The Education of Dyslexic Children from Childhood to Young Adulthood

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Key Words

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Abstract

The past two decades have witnessed an explosion in our understanding of dyslexia (or specific reading disability), the most common and most carefully studied of the learning disabilities. We first review the core concepts of dyslexia: its definition, prevalence, and developmental course. Next we examine the cognitive model of dyslexia, especially the phonological theory, and review empiric data suggesting genetic and neurobiological influences on the development of dyslexia. With the scientific underpinnings of dyslexia serving as a foundation, we turn our attention to evidence-based approaches to diagnosis and treatment, including interventions and accommodations. Teaching reading represents a major focus. We first review those reading interventions effective in early grades, and then review interventions for older students. To date the preponderance of intervention studies have focused on word-level reading; newer studies are beginning to examine reading interventions that have gone beyond word reading to affect reading fluency and reading comprehension. The article concludes with a discussion of the critical role of accommodations for dyslexic students and the recent neurobiological evidence supporting the need for such accommodations.

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BACKGROUND AND DEFINITION

For good readers, gaining meaning from print quickly and effortlessly, like breathing and speaking, is a natural part of life. For these men and women, it is almost unimaginable how something that seems to come so naturally could be difficult for others. Without doubt, since ancient times when man learned to use printed symbols to convey words and ideas, there have been those who struggled to decipher the code. Just how many are affected, the basis of the difficulty, and most importantly, the most effective, evidence-based approaches to educating dyslexic children and young adults were questions that had to wait until quite recently for resolution. We begin by reviewing the core concepts of dyslexia, including its definition, epidemiology, cognitive model, and etiology, especially neurobiological influences. We next consider specific evidence-based reading interventions for word-reading accuracy, fluency, and comprehension and then the exciting neurobiological findings that together have given rise to and must inform contemporary, evidence-based approaches to the education of dyslexic children. We conclude with a discussion of the critical role of accommodations for dyslexic students and the new neurobiological evidence supporting the need for such accommodations.

Fluency: the ability to read words accurately, rapidly, and with good intonation

Historical Roots

Dyslexia has been described in virtually every ethnic group, language, and geographic region. The original report, published as *A Case of Congenital Wordblindness* on November 7, 1896, was prompted by the experience of a British physician, W. Pringle Morgan, with his patient Percy F., age 14, for whom he provided the following description:

> . . . He has always been a bright and intelligent boy, quick at games, and in no way inferior to others his age. His great difficulty has been—and is now—his inability to read. He has been at school or under tutors since he was 7 years old, and the greatest efforts have been made to teach him to read, but, in spite of this laborious and persistent training, he can only with difficulty spell out words of one syllable . . . .
>
> . . . I might add that the boy is bright and of average intelligence in conversation. His eyes are normal . . . and his eyesight is good. The schoolmaster who has taught him for some years says that he would be the smartest

lad in the school if the instruction were entirely in oral . . . (Morgan 1896, p. 1378).

What is so striking is the similarity of Percy F. to the children we continue to see to this day. Such clinical descriptions from every corner of the globe attest to the invariance of dyslexia over both time and place. In his clinical vignette, Dr. Morgan captures the essence of dyslexia: an unexpected difficulty in reading.

Definition: Core Constancy Amid Refinements

Current definition. The basic notion of dyslexia as an unexpected difficulty in reading has remained constant across definitions of dyslexia (Critchley 1970, Lyon 1995) as evidenced by the most current definition provided by a working group meeting in Washington, D.C., in 2002:

> Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction . . . (Lyon et al. 2003, p. 2).

Refinements from prior definitions. Dyslexia (also referred to as specific reading disability) is a member of the family of learning disabilities; in fact, reading disability is by far the most common learning disability, affecting over 80% of those identified as learning disabled (Lerner 1989). Although the recognition of dyslexia as a discrete entity dates back over a century, the concept of a learning disability is relatively new.

The term "learning disabilities," as initially proposed by Samuel Kirk (Kirk 1963) and later operationalized in the Federal Register (U.S. Office Educ. 1977), refers to a broad group of difficulties involving listening, speaking, reading, writing, and mathematics. In contrast to this undifferentiated construct, the current definition explicitly categorizes dyslexia as a "specific learning disability." New to the current definition over the previous one is reference to dyslexia's "neurobiological origin," reflecting the significant advances in neuroscience, particularly the brain imaging of reading and dyslexia that is discussed in detail below.

New, too, is the incorporation of, and emphasis on, the importance of fluent reading: the ability to read text not only accurately, but also rapidly and with proper expression (Rep. Natl. Reading Panel 2000). Thus, the previous reference to "single word decoding" is now supplanted by reference to "difficulties with accurate and/or fluent word recognition," acknowledging converging data pointing to the critical lack of the development of fluent reading as a hallmark of dyslexia that persists into adolescence and then adulthood, even when accuracy improves. The lack of fluent reading is observed clinically by reading that is effortful and slow; it is often considered the sine qua non of dyslexia, especially in young adult and adult readers (Bruck 1998, Lefly & Pennington 1991, Shaywitz 2003). This renewed appreciation of the importance of fluency should encourage its measurement; otherwise, many dyslexic children who can read accurately, but not fluently, will continue to go unnoticed (and untreated) within the classroom (Katzir et al. 2006).

As in the prior definition (Lyon 1995), emphasis is on the phonological weakness giving rise to the reading (and speaking) difficulties characterizing dyslexia. A range of studies has indicated phonological difficulties as the most robust (Fletcher et al. 1994, Shaywitz et al. 1999, Stanovich & Siegel 1994) and specific finding (Morris et al. 1998) in dyslexic children and adolescents, supporting the phonological-core variable differences model proposed earlier by Stanovich (1988). Critical to the notion of a phonological weakness as causal in the development of the concatenation of difficulties observed in

Accommodations: adaptations within the classroom, use of assistive technology, or provision of extra time allowing learning-disabled students to demonstrate their full knowledge

Decoding: determining the pronunciation of a word by analyzing the vowels and consonant combinations within the word

dyslexia has been the repeated demonstration that remediation of the phonological weakness leads to the amelioration of the decoding and word-reading weaknesses in dyslexia (Bradley & Bryant 1983; Byrne & Fielding-Barnsley 1995; Byrne et al. 2000; Foorman et al. 1998; Hatcher et al. 1994; Schneider et al. 1997; Torgesen et al. 1999, 2001).

Core definitional concept: an unexpected difficulty in reading. Perhaps the most consistent and enduring core of any definition of dyslexia is the concept of dyslexia as an unexpected difficulty in reading. "Unexpected" refers to the presence of a reading difficulty in a child (or adult) who appears to have all of the factors (intelligence, motivation, exposure to reasonable reading instruction) present to be a good reader but who continues to struggle (Shaywitz 1998). More challenging has been the question of how to operationalize the unexpected nature of dyslexia. Thus, using differing methods and criteria, definitions have attempted to capture the "unexpected" nature of dyslexia by requiring a discrepancy of a certain degree between a child's measured IQ and his reading achievement. For example, schools have typically relied on criteria based on an absolute discrepancy, most commonly one or one-and-one-half standard deviations between standard scores on IQ and reading tests; others, including many researchers, prefer regression-based methods adjusting for the correlation of IQ and reading achievement (Reynolds 1984, Stuebing et al. 2002).

