for the planning of effective intervention strategies.

- The working memory block, which represents the time-sensitive “slave” systems of the central executive system that are responsible for retrieving, holding, and manipulating information for processing. It has a different developmental timetable than that of executive function, which is represented as a higher level of processing on the schematic.⁶⁶ The role of executive function as strategist, top-down processor, and controller of attention to tasks and regulator of motor intention is illustrated by broken lines to signify that it is not as fully developed in the young child. Deficits in these executive functions are being considered as a possible third core deficit in dyslexia after the phonologic and rapid naming core deficits (Berninger VW, personal communication, 2003).

COMPONENTS IN THE DEVELOPMENT OF THE PHONOLOGIC SYSTEM

If the assessment reveals that the individual with dyslexia has difficulty in the phonologic system, one should consider all of

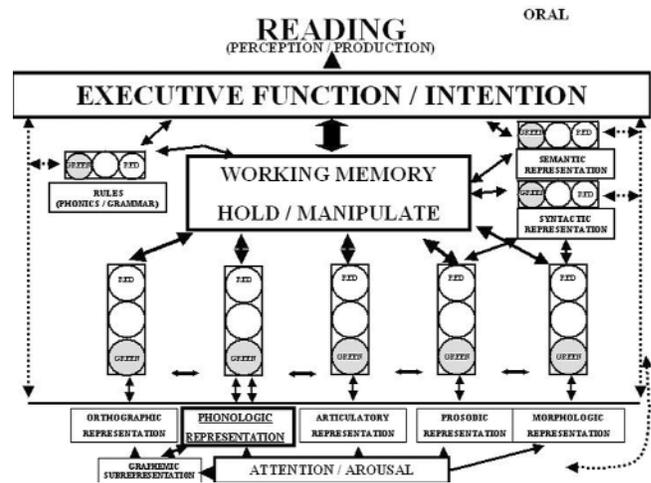


Figure 4. The development of skilled oral reading: a visual schematic illustrating the neural substrates and networks needed for the optimal development of skilled (fluent, with appropriate expression and comprehension) oral reading. The stoplights serve to illustrate whether the neural substrates allow for efficient networking (green), as is shown here. They can be used to explain treatment plans, illustrating when substrates are suboptimal, resulting in a “bottleneck” (yellow), or are nonexistent, requiring a “detour.”

the possible bottlenecks hindering strong synaptic connections—the linguistic and the nonlinguistic. Are motoric phonemic sequences produced easily and consistently? Does the individual have somatosensory awareness of the articulatory gestures? Is the weaker process a lower-level auditory processing inefficiency? Does the child look at your mouth when auditory input is not clear? Is the environment a factor? Has the child had multiple bouts of hearing loss owing to effusions? Is there a possibility of subclinical seizures? Are there comorbid affective disorders? Is the child inattentive to all sensory stimuli? Is the child impulsive, disorganized, or unable to use strategies? Interventions should be designed accordingly to address any of these factors.

COMPONENTS IN THE DEVELOPMENT OF READING

Rumelhart et al observed that reading can be viewed as an interactive process between information processed from current sensory information (bottom up) and the meaning of what has been read (top down).⁶⁷ The connectionist models support this view. Oral reading is the most demanding, and Figure 4 represents the neural components necessary for the development of this skill. A combination and integration of distinct phonologic, morphologic, orthographic, and semantic representations for the decoding of a word are optimal for normal reading development (accurate and automatic decoding) according to Snowling and Nation.⁶⁸ Harm and Seidenberg’s computer simulations confirm the need for this interplay.³¹ Articulatory and prosodic representations are necessary for appropriate oral production but also for enhancement of phonologic, morphologic, and semantic maps. Without efficient phonologic and morphologic decoding ability, the reader must rely on context (semantic and syntactic cues).⁶⁹ The transition into fluent reading

with comprehension depends on developing orthographic automaticity but also on syntactic competence and semantic strength.

To confound the issue further, an appreciation of the developmental course is essential. Snyder and Downey found that 8- to 9-year-old children's syntactic knowledge, followed by their ability to retell a story and their word retrieval ability on a confrontation naming task, accounted for better reading comprehension.⁷⁰ Older children (11–14 years) were found to rely on bottom-up and top-down strategies, depending on the material being read. Bottom-up phonetic processes are used to decode isolated unfamiliar words in less familiar text; more top-down strategies are used when reading stories and text on familiar topics. At this age, their discourse processing skills, followed by their phonologic awareness abilities, accounted for the greater variance in their reading scores. Weak phonemic representations result in weak phonologic representations, thought to be the core deficit in developmental dyslexia.⁷¹ Orthographic representations are acquired more efficiently if there is an appreciation of the phonologic components of the word. Likewise, phonics rules are difficult to apply without a strong phonologic base. Some children might also complain of the words swimming or moving on the page, making it difficult to keep their place and causing fatigue, as well as placing them at risk of orthographic mapping deficits.

Single-word reading is typically more markedly affected in dyslexic individuals owing to the weakness of the phoneme, morpheme, and orthographic representations. However, children with strong cognitive and semantic abilities (lexical-semantic representations) can offset the severity of the decoding deficit in contextualized text reading. They make good use of context for the decoding of unknown words and exhibit greater strength in comprehension than would be expected. Unfortunately, this strategy alone is less efficient than the combination of phonologic decoding and orthographic knowledge because reading material is often on unknown topics (decontextualized).

