Dyslexia and the Brain: What Does Current Research Tell Us?

By: Roxanne F. Hudson, Leslie High, and Stephanie Al Otaiba (2007)

Developmental dyslexia and how it relates to brain function are complicated topics that researchers have been studying since dyslexia was first described over a hundred years ago.

W. Pringle Morgan (cited in Shaywitz, 1996), a doctor in Sussex, England, described the puzzling case of a boy in the British Medical Journal: "Percy … aged 14 … has always been a bright and intelligent boy, quick at games, and in no way inferior to others of his age. His great difficulty has been – and is now – his inability to read" (p. 98).

Almost every teacher in the United States has at least one student who could fit the same description written so many years ago. This situation leads many school personnel to wonder why their articulate, clearly bright student has so many problems with what appears to be a simple task – reading a text that everyone else seems to easily comprehend.

Having information about the likely explanation for and potential cause of the student's difficulties often relieves teachers' fears and uncertainties about how to teach the student and how to think about providing instruction that is relevant and effective. Current research on dyslexia and the brain provide the most up-to-date information available about the problems faced by over 2.8 million school-aged children.

When talking with teachers about their students who struggle with reading, we have encountered similar types of questions from teachers. They often wonder, What is dyslexia? What does brain research tell us about reading problems and what does this information mean for classroom instruction?

The purpose of this article is to explain the answers to these questions and provide foundational knowledge that will lead to a firmer understanding of the underlying characteristics of students with dyslexia. A greater understanding of the current brain research and how it relates to students with dyslexia is important in education and will help teachers understand and evaluate possible instructional interventions to help their students succeed in the classroom.

What is dyslexia?

Dyslexia is an often-misunderstood, confusing term for reading problems. The word dyslexia is made up of two different parts: *dys* meaning not or difficult, and *lexia* meaning words, reading, or language. So quite literally, dyslexia means difficulty with words (Catts & Kamhi, 2005).

Despite the many confusions and misunderstandings, the term dyslexia is commonly used by medical personnel, researchers, and clinicians. One of the most common misunderstandings about this condition is that dyslexia is a problem of letter or word reversals (*b*/*d*, *was*/*saw*) or of letters, words, or sentences "dancing around" on the page (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001).

In fact, writing and reading letters and words backwards are common in the early stages of learning to read and write among average and dyslexic children alike, and the presence of reversals may or may not indicate an underlying reading problem. See Table 1 for explanations of this and other common misunderstandings.

One of the most complete definitions of dyslexia comes from over 20 years of research:

> Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by 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, Shaywitz, & Shaywitz, 2003, p. 2)

Dyslexia is a specific learning disability in reading that often affects spelling as well. In fact, reading disability is the most widely known and most carefully studied of the learning disabilities, affecting 80% of all those designated as learning disabled. Because of this, we will use the terms dyslexia and reading disabilities (RD) interchangeably in this article to describe the students of interest.

It is neurobiological in origin, meaning that the problem is located physically in the brain. Dyslexia is not caused by poverty, developmental delay, speech or hearing impairments, or learning a second language, although those conditions may put a child more at risk for developing a reading disability (Snow, Burns, & Griffin, 1998).

Children with dyslexia will often show two obvious difficulties when asked to read text at their grade level. First, they will not be able to read as many of the words in a text by sight as average readers. There will be many words on which they stumble, guess at, or attempt to "sound out." This is the problem with "fluent word recognition" identified in the previous definition.

Second, they will often show decoding difficulties, meaning that their attempts to identify words they do not know will produce many errors. They will not be very accurate in using letter-sound relationships in combination with context to identify unknown words.

These problems in word recognition are due to an underlying deficit in the sound component of language that makes it very difficult for readers to connect letters and sounds in order to decode. People with dyslexia often have trouble comprehending what they read because of the great difficulty they experience in accessing the printed words.

TABLE 1: Common misunderstandings about students with reading disabilities

Writing letters and words backwards are symptoms of dyslexia.

Writing letters and words backwards are common in the early stages of learning to read and write among average and dyslexic children alike. It is a sign that orthographic representations (i.e., letter forms and spellings of words) have not been firmly established, not that a child necessarily has a reading disability (Adams, 1990).

Reading disabilities are caused by visual perception problems.