We want to emphasize that the difficulty has been not with the notion of a discrepancy, but rather with the real-life practical effect of implementing this model in a primary school setting. For example, children who were clearly struggling as early as kindergarten or first grade had to wait, often until third grade or later, until their failure in reading was of such a magnitude that they met discrepancy requirements. And so it is understandable why this approach has often been referred to as a wait-to-fail model. Attempts to clarify the criteria by meta-analyses comparing discrepant to simply low-achieving poor readers (defined on the basis of a reading score below a certain cut point, e.g., below a standard score of 90) find overlap between the two groups on reading-related constructs but not on IQ-related measures (Stuebing et al. 2002). In addition, both low-achieving and discrepant readers demonstrate comparable growth rates in word reading during the school years (Francis et al. 1996). Knowledge of long-term adult outcome may shed light on possible differences between the two groups not captured by studies during childhood; such efforts are now under way using data from the Connecticut Longitudinal Study (Ferrer et al. 2007, Shaywitz et al. 2003). Not only do poor readers identified by either discrepancy or low-achievement criteria resemble one another on measures of reading and growth rates of reading, but each group also differs along multiple dimensions from groups of typically achieving boys and girls (Fletcher et al. 1999, Lyon et al. 2001).

These findings have strong educational implications: It is not valid to assume that discrepant children require instructional strategies that differ from those for low-achieving readers. It also is not valid to deny the education services available for disabled or at-risk readers to low-achieving, nondiscrepant children. On the other hand, the observed similarity of the discrepant and low-achieving groups in reading-related constructs argues for identification approaches that include both low-achieving children and those struggling readers who are discrepant but who do not satisfy an arbitrary cut point for designation as low achieving. Seventy-five percent of children identified by discrepancy criteria also meet low-achievement criteria in reading; the remaining 25% who meet only discrepancy criteria may fail to be identified and yet still be struggling to read (Shaywitz et al. 1992a).

A recognition of these difficulties combined with accumulating data indicating the importance of early intervention (Lyon et al. 2001; Torgesen et al. 1999, 2001) has prompted researchers and educators to search

for alternative approaches that would promote earlier intervention or prevention for at-risk readers. One such approach focuses on a more dynamic assessment, particularly applicable to early grades, where the ongoing development of fluency in component reading skills (e.g., letter recognition, word reading) is measured frequently and is compared with expected norms (Kame'enui et al. 2000). Another approach, termed "response to intervention" (RTI; Fuchs & Fuchs 2006), has generated considerable interest. Here, all children are first provided with evidence-based reading instruction and their progress is frequently monitored; those who are not making progress are selected to receive additional support (see below for fuller discussion of RTI).

Definitional framework of dyslexia: categorical or dimensional. How best to more broadly conceptualize dyslexia has long been of theoretical interest to investigators and of more practical import to educators who must set policies to identify struggling readers in need of support. Earlier views, mainly stemming from the influential Isle of Wight study (Rutter & Yule 1975, Yule & Rutter 1985), posited a categorical view of dyslexia envisioning reading ability as bimodally distributed, with children with specific reading retardation (dyslexia) forming a so-called hump at the lower tail of the distribution (Rutter & Yule 1975, Yule & Rutter 1985). In contrast, more recent data from an epidemiologic sample, the Connecticut Longitudinal Study, suggests that reading difficulties, including dyslexia, occur as part of a continuum that includes nonimpaired as well as disabled readers (Shaywitz et al. 1992b). Other investigators, too, have pointed out methodological flaws in the British study (van der Wissel & Zegers 1985) or failed to replicate its findings (Jorm et al. 1986, Rodgers 1983, Silva et al. 1985, Stevenson 1988). The importance of the Connecticut data is that these findings place dyslexia within the same dimensional framework as other important disorders that affect the health and welfare of children and adults. Thus, like hypertension and obesity, dyslexia occurs in degrees of severity. A dimensional model also argues that although cut points are placed to help define groups, these are arbitrary and may have no biological validity; those on one or the other side of such a cut point will differ from one another by degree, but not kind. Clinically, for school identification of children for special services, this means that "children who do not meet these arbitrarily imposed criteria may still require and profit from special help" in reading (Shaywitz et al. 1992b, p. 149).

RTI: response to intervention

Evidence-based reading instruction: programs and methods for which there is reliable and valid evidence published in a peer-reviewed journal of effectiveness in teaching children to read

EPIDEMIOLOGY OF DYSLEXIA

Prevalence

Reading difficulties are highly prevalent; the specific prevalence rate will reflect the particular definition and cut points established as criteria for identification. For example, results of the 2005 National Assessment of Educational Progress indicate 27% of high school seniors are reading below the most basic levels (minimum level at which a student can demonstrate an understanding of what she or he has read) (Grigg et al. 2007). Even more primary grade students—36% of fourth grade children—are reading below basic levels (Perie et al. 2005). In our epidemiological Connecticut Longitudinal Study sample in which each participant was individually assessed, we found that 17.5% of students were reading below age or ability levels (Shaywitz et al. 1994).

Developmental Course

Converging data indicate that reading difficulties are persistent and do not remit with age or time (Francis et al. 1994, Shaywitz et al. 1995) (**Figure 1**).

This should put an end to the unsupported, but unfortunately, too widely held notion that reading problems are outgrown or somehow represent a developmental lag. The implication is that reading problems expressed early

must be addressed or they will persist with time. Here, also, it is important to keep in mind that the expression of the difficulty may change, so that difficulties with reading accuracy, especially in very bright children, often evolve into relatively accurate, but not fluent, reading. Given the knowledge of the unremitting course of dyslexia, early intervention takes on a new urgency; particularly since the data strongly indicate a much more positive response to interventions that are provided in the very first few years of school compared with those delivered in the later years of primary school (Torgesen et al. 2006).

Phonemes: elemental particles of speech; the smallest unit of speech distinguishing one spoken word from another

Sex Differences in Dyslexia

The belief that reading difficulties affect predominantly or exclusively males reflects the overwhelmingly larger number of boys compared with girls identified by schools as having a reading problem. However, a series of epidemiological studies, including ones that compare school-identified disabled readers with objective, individually assessed, criterion-identified disabled readers, indicate that a referral bias favors boys in school-identification procedures reflecting boys' disruptive classroom behavior (Shaywitz et al. 1990). Since boys are generally more active and impulsive, they are more likely to be identified through traditional school-identification procedures, whereas girls—who are generally quiet and who may struggle to read—often go unnoticed. A range of data now indicate that although there are somewhat more boys, significant numbers of girls struggle to read (Flynn & Rahbar 1994, Shaywitz et al. 1990). Awareness of a student's reading difficulties should not be dependent on overt signs of a behavioral difficulty; the increased reliance on ongoing monitoring of reading fluency (for example, use of dynamic indicators of basic early literacy skills, or DIBELS; Kame'enui et al. 2000) should help to ensure that all children who are failing to make progress will be identified and receive appropriate interventions.

