

Examining Reading Development and Reading Disability in Diverse Languages and Cultures: Potential Contributions from Functional Neuroimaging

Kenneth R. Pugh, Rebecca Sandak, Stephen J. Frost, Dina Moore, and W. Einar Mencl

Introduction

Neuroimaging studies suggest that across different languages, skilled reading is supported by similar, largely left hemisphere (LH), organized networks. In addition, studies of reading disability (RD) also suggest a common neurobiological signature for this syndrome across varied orthographies (disruption of LH posterior regions that support fluent reading). Thus, at the neurobiological level of analysis, reading and its disorders appear to be more similar than dissimilar across languages and cultures. There is, however, a paucity of neurobiological research on reading development (and RD) in populations of children at high risk for reading difficulties that might be due, in large part, to environmental factors, such as English Language Learners and Native American children. Using the existing research on RD as a starting point, we consider in this paper how developmental neuroimaging might be applied to: 1) help to discriminate RD readers whose deficits are of a congenital origin from those whose deficits are primarily environmental, and 2) provide potentially sensitive neurobiological outcome measures to help evaluate the efficacy of different approaches to the teaching of reading.

Neuroimaging Research and Reading Disabilities

Literacy acquisition is a major cognitive challenge for any child, and in any population some percentage of children will fail to obtain age-appropriate reading levels (Adams, 1990). For English Language Learners (ELL), especially those children with limited English proficiency (LEP), the challenge can be all the more acute, and the incidence of reading difficulties in this population is alarmingly high. The National Assessment of Educational Progress (NAEP, 2000) reports that LEP students, especially Hispanic students, lag far behind their white and

Asian peers in reading performance. While socioeconomic factors clearly contribute to this reading crisis, the linguistic and cognitive challenges associated with learning to read in a non-primary language are likely to be contributing factors as well (August & Hakuta, 1998; Snow, Burns, & Griffin, 1998). As discussed in detail in this current special issue of the *Journal of American Indian Education*, complex socioeconomic factors and cultural incompatibilities also pose elevated risk for reading difficulties in Native American Children (Demmert, 1995).

Using statistical diagnostic criteria, we would classify many of these children as reading disabled (RD). Although RD, as a gene-linked syndrome, likely occurs with similar frequency in all populations and across all written languages (Grigorenko et al., 1997), because of the struggles inherent in learning to read in a second language, or when cultural differences generate cognitive conflicts, the tendency for misdiagnosis in these children is a serious possibility. In this paper we are charged with addressing two questions. First, can neuroimaging techniques be used to help identify reading problems that are of a congenital origin? This kind of information, if obtainable, could be useful in helping us to distinguish true RD from the reading problems associated with the myriad of environmental and linguistic factors that challenge Native American and ELL children. Second, how might neuroimaging be employed in assessing the efficacy of different approaches to the teaching of reading in these children?

Recent studies with primary monolingual English-speaking cohorts have begun to chart the neurobiological consequences of successful training and remediation programs (Shaywitz et al., 2004; Simos, Breier, Fletcher, Foorman, Castillo, & Papanicolau, 2002; Temple et al., 2003); it would be desirable, we think, to make similar use of neuroimaging in evaluating effects of contrasting approaches to reading instruction for ELL and culturally diverse children. In this paper, we examine several domains of neuroimaging research that may be relevant to beginning to explore these important questions. We broadly consider the evidence from studies of monolingual readers in different languages (and different writing systems) for language-invariant or language-specific circuits, along with the current evidence for language-invariant neurobiological signatures of RD. This research can help to frame our expectations and hypotheses as we further explore reading acquisition (at both the behavioral and neurobiological levels-of-analysis) in multilingual and culturally diverse children. We also review recent studies of effects of intensive remediation on brain organization (plasticity).

Spoken and Written Language in Different Languages

Both historically and ontologically, spoken language capacity develops prior to the derived abilities of reading and writing. While brain organization for spoken language perception and production is, to a large degree at least, a biological specialization, reading by contrast is almost certainly not (Lieberman, 1992). Indeed, reading, unlike speech communication, must be explicitly taught, and

difficulties are more likely for print than for speech.