The current consensus based on a large body of research (e.g., Lyon et al., 2003; Morris et al., 1998; Rayner et al., 2001; Wagner & Torgesen, 1987) is that dyslexia is best characterized as a problem with language processing at the phoneme level, not a problem with visual processing.

If you just give them enough time, children will outgrow dyslexia.

There is no evidence that dyslexia is a problem that can be outgrown. There is, however, strong evidence that children with reading problems show a continuing persistent deficit in their reading rather than just developing later than average children (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996). More strong evidence shows that children with dyslexia continue to experience reading problems into adolescence and adulthood (Shaywitz et al., 1999, 2003).

More boys than girls have dyslexia.

Longitudinal research shows that as many girls as boys are affected by dyslexia (Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). There are many possible reasons for the overidentification of males by schools, including greater behavioral acting out and a smaller ability to compensate among boys. More research is needed to determine why.

Dyslexia only affects people who speak English.

Dyslexia appears in all cultures and languages in the world with written language, including those that do not use an alphabetic script such as Korean and Hebrew. In English, the primary difficulty is accurate decoding of unknown words. In consistent orthographies such as German or Italian, dyslexia appears more often as a problem with fluent reading – readers may be accurate, but very slow (Ziegler & Goswami, 2005).

People with dyslexia will benefit from colored text overlays or lenses.

There is no strong research evidence that intervention using colored overlays or special lenses has any effect on the word reading or comprehension of children with dyslexia (American Optometric Association, 2004; Iovino, Fletcher, Breitmeyer, & Foorman, 1998).

A person with dyslexia can never learn to read.

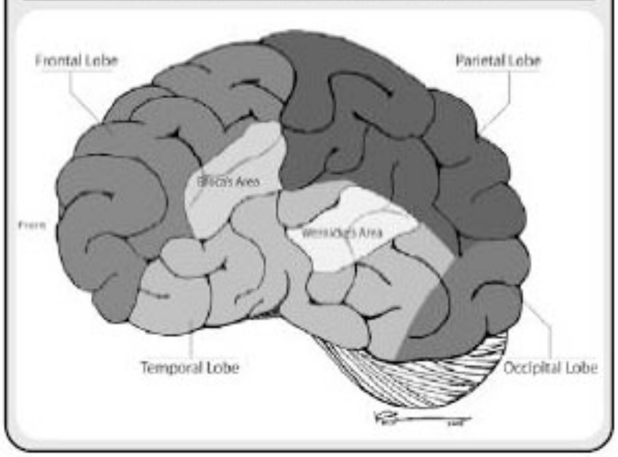
This is simply not true. The earlier children who struggle are identified and provided systematic, intense instruction, the less severe their problems are likely to be (National Institute of Child Health and Human Development, 2000; Torgesen, 2002). With adequately intensive instruction, however, even older children with dyslexia can become accurate, albeit slow readers (Torgesen et al., 2001).

What areas of the brain relate to language and reading?

The human brain is a complex organ that has many different functions. It controls the body and receives, analyzes, and stores information.

The brain can be divided down the middle lengthwise into a right and a left hemisphere. Most of the areas responsible for speech, language processing, and reading are in the left hemisphere, and for this reason we will focus all of our descriptions and figures on the left side of the brain. Within each hemisphere, we find the following four brain lobes (see Figure 1).

FIGURE 1
Left hemisphere of the brain showing lobes and two areas important for language



- The **frontal lobe** is the largest and responsible for controlling speech, reasoning, planning, regulating emotions, and consciousness.

  In the 19th century, Paul Broca was exploring areas of the brain used for language and noticed a particular part of the brain that was impaired in a man whose speech became limited after a stroke. This area received more and more attention, and today we know that Broca's area, located here in the frontal lobe, is important for the organization, production, and manipulation of language and speech (Joseph, Noble, & Eden, 2001). Areas of the frontal lobe are also important for silent reading proficiency (Shaywitz et al., 2002).

- The **parietal lobe** is located farther back in the brain and controls sensory perceptions as well as linking spoken and written language to memory to give it meaning so we can understand what we hear and read.

- The **occipital lobe**, found at the back of the head, is where the primary visual cortex is located. Among other types of visual perception, the visual cortex is important in the identification of letters.

- The **temporal lobe** is located in the lower part of the brain, parallel with the ears, and is involved in verbal memory.