COGNITIVE MODEL OF DYSLEXIA AND ITS IMPLICATIONS

Phonological Theory

Print emerged from the language system, and the relationship between print and spoken language is perhaps best captured by the statement, "Writing is not language, but merely a way of recording [spoken] language by visible marks" (Bloomfield 1933, p. 21). Of the several theories suggested, an explanation reflecting what is known about the relationship between spoken and written language, the phonological model, has received the most support (Hulme et al. 2005, Ramus et al. 2003, Rayner et al. 2001, Shaywitz 2003, Snowling 2000).

Most contemporary approaches to diagnosis and to teaching dyslexic children to read derive from a phonological model of how children gain access to print. In particular, knowledge of this model enables the reader to understand the basis and logic of current evidence-based reading instruction. Here we discuss the nature and educational implications of this model; in a later section, specific evidence-based approaches to reading intervention are presented. To understand why print has meaning and why reading presents a challenge, we first consider the language system and then discuss why reading is more difficult than speaking.

The language system. The language system is conceptualized as a hierarchy of component modules (Fodor 1983); at the lowest level is the phonological module, dedicated to processing the elemental units of language, phonemes. Language is generative; different combinations of just 44 phonemes in the English language produce tens of thousands of words (Abler 1989). The phonological module assembles the phonemes into words for the speaker and disassembles the words back into phonemes for the listener. Reflecting a process referred to as coarticulation, spoken language appears seamless to the listener, with

no clues to its segmental nature (Liberman et al. 1967). Thus, the word "bat" is composed of three phonemes, "b," "aaaa," and "t," but the listener hears this as the holistic word "bat" and not as three separate sounds. It is the seamless nature of spoken language, giving no clue to its underlying segmental nature, that presents a challenge to the would-be reader.

Spoken language is innate, observed in all societies on earth, and has been with us for tens of thousands of years. Exposing a baby to a natural speaking environment results in the development of spoken language; spoken language is spontaneous and does not need to be taught. In contrast, print is artificial; many societies still rely primarily on spoken language. From an evolutionary perspective, print is rather new, only several thousand years old (Lawler 2001). Consequently, as opposed to spoken language, written language is acquired and must be taught. Converging data suggest that the prime challenge for beginning readers is to map the orthography (letters) onto the elemental sounds of spoken language (phonemes), and this serves as the major focus of early reading instruction. However, reflecting the seamless nature of spoken language, perhaps as many as 30% of the population has difficulty noticing the phonemes within words, resulting in difficulty learning to associate the letters with specific sounds within each word (Liberman et al. 1974).

Phonological awareness. Phonological awareness (PA), referring to the ability to recognize, identify, and manipulate syllables and phonemes within spoken language, is at the core of reading and reading difficulties (Snow et al. 1998, Torgesen & Mathes 2000, Wagner & Torgesen 1987). PA predicts reading acquisition (Bradley & Bryant 1983, Hatcher et al. 1994, Hoien et al. 1995) and differentiates good and poor readers (Goswami & Bryant 1990, Wagner & Torgesen 1987), and instruction aimed at improving PA improves reading (Bradley & Bryant 1983; Byrne & Fielding-Barnsley 1995; Byrne et al. 2000; Foorman et al. 1998; Hatcher et al. 1994; Torgesen et al. 1999, 2001). Acquisition of phonological awareness follows a systematic, hierarchical model of word structure, progressing from larger to smaller phonological units (Anthony et al. 2003). Accordingly, children first develop a sensitivity to, or awareness of, spoken whole words, then syllables, then phoneme-level units of language. The latter is referred to as phonemic awareness. Good evidence supports the belief that reading itself is critical for the development of PA. Thus, PA is primarily developed following introduction to reading instruction, independent of age (Goswami & Bryant 1990), and not surprisingly, (illiterate) adults who have never received reading instruction lack phonemic awareness (Morais et al. 1979). The importance of reading instruction to the development of the critical skill of phonemic awareness was demonstrated in a study of four-, five-, and six-year-old children (Liberman et al. 1974) in which none of the four-year-olds, 17% of the five-year-olds, and 70% of the six-year-olds (following a year of schooling and presumed reading instruction) performed well on a test of phonemic awareness. A major advance has been the availability of standardized tests of phonological abilities (e.g., the Comprehensive Test of Phonological Processing; Wagner et al. 1999) that can be administered as early as age five.

Orthography: the specific writing system of a language

Morphemes: the smallest meaningful linguistic units, for example, prefixes, suffixes

Dyslexia in Different Orthographies

Dyslexia has been described in all writing systems, including alphabetic and logographic orthographies (Stevenson et al. 1982). Alphabetic orthographies use letters and letter clusters to represent phonemes, whereas logographic ones (Chinese, Korean, and Japanese Kanji) use characters to represent monosyllabic morphemes of spoken language. Within alphabetic writing systems, dyslexia occurs in languages with highly predictable relations between letters and sounds (e.g., Finnish, German, and Italian) and those described as dense orthographies with a more erratic

Functional magnetic resonance imaging (fMRI): using the magnetic properties of blood to measure blood flow and localize brain processes while subjects perform a cognitive task

relationship between letters and sounds (e.g., especially English, but also Danish, Portuguese, and French) (Caravolas 2005, Goulandris 2003, Ziegler & Goswami 2005). Although dyslexia occurs in all languages, variations in the consistency of the mapping of the orthography to the phonology will influence reading acquisition and strategies, resulting in differences in reading development among languages (Ziegler & Goswami 2005). Of importance from an educational perspective is that the more consistent the letter-sound mappings are, the easier it is for children to learn to read words accurately. Thus, the initial steps of literacy acquisition occur earlier and with more ease in languages such as Finnish and Italian, where there is greater predictability of sound-symbol linkages. Variations in consistency, in turn, will influence the expression of dyslexia across different languages. For example, in orthographies that are more consistent, learning to read words accurately generally occurs readily in dyslexic as well as in good readers. As a result, in these readers, dyslexia may not present itself until later on in school, perhaps after fourth grade or so, and may be expressed only as a problem in reading fluency, with reading accuracy relatively intact (Ziegler & Goswami 2005). The inconsistencies between the sounds and their spellings, not surprisingly, also affect dyslexic children and cause difficulties in spelling. Ziegler & Goswami (2005) posit that these variations will affect how well dyslexic children develop phonemic awareness once literacy instruction begins. They argue that consistent phonemic-letter linkages tend to be held and kept in memory more easily so that they are better instantiated in response to reading instruction; as a result, dyslexic children demonstrate phonological deficits only very early on in these languages. In contrast, in languages such as English, with more unpredictable letter-sounds mappings, deficits in phonemic awareness are noted early on in school and persist through adolescence (Shaywitz et al. 1999) and into adulthood (Bruck & Treiman 1992).