When considered from the neurobiological perspective, it seems clear that the challenge for the brain at the onset of literacy instruction is to generate a distributed system or “circuit,” comprised of visual, language, and associative brain regions, which when properly trained, will permit access of visual words to already well-instantiated phonological representations (Price, Winterburn, Giraud, Moore, & Nopenney, 2003; Pugh et al., 2000a). Thus, learning to read fluently places a high premium on brain plasticity. Neuroimaging techniques can help us to chart this neurobiological developmental trajectory as well as identify deviation from this trajectory in unsuccessful readers. Moreover, with these trajectories (and deviations) established, we can then determine how different factors in the child’s educational environment impact the neurobiological substrate and, ultimately, reading performance. Thus, in principle, a deeper understanding of why certain remediation techniques result in improved performance for certain individuals might be gained by incorporating neuroimaging techniques with careful behavioral measures. These potentially sensitive markers of brain/environment interactions can provide a biological constraint on our understanding of how culture and language shape the reading brain in the developing child.

Given the biological constraints on spoken language development (and processing), it would seem likely that, despite major differences in morphological and syntactic principles, different languages would tend to have similar neurobiological foundations (language invariance). Data from both lesion studies and functional neuroimaging studies of speech perception and production in multiple languages (cf., Indefrey & Levelt, 2004) are broadly consistent with this expectation (Price, 2003). Left hemisphere (LH) temporal and frontal lobe (perisylvian) language zones are uniformly activated for tasks that engage spoken language processes in diverse languages (Indefrey & Levelt, 2004). However, this general pattern of overlapping circuits across various spoken languages does not imply the absence of any language-specific variation at all. For instance, Valaki et al. (2004), using Magneto-encephalography (MEG), compared Spanish, English, and Mandarin speakers performing a spoken word (memory) processing task. While all three groups showed largely overlapping LH activation patterns, relative to the first two cohorts, Chinese speakers showed reliably greater contributions from the RH during performance of this task. The authors speculated that increased demands on prosodic coding in tonal languages such as Chinese, may promote a heightened RH involvement. Thus, while the general claim that speech perception and production in different languages has a largely uniform neurobiological organization seems to have been clearly established at this point, we should remain cognizant of potential differences among them as well. Of importance to the current discussion, for those representative languages currently being explored in immersion studies, linguistic differences among them might result in moderate differences in brain organization for the spoken form prior to the onset of literacy instruction. Direct comparisons between languages

like Hawaiian and Navajo, for instance, might help to establish predictions about developmental differences in children learning to both speak and read these languages prior to instruction in English.

We must remember that an ELL child (including many Native American children who speak more than one language) is not merely coping with the challenges of learning to read a second language, they are still at a fairly early stage in developing a bilingual brain circuitry for its spoken form. The neurobiological mechanisms associated with becoming a proficient bilingual are actively being investigated in many languages, and many populations at present (e.g., Dehaene et al., 1997; Kim, Relkin, Lee, & Hirsch, 1997; Perani et al., 1998). Some general findings have emerged (see Abutalebi, Cappa, & Perani, 2001, for a discussion) that might help provide some context for thinking about neurobiological development in ELL children. Whereas most studies have reported largely overlapping systems for the spoken forms of their first and second languages (L1 and L2) in fluent bilinguals, the degree of overlap appears to depend heavily upon factors such as age of acquisition, and perhaps most importantly, degree of proficiency, in L2 (see Abutalebi, Cappa, & Perani, 2001, for a discussion). Highly proficient speakers of L2 show greater integration of L1 and L2 in brain than less proficient speakers (Kim et al., 1997; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Perani et al., 1998). Thus, spoken language proficiency in L2, by virtue of its effects on brain organization for speech, might impact the ways in which reading circuits develop as literacy skills are taught. Degree of proficiency in English (L2) will be an important individual difference dimension to keep in mind as we begin to map out neurobiological trajectories for reading and RD in ELL children.

Additionally, as noted above, differences in hemispheric distributions of activation have been reported for Chinese (Valaki et al., 2004), and the unique demands of being bilingual are associated with the need to develop brain mechanisms to cope with the demands of language-switching and suppression (Price, Green, & von Studnitz, 1999). All these types of variables will need to be examined as we begin to chart the neurobiological changes as ELL children learn to master both speech and reading in L2.