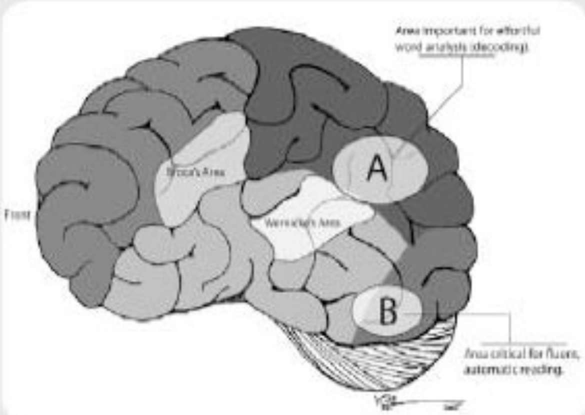
  Wernicke's area, long known to be important in understanding language (Joseph et al., 2001), is located here. This region, identified by Carl Wernicke at about the same time and using the same methods as Broca, is critical in language processing and reading.

In addition, converging evidence suggests that two other systems, which process language within and between lobes, are important for reading (see Figure 2).

The first is the **left parietotemporal system** (Area A in Figure 2) that appears to be involved in word analysis – the conscious, effortful decoding of words (Shaywitz et al., 2002). This region is critical in the process of mapping letters and written words onto their sound correspondences – letter sounds and spoken words (Heim & Keil, 2004). This area is also important for comprehending written and spoken language (Joseph et al., 2001).

The second system that is important for reading is the **left occipitotemporal area** (Area B in Figure 2). This system seems to be involved in automatic, rapid access to whole words and is a critical area for skilled, fluent reading (Shaywitz et al., 2002, 2004).

FIGURE 2
Brain areas in the left hemisphere found to be important for skilled reading (based on the research of B.A. Shaywitz, S.E. Shaywitz, and colleagues)



A = parietotemporal, B = occipitotemporal.

What does brain imaging research tell us about dyslexia?

Structural brain differences

Studies of structural differences in the brains of people of all ages show differences between people with and without reading disabilities.

The brain is chiefly made up of two types of material: gray matter and white matter. Gray matter is what we see when we look at a brain and is mostly composed of nerve cells. Its primary function is processing information.

White matter is found within the deeper parts of the brain, and is composed of connective fibers covered in myelin, the coating designed to facilitate communication between nerves. White matter is primarily responsible for information transfer around the brain.

Booth and Burman (2001) found that people with dyslexia have less gray matter in the left parietotemporal area (Area A in Figure 2) than nondyslexic individuals. Having less gray matter in this region of the brain could lead to problems processing the sound structure of language (phonological awareness).

Many people with dyslexia also have less white matter in this same area than average readers, which is important because more white matter is correlated with increased reading skill (Deutsch, Dougherty, Bammer, Siok, Gabrieli, & Wandell, 2005). Having less white matter could lessen the ability or efficiency of the regions of the brain to communicate with one another.

Other structural analyses of the brains of people with and without RD have found differences in hemispherical asymmetry. Specifically, most brains of right-handed, nondyslexic people are asymmetrical with the left hemisphere being larger than the same area on the right.

In contrast, Heim and Keil (2004) found that right-handed people with dyslexia show a pattern of symmetry (right equals left) or asymmetry in the other direction (right larger than left). The exact cause of these size differences is the subject of ongoing research, but they seem to be implicated in the reading and spelling problems of people with dyslexia.

Functional brain differences

We lack space here for a detailed explanation of imaging techniques. For excellent descriptions of several techniques, readers are directed to Papanicolaou, Pugh, Simos, and Mencl (2004) and Richards (2001).

One commonly used method for imaging brain function is functional magnetic resonance imaging (fMRI), a noninvasive, relatively new method that measures physiological signs of neural activation using a strong magnet to pinpoint blood flow. This technique is called "functional" because participants perform tasks while in (or under) the magnet, allowing measurement of the functioning brain rather than the activity of the brain at rest.

Several studies using functional imaging techniques that compared the brain activation patterns of readers with and without dyslexia show potentially important patterns of differences. We might expect that readers with RD would show underactivation in areas where they are weaker and overactivation in other areas in order to compensate, and that is exactly what many researchers have found (e.g., Shaywitz et al., 1998).