ETIOLOGY

Genetic Influences

Dyslexia is both familial and heritable: The disorder is found in 23% to 65% of the children of parents who are dyslexic, and 40% of the siblings of a dyslexic child are also affected (Pennington & Gilger 1996). Interestingly, a higher heritability for dyslexia has been reported in children with higher IQs (Olson et al. 1999, Wadsworth et al. 2000). Genetic transmission is complex, with both recessive and dominant transmission observed in different cases, with at least 50% or more of the variance explained by genetic factors and the remainder attributed to environmental influences (Olson & Byrne 2005). Linkage studies have implicated genes on four chromosomes—2, 6, 15, and 18—in dyslexia (Fisher & DeFries 2002). At least nine loci have been reported to be associated with the disorder. Much attention has recently centered on DCDC2, located on the short arm (p) of chromosome 6 in band 22 (6p22), and its association with dyslexia has been independently reported by two different investigative groups (Meng et al. 2005, Schumacher et al. 2006). These findings of a strong genetic influence have educational implications: If a child has a parent or sibling who is dyslexic, that child should be considered at risk and observed carefully for signs of a reading difficulty. It is also important to emphasize that a genetic etiology does not constrain a positive response to reading intervention (Torgesen & Mathes 2000; Wise et al. 1999, 2000); once identified, dyslexic children deserve and will benefit from evidence-based interventions.

Neurobiological Influences

Within the past two decades, the development of neuroimaging, particularly functional magnetic resonance imaging (fMRI), has provided investigators and clinicians with the opportunity to examine and treat learning disabilities at a previously dreamed of, but unattainable, level of understanding (Anderson &

Gore 1997, Frackowiak et al. 2004, Jezzard et al. 2001). Using this technology, neuroscientists have been able to identify and localize several interrelated left hemisphere neural networks in reading: an anterior network in the inferior frontal gyrus (Broca's area), long associated with articulation that also serves an important function in silent reading and naming (Fiez & Peterson 1998, Frackowiak et al. 2004), and two in left hemisphere posterior brain regions, one around the parieto-temporal region serving word analysis, the other in the left occipito-temporal region, the word form area, critical for skilled, fluent reading. A number of functional brain imaging studies in disabled readers converge to indicate a failure of left hemisphere posterior brain systems to function properly during reading (Brunswick et al. 1999; Helenius et al. 1999; Horwitz et al. 1998; Paulesu et al. 2001; Rumsey et al. 1992, 1997; Salmelin et al. 1996; Shaywitz et al. 1998) (**Figure 2**). This neurobiological evidence of dysfunction in left hemisphere posterior reading circuits is already present in reading-disabled children and cannot be ascribed simply to a lifetime of poor reading (Seki et al. 2001, Shaywitz et al. 2002, Simos et al. 2000, Temple et al. 2000). Anterior systems, especially involving regions around the inferior frontal gyrus, have also been implicated in disabled readers in reports of individuals with brain lesions (Benson 1994) as well as in functional brain imaging studies (Brunswick et al. 1999, Corina et al. 2001, Georgiewa et al. 2002, Paulesu et al. 1996, Rumsey et al. 1997, Shaywitz et al. 1998). Although dyslexic readers exhibit a dysfunction in posterior reading systems, they appear to develop compensatory systems involving areas around the inferior frontal gyrus in both hemispheres as well as the right hemisphere homologue of the left occipito-temporal word form area (Shaywitz et al. 2002).

Malleability of neural systems for reading. A number of investigators have focused on whether the neural systems for reading are malleable and whether the disruption in these systems in struggling readers can be influenced by a reading intervention. Specific interventions are discussed below; here, we focus on brain imaging as a tool to interrogate the plasticity of these systems and to examine the influence of reading instruction on the development or reorganization (repair) of these neural systems. For example, in a study of second- and third-grade dyslexic and nonimpaired readers, compared with dyslexic readers who received other types of intervention, children who received an experimental evidence-based phonological intervention not only improved their reading but also demonstrated increased activation both in left anterior (inferior frontal gyrus) and left posterior (middle temporal gyrus) brain regions (Shaywitz et al. 2004). These findings indicate that teaching matters and that how children are taught can foster the development of those automatic neural systems that serve skilled reading. Other investigators, too, have found that reading interventions influence neural systems in brain. For example, one study in adults demonstrated greater activation in the left prefrontal cortex after training compared with before training (Temple et al. 2000). Other studies in children have reported intervention-associated changes including fMRI changes in left inferior frontal and posterior areas as well as in right hemisphere and cingulate cortex (Temple et al. 2003); changes in lactate concentration during magnetic resonance spectroscopy in the left frontal regions (Richards et al. 2000); fMRI changes in left frontal and left posterior regions (Aylward et al. 2003); changes in magnetoencephalography in the left superior temporal gyrus (Simos et al. 2002); and changes in fMRI in dyslexic adults in posterior reading systems (Eden et al. 2004). Still to be determined is the precise relationship among the type of intervention, changes in brain activation, and clinical improvement in reading.

fMRI and mechanisms of reading. fMRI has also been very useful in understanding

LPMOT: left posterior and medial occipito-temporal region

LALOT: left anterior and lateral occipito-temporal region

the mechanisms of reading, knowledge that offers the possibility of providing more individualized interventions to dyslexic children and adults. Neurobiological evidence is beginning to emerge to support behavioral data indicating that many dyslexics are not able to make good use of sound-symbol linkages as they mature, and instead, they come to rely on memorized words. Behavioral studies indicate phonologic deficits continue to characterize struggling readers, even as they enter adolescence and adult life (Bruck & Treiman 1992, Shaywitz et al. 1999). In addition, persistently poor adult readers appear to read words by memorization so that they are able to read familiar words but have difficulty reading unfamiliar words. Brain imaging now reveals that such readers demonstrate an aberrant neural connectivity pattern. Thus, in nonimpaired readers, functional connections were observed between the left occipito-temporal word form area and other components of the left hemisphere reading system. In contrast, in persistently poor readers, functional connections were observed between the left occipito-temporal word form area and right frontal neural systems regions associated with memory (Shaywitz et al. 2003).

A more recent fMRI study (Shaywitz et al. 2007) also demonstrates the importance of memory systems in dyslexic readers. This study found that brain regions developing with age in dyslexic readers differ from those in nonimpaired readers, primarily in being localized to a more left posterior and medial (LPMOT), rather than a more left anterior and lateral (LALOT) occipito-temporal region. This difference in activation patterns between dyslexic and nonimpaired readers has parallels to reported brain activation differences observed during reading of two Japanese writing systems, Kana and Kanji. Kana script employs symbols that are linked to the sound or phoneme (comparable to English and other alphabetic scripts); Kanji script uses ideographs where each character must be memorized. In the imaging study of these writing systems, LALOT activation, similar to that seen in nonimpaired readers, occurred during reading Kana. In contrast, LPMOT activation, comparable to that observed in dyslexic readers, was noted during reading of Kanji script (Nakamura et al. 2005), suggesting that the LPMOT region functions as part of a memory-based system. Together, these behavioral and recent neurobiological findings lead us to suppose that as dyslexic children mature, this posterior medial system supports memorization rather than the progressive sound-symbol linkages observed in nonimpaired readers.