At the Santa Fe conference from which this issue of *JAIE* was developed, we heard we heard about progress from highly innovative language immersion programs in four very different languages: Hawaiian, Navajo, Blackfeet, and Yup'ik. The written forms of these languages appear to be very regular with regard to the letter/sound relationships and hence are fairly easy for the child to learn to read. It was suggested that transfer to a more irregular orthography like English might actually be facilitated by learning to read a regular orthography first. This seems highly plausible, but clearly more controlled research will be needed to either confirm or disconfirm this expectation. As a start, we can look to extant research contrasting regular and irregular orthographies to date as discussed below.

Whether (and how) reading skills and their acquisition are influenced by

differences among languages and orthographies is a longstanding question of interest (Perfetti, 2003; Zeigler & Goswami, 2005). Both cognitive and neurobiological research suggests that, although skilled adult reading appears to be highly similar regardless of such differences, greater dissimilarity has been noted in acquisition rates of typically developing (TD) children, and in the characteristics of disabled readers during childhood (Lyytinen et al., 2004).

Word recognition in skilled adult readers does not appear to differ fundamentally across regular and irregular orthographies (Carello, Turvey, & Lukatela, 1992; Frost, 1998; Perfetti, 1985; Perfetti, 2004; Zeigler, Perry, Jacobs, & Braun, 2001). For example, using fast-priming paradigms, Lukatela and Turvey (1994a; Lukatela, Savic, Urosevic, & Turvey, 1997) observed similar and robust effects of sub-lexical phonological processes on word identification latencies for both English and Serbo-Croatian, a highly transparent orthography. Although important language differences have been suggested with respect to the size or type of phonological unit that drives lexical access (e.g., see the German/English comparison study of Goswami, Ziegler, Dalton, & Schneider, 2003; Ziegler et al., 2001), it can be reasonably argued that strong phonological influences on word recognition are generally found across languages that differ in orthographic depth (Frost, Katz & Bentin, 1987; Zeigler & Goswami, 2005). Indeed, there is also provocative evidence that readers of Mandarin Chinese are sensitive to the sub-lexical phonological information contained in the phonetic components of compound words (Lee, Hung, Tse, Lee, Tsai, & Tzeng, 2005; Liu, Chen, & Sue, 2003; Lui & Perfetti, 2003; Perfetti, Zhang, & Berent, 1992), suggesting parallels with findings for alphabetic writing systems. Of course reading will not be entirely uniform in every detail across different orthographies, and this is an active research domain with many outstanding disagreements and debates (see Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Harm & Seidenberg, 1999; Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Korne, 2003), but we argue that word recognition in reading is governed by very similar cognitive principles, and arrives at essentially the same endpoint in skilled reading, in orthographies with very different characteristics (see also Frost, 1998; Perfetti, 1985). In our view, this is due to the universal requirement to develop fast and efficient access to already well-learned (and biologically constrained) phonological forms, which pressures the reader to be maximally sensitive to sub-lexical phonological units in order to facilitate this process (Frost, 1998; Perfetti, 2004; Van Orden, Pennington, & Stone, 1990).

Important cross-linguistic differences have been documented in younger readers; generally, these findings suggest that learning to read is more challenging in less regular orthographies. For TD children, it has been consistently observed that literacy acquisition in English proceeds at a much slower rate (perhaps half as rapidly over the first four years of schooling) than in German or Finnish (Aro & Wimmer, 2003; Ellis et al., 2004; Lyytinen, Guttorm, Huttunen, Hamalainen, Leppanen, & Vesterinen, in press; Seymour, Aro, & Erskine, 2003). Indeed, in a comparison among three alphabetic (English, Greek, Albanian) and two

Japanese (Hirigana, a phonologically regular syllabic system, and Kanji, an irregular logographic system), orthographies, Ellis et al. (2004) found systematically greater rates of gain in word and pseudoword reading with increases in regularity and grain size across these writing systems. In an updated version of the orthographic depth hypothesis (Katz & Frost, 1992), Ziegler and Goswami (2005) suggest that a regular orthography biases processing toward smaller grapheme/phoneme units, while less regular systems like English encourage a greater reliance on larger units (such as rimes). These authors suggest however, that phonological mediation is language-invariant, and that phonological deficits in RD, discussed next, are similarly universal.

