Focus on Basics

CONNECTING RESEARCH & PRACTICE

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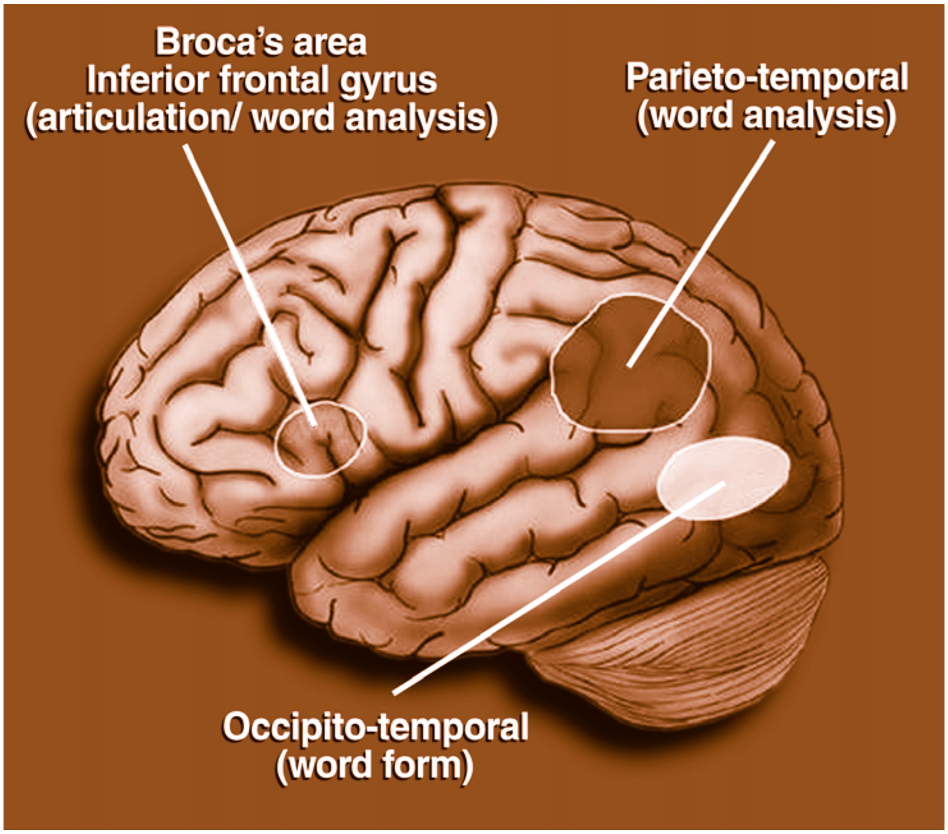
Learning Disabilities



The Neurobiology of Reading and Dyslexia

by Sally E. Shaywitz & Bennett A. Shaywitz

Developmental dyslexia is defined as an unexpected difficulty in reading in adults and children who otherwise possess the intelligence and motivation considered necessary for accurate and fluent reading and who also have had reasonable reading instruction. Dyslexia (or specific reading disability) is the most common and most carefully studied of the learning disabilities, affecting 80 percent of all individuals identified as learning disabled. This article reviews recent advances in the neurobiology of dyslexia and their implications for adults with dyslexia; it provides an update to a previous article we wrote for Focus on Basics.

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Reading and Dyslexia

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Epidemiology of Dyslexia

Epidemiological data indicate that, like hypertension and obesity, dyslexia occurs in gradations and fits a dimensional model. In other words, within the population, reading ability and reading disability occur along a continuum, with reading disability representing the lower tail of a normal distribution of reading ability. Dyslexia is perhaps the most common neurobehavioral disorder affecting children, with prevalence rates ranging from 5 to 17.5 percent. While some may question whether, in fact, so many children are struggling to read, data from the 2005 National Assessment of Educational Progress indicate that only 31 percent of fourth graders are performing at or above proficient levels (Perie et al., 2005).

Dyslexia does not resolve over time. Thus, longitudinal studies, both prospective and retrospective, indicate that dyslexia is a persistent, chronic condition; it does not represent a transient "developmental lag." Over time, poor readers and good readers tend to maintain their relative positions along the spectrum of reading ability; children who early on function at the 10th percentile for reading and those who function at the 90th percentile and all those in-between tend to maintain their positions (Francis et al., 1996).