Implications of brain imaging studies. The brain imaging studies reviewed above provide neurobiological evidence that illuminates and clarifies current understanding of the nature of dyslexia and its treatment. For example, brain imaging has taken dyslexia from what had previously been considered a hidden disability to one that is visible—the findings of a disruption in posterior reading systems are often referred to as a neural signature for dyslexia.

Important, too, is the demonstration of a disruption in the occipito-temporal or word form system, a system that converging brain imaging studies now show is linked to fluent (automatic, rapid) reading. Disruption in this system for skilled reading has very important practical implications for the dyslexic reader—it provides the neurobiological evidence for the biologic necessity for additional time on high stakes tests (see Accommodations section below).

Studies demonstrating the effects of a reading intervention on neural systems for reading have important implications for public policy regarding teaching children to read: The provision of an evidence-based reading intervention at an early age improves reading fluency and facilitates the development of those neural systems that underlie skilled reading (see section on interventions). fMRI studies focusing on the mechanisms of reading indicate that poor readers rely on memory rather than understanding how letters link

to sounds. Furthermore, these studies underscore the importance of fluency; many bright but struggling readers memorize words and can read them relatively accurately but not automatically, and so they read slowly and with great effort.

Thus, evidence is beginning to emerge to indicate that many dyslexics compensate for their poor reading by memorizing words. The problem, of course, for poor readers, is that memory has a limited capacity. For example, by third or fourth grade, a reader comes across perhaps 3000 or more new words a year. Many of these words are difficult to memorize because they are long, complicated, new, or rare words. Those typical readers who have learned about the sound-symbol organization of written language are able to analyze words based on the letter-sound linkages and have a distinct advantage over the dyslexic reader. The reliance on memory systems in these populations of older disabled readers may have implications for treatment of dyslexia. For example, it suggests that more pragmatic interventions focusing on sight words (such as those occurring in assigned reading materials) and provision of accommodations such as aural presentation of literature (e.g., books on tape; see Accommodations section below) might take on a more significant role in these older dyslexic individuals than would an approach used in younger students that is based primarily on teaching sound-symbol associations.

DIAGNOSIS AND TREATMENT

Diagnosis of Dyslexia

Dyslexia is more than simply a score on a reading test. Reflecting the core phonological deficit, a range of downstream effects is observed in spoken as well as in written language. Phonological processing is critical to both spoken and written language. Although most attention has centered on the print difficulties (and they are the most severe), the ability to notice, manipulate, and retrieve phonological elements has an important function in speaking—for example, in retrieving phonemes from the internal lexicon and serially ordering them to utter the spoken word. Thus, it should not be surprising that problems with spoken language, albeit more subtle than those in reading, are often observed. These include late speaking, mispronunciations, difficulties with word retrieval, needing time to summon an oral response, and confusing words that sound alike, for example, saying "recession" when the individual meant to say "reception." A range of problems are noted in reading (especially small function words and unfamiliar words, slow reading); difficulties in spelling; ability to master a foreign language; handwriting; and attention (Shaywitz 2003). The lack of reading fluency brings with it a need to read "manually" (a process consuming great effort) rather than automatically; the cost of such reading is a tremendous drain on attentional resources. This is often observed in the classroom when struggling readers, asked to read quietly, deplete their attentional resources as they struggle with the print, and consequently appear to be daydreaming or not attending to the assigned reading. Some have posited that the need to call upon exceptional attentional resources during reading leads to the clinical appearance of attentional difficulties, in this instance, secondary to the reading difficulty and not primary (Pennington et al. 1993). That is, it is to be viewed as distinct from a primary attentional problem. In addition, it has long been known that there is also a high comorbidity between dyslexia and attention deficit/hyperactivity disorder, ranging from 15% to 50% (Biederman et al. 1996, Shaywitz et al. 1994). Therefore, both primary and secondary attentional difficulties are often noted in individuals who are dyslexic.

In contrast to these difficulties, other cognitive abilities, including thinking, reasoning, vocabulary, and listening comprehension, are usually intact. Intact higher-level abilities offer an explanation of why reading comprehension is often appreciably above single-word

Phonological processing: a category of oral language processing involved with accessing the specific sounds making up spoken words

reading accuracy and fluency in dyslexia (reviewed in Shaywitz 2003).

Dyslexia is a clinical diagnosis, best made by an experienced clinician who has taken a careful history, observed the child or young adult reading, and administered a battery of tests that assess the child's cognitive ability, academic skills including reading accuracy, fluency, and comprehension, spelling, and mathematics (an area in which skills are often high), and language skills, particularly phonological processing (Marzola & Shepherd 2005, Shaywitz 2003). The uneven peaks and valleys of both cognitive and academic functioning contribute to the clinical picture of dyslexia: a weakness in phonologically based skills in the context of often-stronger cognitive and academic skills in nonreading-related areas.

As children mature, compensation often occurs that results in relatively accurate, but not fluent, reading. Awareness of this developmental pattern is critically important for the diagnosis in older children, young adults, and beyond. The consequence is that such dyslexic older children may appear to perform reasonably well on a test of word reading or decoding; on these tests, credit is given irrespective of how long it takes the individual to respond or if initial errors in reading are later corrected. Accordingly, tests of reading fluency—how quickly and accurately individual words and passages are read—and tests assessing reading rate are keystones of an assessment for, and an accurate diagnosis of, dyslexia.

Teaching Reading to Dyslexic Students

Within the past decade, an evidence-based approach to teaching children (including dyslexic children) to read has emerged. Much of the evidence base was synthesized by the National Reading Panel established by the U.S. Congress in 1998 with a mandate to review existing research on teaching children to read and then to present the data in a Report to Congress. The panel worked for two years reviewing the extant data on teaching children to read published in peer-reviewed journals, performing meta-analyses where the data allowed, and reporting to Congress on its findings in April 2000. As a result of its exhaustive review, the panel found that five essential elements should be incorporated into effective reading instruction—phonemic awareness, phonics, fluency, vocabulary, and comprehension (Rep. Natl. Reading Panel 2000)—and that these are optimally taught systemically and explicitly. These empirically rooted findings converge with what we know about why print has meaning. As noted above, a core deficit in phonological processing is observed in a majority of children and adults with developmental dyslexia (Liberman & Shankweiler 1991). Thus, it is not surprising that a majority of the many recent well-controlled research studies have focused on preventing or remediating these core phonological deficits.