This type of functional imaging research has just begun to be used with children. This is in part because of the challenges involved in imaging children, including the absolute need for the participant's head to remain motionless during the scanning.

We will present the largest, best-specified study as an example of these new findings with children. Shaywitz et al. (2002) studied 144 righthanded children with and without RD on a variety of in- and out-of-magnet tasks. They compared brain activation between the two groups of children on tasks designed to tap several component processes of reading:

- identifying the names or sounds of letters
- sounding out nonsense words
- sounding out and comparing meanings of real words

The nonimpaired readers had more activation in all of the areas known to be important for reading than the children with dyslexia.

Shaywitz et al. (2002) also found that the children who were good decoders had more activation in the areas important for reading in the left hemisphere and less in the right hemisphere than the children with RD.

They suggested that for children with RD, disruption in the rear reading systems in the left hemisphere that are critical for skilled, fluent reading (Area B in Figure 2) leads the children to try and compensate by using other, less efficient systems (Area A in Figure 2 and systems in the right hemisphere).

This finding could explain the common experience in school that even as children with dyslexia develop into accurate readers, their reading in grade-level text is often still slow and labored without any fluency (e.g., Torgesen, Rashotte, & Alexander, 2001).

In summary, the brain of a person with dyslexia has a different distribution of metabolic activation than the brain of a person without reading problems when accomplishing the same language task. There is a failure of the left hemisphere rear brain systems to function properly during reading.

Furthermore, many people with dyslexia often show greater activation in the lower frontal areas of the brain. This leads to the conclusion that neural systems in frontal regions may compensate for the disruption in the posterior area (Shaywitz et al., 2003). This information often leads educators to wonder whether brain imaging can be used as a diagnostic tool to identify children with reading disabilities in school.

Can we screen everyone who has reading difficulties?

Not yet. It is an appealing vision of putting a child we are concerned about in an fMRI machine to quickly and accurately identify his or her problem, but research has not taken us that far.

There are several reasons why a clinical or school-based use of imaging techniques to identify children with dyslexia is not currently feasible. One is the enormous cost of fMRI machines, the computers, and the software needed to run them. Another part of the cost is the staff that is needed to run and interpret the results.

Also, in order for this technology to be used for diagnosis, it needs to be accurate for individuals. Currently, results are reliable and reported for groups of participants, but not necessarily for individuals within each group (Richards, 2001; Shaywitz et al., 2002).

The number of children who would be identified as being average when they really have a problem (false negatives) or as having a problem when they are average (false positives) would need to be significantly lower for imaging techniques to be used for diagnosis of individual children.

Can dyslexia be cured?

In a word, no. Dyslexia is a lifelong condition that affects people into old age. However, that does not mean that instruction cannot remediate some of the difficulties people with dyslexia have with written language. A large body of evidence shows what types of instruction struggling readers need to be successful (e.g., National Institute of Child Health and Human Development, 2000; Snow et al., 1998; Torgesen, 2000).

Now researchers can also "look" inside the brains of children before and after an intensive intervention and see for the first time the effects of the intervention on the brain activity of children with RD. The following are two such studies.

Aylward et al. (2003) imaged 10 children with dyslexia and 11 average readers before and after a 28-hour intervention that only the students with dyslexia received. They compared the two groups of students on out-of-magnet reading tests as well as the level of activation during tasks of identifying letter sounds.

They found that while the control children showed no differences between the two imagings, the students who received the treatment showed a significant increase in activation in the areas important for reading and language during the phonological task. Before the intervention, the children with RD showed significant underactivation in these areas as compared to the control children, and after the treatment their profiles were very similar.

These results must be viewed with caution because of several limitations. One limitation is the lack of specificity about the intervention that was provided, another is the small sample size, and the last is the lack of an experimental control group (i.e., a group of children with RD who did not receive the treatment). Without an experimental control group, we cannot be certain that the intervention caused the changes found in the brain activation because of so many other possible explanations.

Shaywitz et al. (2004) addressed these limitations in their investigation of brain activation changes before and after an intervention. They studied 78 second and third graders with reading disabilities who were randomly assigned to three groups:

- the experimental intervention
- school-based remedial programs
- control

A summary of the instructional intervention is provided in Table 2 and a full and detailed description of the intervention and out-of-magnet reading assessments can be found in Blachman et al. (2004).