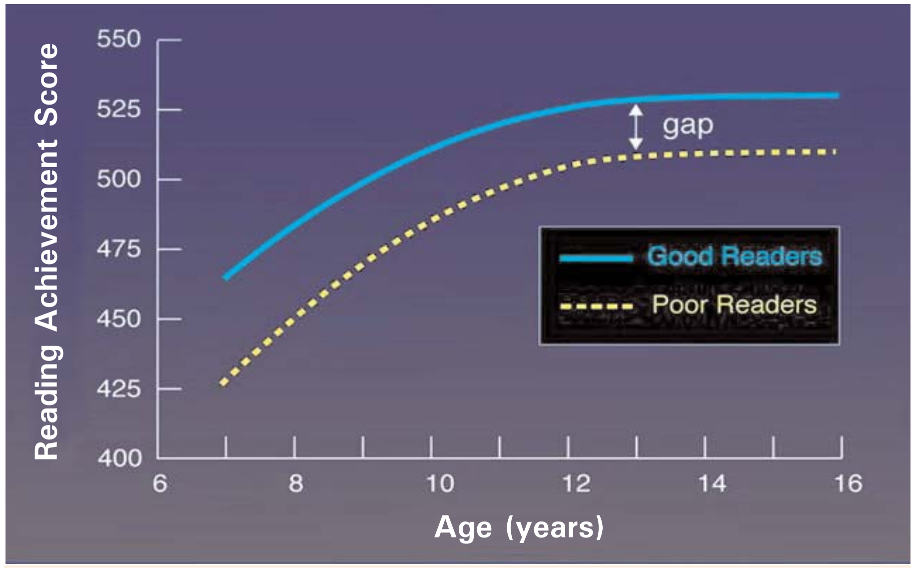

Figure 1. Trajectory of reading skills over time in nonimpaired and dyslexic readers. Ordinate is Rasch scores (W scores) from the Woodcock-Johnson reading test (Woodcock & Johnson, 1989) and abscissa is age in years. Both dyslexic and nonimpaired readers improve their reading scores as they get older, 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 an article by Francis and colleagues (Francis et al., 1996) and reprinted with permission (S. Shaywitz, 2003).

Etiology

Dyslexia is both familial and heritable. Family history is one of the most important risk factors, with 23 percent to as much as 65 percent of children who have a parent with dyslexia reported to have the disorder (reviewed in S Shaywitz, 2003). A rate among siblings of affected persons of approximately 40 percent and among parents ranging from 27 to 49 percent provides opportunities for early identification of affected siblings and often for delayed but helpful identification of affected adults such as a parent of the child known to be dyslexic. Genes on four chromosomes, 2, 6, 15, and 18, have been implicated in dyslexia (Fisher & DeFries, 2002). 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 although a child may have dyslexia on a genetic basis, that child will respond to and benefit from an evidence-based reading intervention.

The Cognitive Basis of Dyslexia

Among investigators in the field, there is now a strong consensus supporting the phonological theory (reviewed in Ramus et al., 2003). This theory recognizes that speech and language are acquired naturally, whereas reading must be taught. To read, the beginning reader must recognize that the letters and letter strings (the orthography) represent the sounds of spoken language. In order to read, a person has to develop the insight that spoken words can be pulled apart into the elemental

Figure 2 (on cover). Neural systems for reading. Three neural systems for reading are illustrated in this figure of the surface of the left hemisphere: an anterior system in the region of the inferior frontal gyrus (Broca's area) believed to serve articulation and word analysis; two posterior systems, one in the parieto-temporal region believed to serve word analysis, and a second in the occipito-temporal region (termed the word-form area) and believed to serve for the rapid, automatic, fluent identification of words. Reprinted with permission (S. Shaywitz, 2003).

particles of speech (phonemes) and that the letters in a written word represent these sounds; such awareness is largely missing in dyslexic children and adults (reviewed in S. Shaywitz, 2003). Results from large and well-studied populations with reading disabilities confirm that in young school-age children as well as in adolescents a deficit in phonology represents the most robust and specific correlate of reading disability (S. Shaywitz et al., 1999). Such findings form the basis for the most successful and evidence-based interventions designed to improve reading.