Early Intervention

Probably the most hopeful research has been early intervention studies of children at-risk for dyslexia based on their problems with phonological processing or initial word-identification skills (Lonigan 2003) in kindergarten or the first grade. Both classroom-level interventions (Adams & Carnine 2003, Foorman et al. 1998, Fuchs & Fuchs 2005) and pullout remedial approaches (Blachman 1997, D'Agostino & Murphy 2004, Torgesen et al. 1999, Vellutino et al. 2006) and combinations of classroom and pullout approaches (O'Connor 2000, Simmons et al. 2003, Vaughn et al. 2003) have reported positive results. Although definitions of reading-disabled or dyslexic subjects in these studies varied, on average, large effects sizes (>0.70) were reported. Together, these studies suggest that prevention programs that explicitly focus on phonemic awareness, phonics, and meaning of text in the earliest grades of reading instruction reduce the base rates of at-risk

National Reading Panel: Congressionally mandated in 1998 to review research literature on teaching reading, and in 2000 reported on the most effective methods and approaches

Phonics: an approach to early reading instruction emphasizing letter-sound linkages

students to below 5%. Although one cannot explicitly define such children as having dyslexia because they are typically just learning to read, and it is difficult to define a word-reading deficit at this level of reading development, it appears that these systematic programs can significantly improve core reading skills in the weakest readers at these ages.

Interventions for Older Students

For older students the remedial research literature includes a range of intervention programs, including those described as direct instruction and those that are more strategy based (Swanson et al. 1999). Here, the evidence is less encouraging than for younger children. Investigations using remedial interventions that begin after the second grade indicate it is more challenging to bring children or adults up to expected grade levels once they fall behind, although significant improvements in reading can still occur (effect sizes >0.60). As an example, Lovett et al. (2000) combined a program referred to as an explicit, scripted direct-instruction approach (based on Reading Mastery; Engelmann & Bruner 1988) that focused on phonological analysis and blending of phonemes with a strategy-based program (an expanded and adapted version of the Benchmark program; Gaskins et al. 1986) that focused on teaching children metacognitive strategies to assist in word identification. This combined program, and adaptations of it for different grade levels, have been evaluated with severe dyslexic students in both elementary and middle school in randomized experimental designs with control groups. Results of implementation of such combination programs indicated that this approach resulted in significantly better standardized reading measure outcomes than the individual components alone or other contrast programs (Lovett et al. 2003).

In an intensive eight-week evaluation of two different phonologically based programs, Torgesen et al. (2001) focused on older elementary students with word-reading abilities below the fifth percentile. The investigators showed that these explicit programs resulted in significant improvements in reading on standardized reading measures following the interventions, and many of the students tested in the average range on word identification measures (but not fluency measures). More importantly, the gains made in word identification lasted for more than two years post intervention.

These and many other studies (for more comprehensive reviews, see Fletcher et al. 2007; Shaywitz 2003; Swanson et al. 1999, 2003) have provided the evidence that phonologically based decoding and word recognition skills are "teachable aspects of reading for most children" (Moats & Foorman 1997, p. 188). This corpus of evidence indicates that focused, intense, systematic, and explicit interventions can positively impact word-reading development, with some expected transfer impacting comprehension, in even the most severely disabled dyslexic readers and that many different types of remediation programs can be effective. This is an important finding, for there is often a tendency to search for the one (magical) program that will address all struggling readers' difficulties. Current knowledge supports several types of intervention programs as effective. Evidence is not yet available that would allow the selection of one specific program over others or to support the choice of an individual program that would be specifically more beneficial to particular groups of dyslexic readers.

Beyond Word Accuracy

Fluency. The consistent improvement in phonologically based word attack and decoding skills has not always generalized to accurate, fluent text reading or adequate reading comprehension, the ultimate goal of all reading interventions (Lovett et al. 1989, Torgesen et al. 1997). Moats & Foorman (1997) review this problem and state, "generalization and transfer of decoding proficiency to fluent word recognition and better reading

Scaffolding: a teaching strategy where the teacher provides scaffolds (supports) that facilitate the child's ability. For example, the teacher reads a passage slightly more difficult than the child is able to read by him/herself. The child then reads the same passage repeatedly and gradually learns to read this previously difficult section with facility

comprehension was not automatic . . ." (p. 188), a conclusion that has continued to be echoed by other studies and reviews (Lyon & Moats 1997, Rayner et al. 2001, Rep. Natl. Reading Panel 2000, Snow 2002, Torgesen et al. 1997).

These results and questions have more recently raised significant interest in whether fluency deficits can be treated in reading-disabled and dyslexic subjects and whether such interventions (see Kuhn & Stahl 2003, Rep. Natl. Reading Panel 2000 for more comprehensive reviews) should be focused on connected-text or word-level strategies. Meyer & Felton (1999) found that most fluency programs use repeated reading of connected text, although some newer programs focus on broader developmental models of fluency encompassing both building semantic knowledge and orthographic pattern awareness (Wolf et al. 2000).

As examples of the repeated reading approaches, Stahl & Heuback (2005) and Young and associates (1996) reported significant gains in their poor readers' text reading fluency using connected text methods, whereas Levy and associates (1997) and Tan & Nicholson (1997) focused their interventions at the word level and showed similar but less robust gains in connected text fluency. A key aspect of most fluency-focused intervention programs with dyslexic students is that they require significant reading of connected text with scaffolding support by either peers or teachers. The conceptual framework behind these approaches is that as word identification becomes more automatic, due to increasing orthographic awareness via practice, an improving reader requires less strategic attention on the act of reading as it becomes automatic and can direct more cognitive energy and focus on comprehension of meaning. Kuhn & Stahl's (2003) review of fluency-oriented instructional approaches found that repeated reading of text with scaffolding typically produces gains in fluency and reading-related skills similar to reading the equivalent amounts of nonrepetitive text (average effect sizes 0.35–0.50). This finding suggests that it's the amount of reading that is critical in supporting the development of fluent and automatic reading. Chard and associates' (2002) review of studies specific to students with dyslexia found slightly higher average effect sizes (0.50–0.70) for a range of intervention approaches focused on fluency.

Reading comprehension. Although children and adults with dyslexia are defined by their word identification and decoding problems, some may also have reading comprehension difficulties that are not due to an underlying oral language disorder. Because of this, some researchers have focused on intervention programs aimed at reading comprehension abilities. Most remedial approaches have developed comprehension-related strategy instruction or specific comprehension-related skill instructional types of programs. Strategy-related programs have focused on developing critical thinking skills related to understanding of text and constructing its meaning based on the reader's prior knowledge, prediction of text, monitoring of text structure, and question asking, as examples. Skill-related programs focus more on finding ideas and facts, developing multiple meaning of words and increasing vocabulary, and summarizing text.

Several reviews (Jenkins & O'Connor 2003, Swanson et al. 1999, Vaughn & Klingner 2004) suggest that various types of comprehension-focused intervention studies in reading-disabled children and adults, particularly those using explicit, strategy-focused approaches, were effective. Unfortunately, because of the wide range of methodologies used in these studies and the variety of programmatic approaches, the resulting range of effect sizes seen in comprehension-focused intervention studies of dyslexic students is typically broad (0.20–0.70). It appears that many of these studies support the efficacy of the comprehension-focused remediation programs' ability to teach their specific strategies, but the ability of students to apply those

strategies in new text reading and comprehension situations is less consistent.