RD children in irregular orthographies like English generally show deficits both on accuracy and latencies of word and pseudoword reading. In more regular orthographies such as Finnish or German, while word reading accuracy in RD children approximates TD children, latencies are very much at deficit (Lyytinen et al., 2004); RD readers are exceedingly slow and dysfluent in both regular and irregular orthographies. The hypothesis that RD is attributable to the same core phonological deficit in all languages is tenable (Fowler, 1991; Goswami, 2000; Ziegler & Goswami, 2005). Indeed, it appears likely that reduced precision in representing and processing phonological information may be the universal hallmark of RD (Goswami, 2000).

As we begin to assess reading development and reading disability in immersion programs, we must take careful stock of the characteristics of the writing system with regard to ease of decoding. As suggested by the preceding review, the ways in which congenital reading challenges will manifest might vary across the different writing systems with regard to accuracy but slow and labored reading is expected in all.

Neurobiological Studies in English: The Posterior and Anterior Reading Circuitry in Typical Development and RD

Substantial converging evidence suggests that visual word identification involves a left hemisphere (LH) posterior cortical reading system with ventral, dorsal, and anterior components (Pugh et al., 2000a). The dorsal system includes the angular gyrus and supramarginal gyrus in the inferior parietal lobule, and the posterior aspect of the superior temporal gyrus (Wernicke's Area). This region seems to be involved in mapping visual percepts of print onto the phonological and semantic structures of language (Black & Behrmann, 1994; Geschwind, 1965; Price, 2000). In skilled readers, temporoparietal aspects of the dorsal system (particularly the supramarginal gyrus) respond with greater activity to pseudowords and low frequency words than to familiar words (Simos, Breier, Fletcher, Foorman, Castillo, & Papanicolaou, 2002; Xu et al., 2001). Indeed, in beginning readers who will eventually become skilled readers, our studies suggest that the dorsal system predominates as it first learns to decode print; in RD readers this system is disrupted (Pugh et al., 2000b; Shaywitz et al., 1998, 2002). This is consistent with behavioral studies that implicate skill in the phonological analysis of speech

(measured by phonological awareness tasks and pseudoword reading) as critical predictors of success in early reading acquisition (Bradley & Bryant; 1985; Wagner & Torgesen, 1987). Together, these findings suggest that the dorsal system is associated with decoding and is critical for extracting and learning the relationships between the orthography and its phonological forms (O_P), and connecting these to morphological and semantic information (Price, 2000).

An anterior system centered in posterior aspects of the inferior frontal gyrus (IFG) appears to be associated with phonological recoding during reading, among other functions (e.g., phonological memory, syntactic processing); the more anterior aspects of IFG seem to play a role in semantic retrieval (Poldrack, Wagner, Prull, Desmond, Glover, & Gabrieli, 1999). The phonologically relevant components of this multi-functional system have been found to function in silent reading and in naming (see Fiez & Petersen, 1998 for review) and, like the temporoparietal system, are more strongly engaged by low-frequency words and pseudowords than by high-frequency words (Fiebach, Friederici, Mueller, & von Cramon, 2002; Fiez & Peterson, 1998), and by low frequency words with inconsistent orthographic-to-phonological mappings (e.g., PINT) relative to consistent words (MILL). We have speculated that this anterior system operates in close conjunction with the temporoparietal system to decode new words during normal reading development (Pugh et al., 2000a).

The ventral system appears to be late developing and appears to support fluent reading performance subsequent to initial instruction (Booth et al., 2001; Shaywitz et al., 2002). It includes a LH inferior occipitotemporal/fusiform area and extends anteriorly into the middle and inferior temporal gyri. It has been suggested that occipitotemporal components of this ventral system function as a pre-semantic visual word form area (VWFA) by some researchers (c.f., Cohen, Lehericy, Chochon, Lemer, Rivaud, & Dehaene, 2002, but see Price et al., 2003 for an alternative account). More anterior foci within the ventral system extending into the middle to inferior temporal gyri appear to be semantically tuned (Fiebach et al., 2002, Simos et al., 2002; Tagamets, Novick, Chalmers, & Friedman, 2000). The ventral system, particularly the more occipitotemporal aspect, is also fast-acting in response to linguistic stimuli in skilled readers, but not in reading disabled individuals (Salmelin, Service, Kiesila, Uutela, & Salonen, 1996; Tarkiainen, Cornelissen, & Salmelin, 2003). Indeed, recent studies examining both timing and stimulus-type effects suggest that moving anteriorly through this system, sub-regions respond to word and word-like stimuli in a progressively abstracted and linguistic manner (Tarkiainen et al., 2003).