Implications of the Phonologic Model of Dyslexia

Reading entails two main processes: decoding and comprehension. In dyslexia, a deficit at the level of the phonologic module impairs the ability to segment the spoken word into its underlying phonologic elements and then link each letter(s) to its corresponding sound(s). As a result, the reader experiences difficulty, first in decoding the word and then in identifying it. The phonological deficit is domain-specific; it is independent of other non-phonological abilities. In particular, the higher order cognitive and linguistic functions involved in comprehension, such as general intelligence and reasoning, vocabulary, and syntax, are generally intact. This pattern, a deficit in phonologic analysis contrasted with intact higher-order cognitive abilities, offers an explanation for the paradox of otherwise intelligent, often gifted, creative people who experience great difficulty in reading. According to the model, a circumscribed deficit in a lower-order linguistic function (phonology) blocks access to higher-order language processes. The problem is that the affected reader cannot use his or her higher-order linguistic skills to access the meaning until the printed word has first been decoded and identified.

The Phonologic Deficit in Adolescence and Adult Life

Deficits in phonological coding continue to characterize dyslexic readers even in adolescence; performance on phonological processing contributes most to discriminating dyslexic and average readers, and average and superior readers as well. Children with dyslexia neither spontaneously remit nor do they catch up with their peers in the development of reading skills. That is not to say that many dyslexic readers do not become proficient in reading a finite domain of words that are in their area of special interest, usually words that are important for their careers. For example, an individual who is dyslexic in childhood but who, in adult life, becomes interested in nursing and who then learns to decode words that form a mini-vocabulary important in nursing. Such individuals, while able to decode words in this domain, still exhibit evidence of their early reading problems when they have to read unfamiliar words, which such a person may do accurately, but not fluently and automatically.

In adolescents and adults, oral reading, the rate of reading, as well as facility with spelling may be most useful clinically in differentiating average from poor readers. From a clinical perspective, these data indicate that as children approach adolescence, a manifestation of dyslexia may be a very slow reading rate; in fact, children may learn to read words accurately, but they will not be fluent or automatic, reflecting the lingering effects of a phonologic deficit. Because they are able to read words accurately (albeit very slowly) dyslexic adolescents and young adults may mistakenly be assumed to have "outgrown" their dyslexia. Data from studies of children with dyslexia who have been followed prospectively support the notion that in adolescents, the rate of reading as well as facility with spelling may be most useful clinically in differentiating average from poor readers in students in secondary school, college, and even graduate school (S. Shaywitz, 2003). These older dyslexic students may be similar to their unimpaired peers on untimed measures of word recognition yet continue to suffer from the phonologic deficit that makes reading less automatic, more effortful, and slow. For these readers with dyslexia the provision of extra time is an essential accommodation; it allows them the time to decode each word and to apply their unimpaired higher-order cognitive and linguistic skills to the surrounding context to get at the meaning of words that they cannot entirely or rapidly decode.

"Dyslexia does not resolve over time."

Neurobiological Studies of Disabled Readers

Neural systems influencing reading were first proposed over a century ago by Dejerine, a pioneer in the study of the localization of functions in the brain, in studies of adults who suffered a stroke with subsequent acquired alexia, the sudden loss of the ability to read. It has only been within the last two decades that neuroscientists have been able to determine the neural systems that influence reading and reading disability. This explosion in understanding the neural bases of reading and dyslexia has been driven by the development of functional neuroimaging, techniques that measure changes in metabolic activity and blood flow in specific brain regions while subjects are engaged in cognitive tasks.

A number of research groups, including our own, have used functional brain imaging to examine the functional organization of the brain for reading in non-impaired and dyslexic readers. Converging evidence points to three important neural systems for reading in children and adults: one anterior system and two posterior systems. The anterior system, located around the inferior frontal gyrus, and the posterior system in the parieto-temporal region are involved in word analysis (decoding). A second posterior system located in the occipito-temporal region, an area which Cohen and Dehaene (Dehaene et al., 2005) have termed the visual word-form area, is associated with the ability to read words fluently and automatically, the hallmark of a skilled reader. The figure on the cover illustrates these systems.