TABLE 2: Summary of intervention used in brain imaging study of students with RD

Duration

The individual tutoring intervention occurred daily for 50 minutes from September to June, which yielded an average of 126 sessions or 105 tutoring hours per student.

Instruction

Each session consisted of a framework of five steps that the tutors followed with each student. This framework was not scripted, but was individualized based on the student's progress.

- **Step 1:** Brief and quick-paced review of sound-symbol relationships from previous lessons and introduction of new correspondences.
- **Step 2:** Word work practice of phonemic segmentation and blending with letter cards or tiles, which occurred in a very systematic and explicit fashion.
- **Step 3:** Fluency building with sight words and phonetically regular words made up of previously taught sound-symbol correspondences.
- **Step 4:** Oral reading practice in phonetically controlled text, uncontrolled trade books, and nonfiction texts.
- **Step 5:** Writing words with previously taught patterns from dictation.

Content

The intervention consisted of six levels that began with simple closed syllable words (e.g., *cat*) and ended with multisyllabic words consisting of all six syllable types.

For a complete description of the instructional intervention, see Blachman et al. (2004).

Before the intervention, all groups looked similar in their brain activity, but immediately after the intervention the experimental and control groups had increased activation in the left hemispheric regions important for reading.

One year after intervention, the experimental group showed increased activity in the occipitotemporal region important for automatic, fluent reading (Area B in Figure 2), while at both time points the level of compensatory activation in the right hemisphere decreased.

Shaywitz et al. (2002) concluded, "These findings indicate that … the use of an evidence-based phonologic reading intervention facilitates the development of those fast-paced neural systems that underlie skilled reading" (p. 931).

Important considerations to keep in mind about the brain research

While research advances have allowed us to look more closely within the brain for the first time and revealed important information about how and where we think during reading, there are important considerations that must be remembered.

One is that with the exception of the research by B.E. Shaywitz, S. Shaywitz, and their colleagues, the sample sizes in each study are very small. The evidence from these small studies is converging into results that are reliable, but the results may change as more and more participants are included in the research base. This is especially true with children where both the number of studies and the sample sizes are quite small.

Second, we must consider the type of task being used in the magnet. Because of the requirement that the person's head not move during the imaging, researchers are not able to study people actually reading aloud. Instead, they give tasks that require the person to read silently and then make a decision that he or she indicates with a push button (e.g., Do the letters *t* and *v* rhyme? Do *leat* and *jete* rhyme?).

Because the researchers have worked carefully on these tasks and have specified the particular process that is being measured, we can trust their conclusions about what the activation levels mean; however, the tasks are quite removed from natural classroom reading and should not be interpreted as if they were the same. The area of brain research is developing rapidly; technological advances are being made that will address these issues as time goes on.

Recommendations for teachers

What does all of this information mean for school personnel and their students? Once teachers understand the underlying processes and causes of reading disabilities, they can use this information as they work with students and their families. The following are specific recommendations based on the neurological research:

- Adequate assessment of language processing is important in determining why students struggle to learn to read.

  Dyslexia, or reading disability, is a disorder of the language processing systems in the brain. Specific information about exactly what sorts of weaknesses are present is needed in order to determine the appropriate instruction to meet each student's needs.

- Imaging research confirms that simple tasks can more reliably be interpreted as "red flags" suggesting that a young child may be at risk for dyslexia.

  It is vital to begin using screening and progress monitoring procedures early on to measure children's understanding of sounds in speech, letter sounds in words, and fluent word recognition. Using such assessment in an ongoing way throughout a child's school career can help teachers know what skills to teach and whether a child is developing these skills.

- Explicit, intense, systematic instruction in the sound structure of language (phonemic awareness) and in how sounds relate to letters (phonics) is needed for readers with dyslexia.

  Imaging research confirmed that instruction in the alphabetic principle caused distinct differences in brain activation patterns in the students with RD (Shaywitz et al., 2004). Keep in mind that the intervention was explicit, intense, long term, and specifically focused on phonological processing, phonics, and fluency.

- The roles of motivation and fear of failing are important when discussing reading problems.

  Students do not struggle simply because they are not trying hard enough. They may have a brain difference that requires them to be taught in a more intense fashion than their peers. Without intense intervention, low motivation may develop as students try to avoid a difficult and painful task.