As content becomes more syntactically complex, the child requires a facility with syntax to be able to read and understand the material, especially if its content is not familiar. Dyslexic individuals often have a history of poor morphosyntactic development. Thus, more ambiguous and abstract language presents obstacles to comprehension. Similarly, the impoverished vocabulary stores of some children seriously impact their reading comprehension; although they might be able to decode the word, they do not know what it means.

If a child presents with a reading disability, consideration of each factor on the schematic might clarify which factors are playing a role and need to be addressed in the treatment plan. Weakness in the representation of articulatory gestures and phonologic representations implicates lower-level sensory processing, as do difficulties with auditory processing. Do the children complain of words moving on the page? Talcott et al found a unique variance for visual motion sensitivity and orthographic skills and a similar variance for auditory sensitivity to change and phonologic skills in a subset of subjects with dyslexia.⁵⁴ Rapid word retrieval is often a factor in inefficient reading and is thought to be the result of deficits in phonologic, morphologic, and semantic processing; attention; executive function; articulatory processing; and/or a weak visual-verbal connection.^{22,72} There is presumed to be an interplay between

all of these neural components, so that a breakdown in any one could result in problems. Wolf et al pointed out that these same networks subserved reading and might account for the word retrieval deficits being found in the poorest readers.²² Children with these retrieval deficits progress more poorly and have significant difficulty with sight word reading, especially with fluency. A poor vocabulary suggests weak semantic representations, creating fewer resources for comprehension. A weak syntactic system would contribute to difficulty with comprehension as well. Impaired attention, working memory, and executive function and intention resources could contribute to inefficient acquisition of reading from both a bottom-up and a top-down approach. Slow temporal processing strains the time-sensitive working memory system too. Interventions designed to address the needs of the individual child should consider all of these factors.

The most prevalent comorbid condition impacting the development of the individual with dyslexia is attention deficit. Optimal attention increases learning. Attention deficit results in inconsistent perception of stimuli hampering the development of strong neural connections and weakens the working memory necessary for processing multiple perceptions. Optimal treatment of the attention deficit is an imperative. The child who is struggling with cognitive and linguistic development places more demand on the attention system when learning, and research has found it to be a deterrent to a good response to intervention.

SUMMARY

Although treatment studies have shown that the majority of children respond to evidence-based treatment interventions, there are still a significant number of children who are resistant to treatment. They are the challenges for future research and the children who require more comprehensive evaluation and individualized interventions. As described by Heilman and Alexander,⁴³ although appropriate language intervention is the key component in the treatment plan for the child with oral and/or written language impairments resulting from a faulty foundation in the phonologic system, other factors must be considered for optimal outcome. The child's attention, working memory, and executive functions must be assessed and treated optimally. Sensorimotor deficits, including dysgraphia, can impact skill acquisition and should also be remediated. The linguistic and social emotional environments at home and school must be evaluated and addressed with treatment if necessary. Is there evidence of an associated psychiatric disorder? (Considering the high degree of comorbidity between attention-deficit hyperactivity disorder [ADHD], mood disorders, and anxiety disorders, a careful assessment of the child's psychologic and emotional status is often extremely important. The reader is referred to the article by Sundheim and Voeller in this issue.⁷³) Related to this is the child's ability to persevere in the face of frustration, which is an extremely valuable asset. Some children are born with that trait, others have to be encouraged to develop it, and some have decided that they will never learn to read and have given up. Reinforcement of the appropriate work ethic will allow the child to become successful in spite of being less dextrous with language, fine motor skill, or organizational abilities. Compensatory accommodations should be considered; does the child need more

time, a quiet room for test taking, an FM amplifier, a scribe, a voice-activated word processing program, or Books on Tape from the Library for the Blind and Dyslexic?

A child's language development is a dynamic process. The clinician's challenge is optimally tracking this process, identifying deficits that can hinder optimal acquisition of critical language skills, and guiding interventions to address them. The clinician should continue to monitor progress even after intensive treatment has moved a child's performance into the average range. Behavioral and imaging studies have demonstrated that the newly strengthened language systems might continue to have subtle weaknesses that might impede acquisition of the skills called for at the next level. The same process of assessment and thoughtful evaluation of all of the factors that need to be in place for optimal development must be repeated. With the advent of more rigorous intervention research, the outlook for the child with dyslexia is much more optimistic. As the science of intervention grows, more refined and sophisticated techniques will become available, and the individual with dyslexia will be free to function even more efficiently at school, at home, and in the workplace.

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Appendix: Sources for Commercial Orton-Gillingham Methods

| Program | Address |
|--------------------------|---|
| Project Read | http://www.projectread.com |
| The Herman Approach | http://www.lexialearning.com/training_herman.htm |
| The Slingerland Approach | http://www.slingerland.org/organization/approach.htm |
| The Spalding Method | http://www.spalding.org |
| The Wilson Approach | http://asp.wilsonlearning.com/approach.asp |
| LANGUAGE! | http://www.sopriswest.com |
| Alphabetic Phonics | Educational Publishing Service, Cambridge, MA |

For an overview of most of these methods, go to <http://www.ldonline.org/ld_indepth/reading/mssl_methods.html>.