These investigations have consistently demonstrated a failure of left hemisphere posterior brain systems to function properly in dyslexic readers and further indicate that dysfunction in left hemisphere posterior reading circuits is already present in dyslexic children and cannot be ascribed simply to a lifetime of poor reading (reviewed in Price & Mechelli, 2005; S. Shaywitz & Shaywitz, 2005). This disruption in posterior neural systems, especially the disruption in the word form area (believed to be where rapid automatic, fluent identification of words occurs) during reading has been termed the "neural signature for dyslexia." The significance of the neural signature for dyslexia can not be overstated. For the first time there is now unequivocal neurobiological evidence that what has always been considered a hidden disability is "real."

fMRI in Reading Interventions

Functional imaging has also been helpful in examining whether the neural systems for reading are malleable and whether the disruption in these systems in struggling readers can be modified by an effective reading intervention. Compared to struggling readers who received other types of intervention, children who received an experimental intervention (which focused on evidence-based application of the alphabetic principle) not only improved their reading but, compared to pre-intervention brain imaging, demonstrated increased activation in the neural systems for reading. Other investigators, too, have found that an effective reading intervention influences neural systems in the brain (reviewed in Shaywitz & Shaywitz, 2005). These data 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 which underlie skilled reading.

Functional Brain Imaging in Adults with Childhood History of Dyslexia

Functional magnetic resonance imaging also has been helpful in clarifying potentially different types of reading disability in adults with a childhood history of dyslexia. We used data from the Connecticut Longitudinal Study, a representative sample of young adults who have been prospectively followed since 1983 when they were age five years and who have had their reading performance assessed yearly throughout their primary and secondary schooling (reviewed in S. Shaywitz, 2003, pages 26-35). Three groups were identified and imaged: 1) non-impaired readers who had no evidence of reading problems; 2) accuracy improved readers who were inaccurate readers in third grade but by ninth grade had compensated to some degree so they were accurate (but not fluent); 3) persistently poor readers who were inaccurate readers in third grade and remained inaccurate and not fluent in ninth grade.

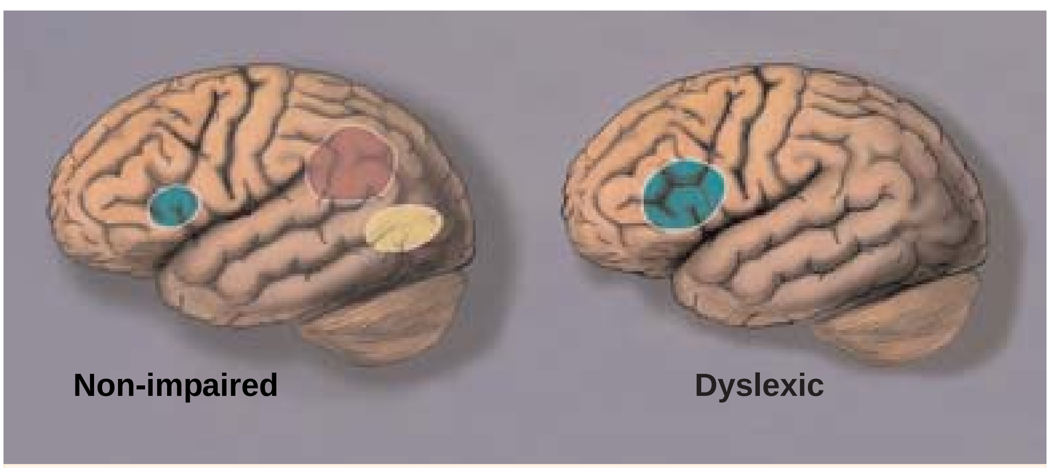

Figure 3. A neural signature for dyslexia. Schematic view of left hemisphere brain systems for reading observed during fMRI in nonimpaired (left) and dyslexic (right) readers. In nonimpaired readers, three systems are evident: one anterior in the area of the inferior frontal gyrus and two posterior, 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 to non-impaired 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 with permission (S. Shaywitz, 2003).