- School personnel can use their knowledge of the neurological characteristics and basis of dyslexia to help their students understand their strengths and weaknesses around reading and language.

  Understanding a possible reason why they find something difficult that no one else seems to struggle with may help relieve some of the mystery and negative feelings that many people with a disability feel. Sharing our knowledge of brain research may demystify dyslexia and help students and their parents realize that language processing is only one of many talents that they have and that they are not "stupid," they simply process language differently than their peers.

Recommendations for parents

The identification of a child with dyslexia is a difficult time for parents and teachers. We suggest that teachers can help parents learn more about their child's difficulty in the following ways:

- Teachers can share information about the student's specific areas of weakness and strength and help parents realize the underlying causes of their child's difficulty.

  This conversation can also include information about how to help their child use areas of strength to support areas of weakness.

- It is critical to help parents get clear about what dyslexia is and is not.

  Sharing the common misconceptions and the correct information found in Table 1 with parents may help clear up any confusion that may exist.

- Early intervention with intense, explicit instruction is critical for helping students avoid the lifelong consequences of poor reading.

Engaging parents early in the process of identifying what programs and services are best for their child will ensure greater levels of success and cooperation between home and school.

- There are many organizations devoted to supporting individuals with RD and their families.

  Accessing the knowledge, support, and advocacy of these organizations is critical for many families. A list of several large organizations to share with parents can be found in Table 3.

- Finally, teachers can often best help families by simply listening to the parents and their concerns for their children.

  Understanding a disability label and what that means for the future of their child is a very emotional process for parents and many times teachers can help by providing a sympathetic ear as well as information.

TABLE 3: Informational resources about dyslexia for parents and teachers

The Council for Exceptional Children, Division for Learning Disabilities

1110 North Glebe Rd., Suite 300,
Arlington, VA 22201-5704, USA
Phone: 1-888-CEC-SPED
URL: ***www.teachingld.org***

The Division for Learning Disabilities (DLD) is a division of the Council for Exceptional Children (CEC), an international professional organization dedicated to improving educational outcomes for individuals with exceptionalities and students with disabilities. DLD works on behalf of students with learning disabilities and the professionals who serve them.

The International Dyslexia Association

Chester Building, Suite 382,
8600 LaSalle Road,
Baltimore, MD 21286-2044, USA
Phone: 1-410-296-0232
URL: ***www.interdys.org***

The International Dyslexia Association (IDA) is a scientific and educational organization dedicated to the study and treatment of dyslexia. IDA focuses its resources in four major areas: information and referral services, research, advocacy, and direct services to professionals in the field of learning disabilities.

Learning Disabilities Association of America

4156 Library Road,
Pittsburgh, PA 15234-1349, USA
Phone: 1-412-341-1515
URL: ***www.ldaamerica.org***

The Learning Disabilities Association of America (LDA) is an organization founded by parents of children with learning disabilities. The LDA works to provide education, encourage research into learning disabilities, create a climate of public awareness, and provide advocacy information and training.

LD OnLine

WETA Public Television,
2775 Quincy Street,
Arlington, VA 22206, USA
URL: ***www.ldonline.org***

LD OnLine is an educational service of public television station WETA in association with the Coordinated Campaign for Learning Disabilities. It features thousands of articles on learning and reading disabilities, monthly columns by experts, a free question-and-answer service, and a directory of professionals and services.

National Center for Learning Disabilities

381 Park Avenue S., Suite 1401,
New York, NY 10016, USA
Phone: 1-888-575-7373
URL: ***www.ncld.org***

The National Center for Learning Disabilities (NCLD) is an organization devoted to working with individuals with LD, their families, educators, and researchers. NCLD provides essential information, promotes research and programs to foster effective learning, and advocates for policies to protect and strengthen educational rights and opportunities.

Imaging research has demonstrated that the brains of people with dyslexia show different, less efficient, patterns of processing (including under and over activation) during tasks involving sounds in speech and letter sounds in words. Understanding this has the potential to increase the confidence teachers feel when designing and carrying out instruction for their students with dyslexia.

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Hudson teaches at the University of Washington (Box 353600, Seattle, WA 98195, USA). E-mail rhudson@u.washington.edu. High teaches in the Taylor County School District, Perry, Florida. Al Otaiba teaches at the Florida Center for Reading Research and Florida State University in Tallahassee.

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