Treatment Resisters

In their focus on treatment resisters, Torgesen & Mathes (2000) highlighted a key set of findings across all intervention studies: A number of children and adults do not respond to programs that are shown to be effective in their peers. Such results highlight the heterogeneity of the dyslexia population, but also suggest that no one explicit remedial instructional program, whether focused at the level of word identification, fluency, or comprehension, or any combination of these processes, will be able to successfully address the needs of all such readers. The kinds of issues raised by such consistent findings of treatment-resisters across different interventions focus on contextual or procedural factors rather than content itself. Questions include how best to understand the role of (*a*) instructional intensity (length of intervention, hours of instruction, optimal ratios of teachers to students, reading time, etc.); (*b*) program integrity/fidelity; (*c*) teacher ability/experience; (*d*) program focus/explicitness/multidimensionality; and (*e*) individual student prior instructional experiences/exposure and reading abilities. The ways in which these factors, individually and together, affect treatment outcomes is just beginning to be addressed, particularly for treatment resisters. The answers to these unresolved questions will provide critical information to better understand the ways in which effective instructional programs may affect any specific student with dyslexia.

Response to Intervention

It has become increasingly apparent that several causes exist for students' deficiencies in reading. Such students may be instructional casualties resulting from poor, inappropriate, or noneffective reading instruction. On the other hand, some reading-deficient students have received quality reading instruction but still have not mastered reading due to their underlying individual core phonological and linguistic deficits. In addition, some students have experienced both factors. Such problems are not easily addressed via one-time evaluations or interventions without some developmental perspective and sequential evaluations over time.

The thrust of RTI frameworks (Fuchs & Fuchs 2006) is to address these traditional limitations in the treatment of persons with dyslexia by focusing on change over time. A typical model would screen all students on core academic abilities—in this case reading—and identify those at risk using somewhat liberal criteria (resulting in more false positives). These students are then followed using frequently repeated reading-focused evaluation probes during an academic year (or years) while they are receiving systematic reading instruction. Those students who do not make adequate progress compared with their typically developing peers (comparing the amount of change over a given time period) are then provided with increasingly intense and, as needed, alternative approaches to reading interventions and continue to be monitored over time. Students who receive the best available quality instruction and who do not respond to these increasingly explicit, intense, and alternative approaches over time would then be classified as dyslexic or learning disabled (Presid. Commiss. Excell. Spec. Educ. 2002). Clearly, such multitiered models still depend on measures sensitive to change, definitions of adequate change, validated interventions of increasing intensity, instructional integrity, and a systematic approach at the school/teacher level to ensure that all students are monitored. McMaster and colleagues (2005) have provided one of the better examples of this approach to children across 33 classrooms. Less than 5% of those children who, via the ongoing weekly monitoring of reading, received increasingly intense and ultimately one-on-one instruction were still considered not to have made adequate progress in reading, compared with

nearly 15% of the control classrooms using standard reading instruction and practices. The use of RTI models is expected to be a rapidly growing trend in the school identification of reading difficulties.

Summary of Interventions

Explicit, intense, systematic, and developmentally appropriate interventions are effective and provide an evidence-based approach in treating dyslexia. Interventions focused at word decoding and single-word identification levels have had the most consistent evidence and have been shown to be the most effective, particularly in prevention and early childhood studies. Fluency- and comprehension-focused interventions have had less investigation but have still shown significant, albeit more variable, effects on reading outcomes in these students. Programs that systematically integrate multiple-focused interventions are considered the most effective, although their specific sequencing, degree of overlap, and level of focus on each component during each phase are still open to critical investigation. At this point, determining which instructional program works best is not necessarily important, but rather determining what program works best for what kind of dyslexic student with what kind of characteristics in what kind of implementation.

Overall, significant progress has been made in understanding the cognitive basis of dyslexia and in using this knowledge to inform instructional practices. At the same time, it must be kept in mind that we are only in the early stages of discovering and developing specific reading interventions that will consistently improve all components of reading, including accuracy, fluency, and comprehension. Broad-stroke gains have been made in developing an overall template for providing reading interventions to dyslexic students; however, we await evidence to guide the more fine-grained selection of specific interventions for individual struggling readers at all ages and at all levels of reading ability.

Accommodations

A complete education for a dyslexic student includes evidence-based reading interventions and accommodations. As noted above, intervention data, although promising, have yet to indicate that the gap has been closed in the ability of dyslexic students to read words fluently beyond the first few grades. Accordingly, although dyslexic children will improve their accuracy, deficient fluency continues to be a concern at all grade levels, and increasingly so as children move up into middle and high school and then into postsecondary education.

Accommodations are of three general types: (*a*) those that by-pass the reading difficulty by providing information through an auditory mode, (*b*) those that provide compensatory assistive technologies, and (*c*) those that provide additional time so that the dysfluent reader can demonstrate his/her knowledge.

First, beginning quite early in their schooling, dyslexic readers require alternative modes of acquiring information so that their vocabulary and fund of knowledge better reflect their intellectual level than does their impaired reading ability. Access to recorded materials, whether they are based on the school curriculum or reflect what peers are reading for pleasure, are a necessity for such children if they are to keep up with their classmates and with their own intellectual curiosity and interests. Next, assistive technology, computers, and both print-to-speech as well as speech-to-print software provide further compensation for oft-noted difficulties with handwriting, spelling, and lack of fluency. A major advance has been the convergence of behavioral and neuroimaging data providing evidence for the critical need for extra time on examinations for dyslexic students, particularly as they progress toward high school graduation and beyond. Behavioral data indicating the persistence of dysfluent reading are now supported by neurobiological data demonstrating that the left anterior lateral occipito-temporal (word-form) region responsible for fluent,

rapid reading is disrupted in dyslexic children and adults (Dehaene et al. 2005; Shaywitz et al. 1998, 2003). As the neurobiological data indicate, dyslexic readers develop compensatory neural pathways, and these systems support increased accuracy over time. However, the word-form region does not develop (Shaywitz et al. 2007), and compensatory pathways do not provide fluent or automatic reading. Accordingly, if such students are to demonstrate the full range of their knowledge, provision of additional time on examinations is a necessity to compensate for the lack of availability of the efficient word-form area. Currently, no quantitative data are available to serve as a reliable metric for gauging the specific amount of extra time needed by a student, and this determination is best guided by the student's own experience over the years. Because the persistence of the reading difficulty is indicated by both behavioral and imaging longitudinal data, requiring that students in postsecondary settings be tested every three or five years is not consistent with scientific knowledge. Furthermore, it is extremely expensive and even problematic. As students progress through school to higher grades and compensate in reading accuracy, simple reading measures of word identification fail to capture difficulties in fluent reading and so are often misleading. In addition, since such nonautomatic readers must call upon attentional resources during reading, these students are highly susceptible to noise and other distractions. Study and test taking in quiet, separate rooms allow these dysfluent readers to concentrate and make maximum use of their often strained attentional resources.

In summary, given that dyslexia represents a disparity between an individual's reading and intellectual abilities; accommodations are critical to assure fairness and equity. Contemporary management of dyslexia provides evidence-based accommodations; these include access to recorded materials; computers and print-to-speech software; and additional time on examinations, with the amount of time determined by the student's experience (Shaywitz 2003). Such accommodations are provided based on a student's history, observations of his/her reading aloud, and test results. With the provision of such accommodations, dyslexic students are entering and succeeding in a range of professions, including journalism, literary writing, science, medicine, law, and education (Shaywitz 2003).