During real word reading, brain activation patterns in the accuracy improved readers and persistently poor readers diverged, with accuracy improved readers demonstrating the typical disruption of posterior systems, but with persistently poor readers activating posterior systems, similar to that observed in non-impaired readers, despite the significantly better reading performance in non-impaired compared to persistently poor readers on every reading task administered. Evidence indicated that rather than decoding words, the persistently poor group was reading primarily by memory.

A more recent fMRI study (B. 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 non-impaired readers, primarily in being localized to a more left posterior and medial, rather than a more left anterior and lateral occipito-temporal region. This difference in activation patterns between dyslexic and non-impaired 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 (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, activation, similar to that seen in non-impaired readers, occurred during reading Kana. In contrast, activation, comparable to that observed in dyslexic readers, was noted during reading of Kanji script, suggesting that the portion of the word form region developing in dyslexic readers functions as part of a memory-based system. The importance of compensatory memory systems in dyslexic readers is significant and may help explain how many very bright dyslexic adults are able to function so well in their chosen professions.

Because it is a longitudinal study, data from the Connecticut Longitudinal Study as early as kindergarten and first grade were available and indicated that the two groups of disabled readers (persistently poor and accuracy improved readers) began school with comparable reading skills but with persistently poor compared to accuracy improved readers, having poorer cognitive, primarily verbal, ability and attending more disadvantaged schools.

These findings suggest that persistently poor readers may be doubly disadvantaged in being exposed to a less rich language environment at home and then less effective reading instruction at school. In contrast, protective factors in the accuracy improved readers, for example, the presence of compensatory factors such as stronger verbal ability and exposure to a richer language environment at home, allowed the accuracy improved readers to minimize, in part, the consequences of their phonologic deficit so that as adults accuracy improved readers were indistinguishable from non-impaired readers on a measure of reading comprehension.

These findings of differences neurobiologically, cognitively, and educationally suggest that the two types of reading disability we observed in the Connecticut Longitudinal sample may represent different etiologies. The compensated group (accuracy improved readers), with early higher verbal ability and a disruption in posterior systems during reading real words may represent a primarily genetic type of reading disability; we would postulate that such children represent the classic dyslexic reader with an unexpected difficulty in reading. Alternatively, the persistent group who score lower on verbal measures early on and who attend more disadvantaged schools, may have their reading difficulties influenced more by environmental factors. Obviously, other factors may be operating as well and some of each factor, genetic and environmental may be contributing to the reading problems of many. On-going studies of genetic differences between these groups may help confirm or refute this hypothesis.

Accommodations

The considerable neurobiological data reviewed above provides strong support for the use of accommodations by the dyslexic reader. Thus, disruption of the word form area means that the dyslexic reader must develop alternate, compensatory neural pathways and these systems support increased accuracy over time. However, the word form region does not develop 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. Such neurobiological findings should make testing agencies, certification boards and others more willing to allow children and adolescents with dyslexia to receive accommodations on high stakes tests.

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Specific accommodations are discussed in detail in *Overcoming Dyslexia* (S. Shaywitz, 2003) and are just briefly reviewed here. 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 older children, a history of reading-related difficulties and lack of fluency are indicative of dyslexia. For older children and adults with dyslexia, accommodations generally involve provision of extra time. This allows dyslexic readers who we now know have a disruption in the word form area influencing skilled, fluent reading to be on a level playing field with their peers who do not have a reading disability.

Accommodations also involve providing the dyslexic student with the use of assistive technologies, allowing the student to acquire information via an aural route rather than through reading. In addition, since such non-automatic readers must call upon attentional resources during reading, they are highly susceptible to noise and 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. This allows dyslexic readers to gain information that their peers are obtaining by reading.

With provision of such accommodations, dyslexic students are entering and succeeding in a range of professions including journalism, literary writing, science, medicine, law, and education. The utilization of advances in neuroscience to inform educational policy and practices provides an exciting example of translational science being used for the public good.

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