SUMMARY POINTS

1. The core concept of dyslexia as an unexpected difficulty in reading has remained invariant over the century since its first description; dyslexia is found in all languages including both alphabetic and logographic scripts.
2. A deficit in phonological processing, accessing the individual sounds of spoken words, represents the core weakness in dyslexia, and its remediation is the focus of early intervention programs for at-risk and struggling readers.
3. Dyslexia is a chronic, persistent difficulty and is neither a developmental lag nor outgrown; the implication is that reading problems must be recognized and addressed early.
4. Evidence-based interventions are now available and have positive effects on reading. The most consistent and largest effect sizes are associated with provision of prevention programs explicitly focused on phonological awareness, phonics, and meaning of text.
5. Intervention programs for children beyond second grade, though effective, are challenging and have produced less-consistent results. Such evidence-based programs focus on systematic, phonologically based instruction and teaching metacognitive

strategies to assist in word identification. No single program is the most effective; many types of remediation programs can be effective.

6. Fluency deficits have proven much more difficult to remediate than word accuracy problems. Many children who respond to programs aimed at improving word identification skills remain dysfluent, slow readers. Approaches that focus on repeated oral reading with feedback and guidance have shown the most consistent positive results. For readers who are not fluent and cannot read individual words automatically, reading remains effortful and slow.
7. Neurobiological studies have revealed differences in the neural circuitry for reading between nonimpaired and dyslexic readers and identified a neural signature for dyslexia. Brain imaging has also indicated a target (the left occipito-temporal word form area) for intervention for skilled or fluent reading and that these systems are malleable and respond to effective reading interventions. Such findings demonstrate the importance and powerful impact of effective reading instruction.
8. Interventions, while promising, have yet to close the gap in the ability of dyslexic children to read fluently; dyslexic children often remain accurate but slow readers. Neurobiological evidence indicates that the failure of the word form area to function properly in dyslexic children and young adults is responsible for their characteristic inefficient, slow reading. Accommodations, particularly the provision of extra time, are essential for dyslexic students to fully demonstrate their knowledge.

FUTURE ISSUES

1. To identify which specific instructional components/programs work best for which specific types of dyslexic students and under what kinds of implementation practices.
2. To identify which specific instructional elements in which specific combination improve fluency and reading comprehension, particularly in older students.
3. To identify the role of attentional difficulties in dyslexic readers.
4. To determine effective methods of identifying at-risk children earlier and more accurately.
5. To determine mechanisms by which the phonology and orthography are integrated in the word form region and how this process could be facilitated.

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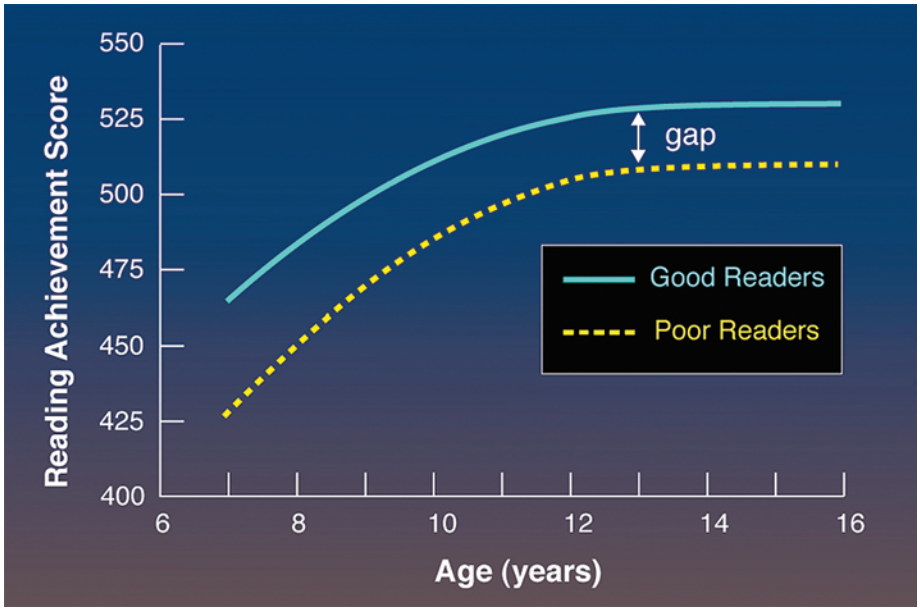

Figure 1

Trajectory of reading skills over time in nonimpaired and dyslexic readers. Ordinate is Rasch scores (W scores) from the Woodcock-Johnson reading test (Woodcock & Johnson 1989) and abscissa is age in years. Both dyslexic and nonimpaired readers improve their reading scores as they get older, but the gap between the dyslexic and nonimpaired readers remains. Thus, dyslexia is a deficit and not a developmental lag. (Figure derived from data in Francis et al. 1996 and reprinted from Shaywitz 2003 with permission.)

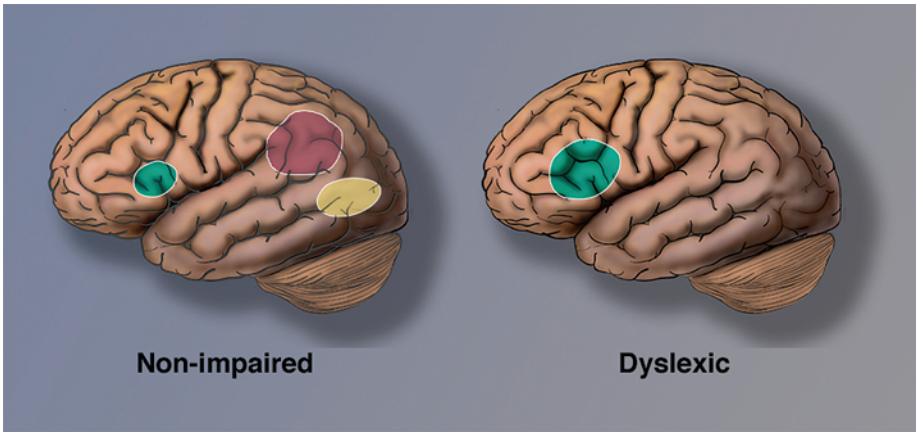

Figure 2

Neural signature for dyslexia. Schematic view of left hemisphere brain systems for reading observed during fMRI in nonimpaired (*left*) and dyslexic (*right*) readers. In nonimpaired readers, three systems are evident: one anterior in the area of the inferior frontal gyrus and two posterior, the top system around the parieto-temporal region and the bottom system around the occipito-temporal region. In dyslexic readers, the anterior system is slightly overactivated compared with systems of nonimpaired readers; in contrast, the two posterior systems are underactivated. This pattern of underactivation in left posterior reading systems is referred to as the neural signature for dyslexia. Figure reprinted from (Shaywitz 2003) with permission.

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