For both children and adults with reading disabilities, there are marked functional differences with regard to activity generated in the dorsal, ventral, and anterior systems during reading (Brunswick, McCrory, Price, Frith, & Frith, 1999; Paulesu, 2001; Pugh et al., 2000a; Rumsey, Nace, Donohue, Wise, Maisog, & Andreason, 1997; Salmelin et al., 1996; Shaywitz et al., 1998, 2002). Specifically, RD readers tend to under-engage the LH posterior dorsal and ventral systems used by non-impaired readers in word and pseudoword reading; this disruption is also

evident as reduced functional connectivity among these regions during reading (Horwitz, Rumsey, & Donohue, 1998; Pugh et al., 2000b). Instead, they tend to show evidence of two, apparently compensatory, responses to their LH posterior dysfunction: an increased functional role for RH posterior sites (Sarkari et al., 2002; Pugh et al., 2000a; Shaywitz et al., 1998, 2002) and increased bi-hemispheric IFG activation (Brunswick et al., 1999; Shaywitz et al., 1998, 2002).

In our cross-sectional developmental study, we examined changes in the LH circuitry in nonimpaired and RD cohorts ranging in age from seven through 17 (Shaywitz et al., 2002). Multiple regression analyses were employed to examine correlations between activation at different brain regions and reading skill (measured by performance on standard reading tests). The critical finding for typically developing children was that the higher the reading skill, the stronger the response in the LH ventral cortex (with several RH regions showing age- and skill-related reductions). Thus, we argued that a beginning reader on a successful trajectory employs a widely distributed cortical system including RH temporoparietal and frontal regions. As reading skill increases, these regions still play some role, but importantly, the LH ventral system appears to become the critical support for fluent recognition of printed (word) stimuli (see Booth et al., 2001; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003 for similar findings). In contrast, for children who are reading disabled, this pattern of ventral development is disrupted. This disruption is characterized neurobiologically by 1) poorly developed LH dorsal and ventral function, 2) increased reliance with age on the anterior system and 3) an increased tendency with age to engage RH homologues to the dysfunctional LH posterior circuits (Sarkari et al., 2002; Shaywitz et al., 2002).

The functional neuroanatomy of word recognition (and sentence processing) in reading has been investigated in a variety of languages (which employ both alphabetic and non-alphabetic writing systems) in recent years (e.g., Chee, Tan, & Thiel, 1999; Fiebach et al., 2002; Kuo et al., 2003; Paulesu et al., 2000; Salmelin et al., 1996). Neuroimaging studies of alphabetic languages implicate a set of left hemisphere cortical regions including occipitotemporal, temporoparietal, and inferior frontal networks; these networks are almost always engaged in reading irrespective of the specific language and/or writing system under investigation. Language-specific differences appear to be most a matter of degree, not of kind. That is, in one language, a given neural network might be more or less activated than in another language, but the general circuit appears similar in its taxonomic organization (Paulesu et al., 2000). It has been suggested that these relative differences in the “weighting” of one or another network within the broad reading circuit might be associated with variation in processing demands associated with factors such as the orthographic depth of the writing system (Paulesu et al., 2000). This overlap is perhaps not surprising given the evidence for similar demands on sub-word processing. Even in languages with orthographies as distinct as Chinese broadly similar activation has been reported at occipitotemporal, temporoparietal, and inferior frontal sites (Kuo et al., 2003).

Some differences have been reported for Chinese reading at both superior parietal (Kuo et al., 2003), and left middle frontal regions (Tan, Liu, Perfetti, Spinks, Fox, & Gao, 2001), but overall the reading networks are largely similar to those observed for alphabetic writing systems (Kuo et al., 2003).

These similarities across languages, at both the behavioral and brain levels-of-analysis, would lead us to anticipate a highly integrated reading circuitry for L1 and L2 in fluent bilingual readers; though a good deal of pressure on the brain for both integration and for maintaining distinctions would follow from this common neural system (Price, 1999). Bilingual reading studies appear to reinforce this expectation, at least for readers proficient in L1 and L2 (e.g., Chee et al., 1999; Illes et al., 1999; Price et al., 1999).

A body of evidence is accumulating suggesting that there are many commonalities in the ways in which reading disability manifests across languages (e.g., early problems in metalinguistic processing and phonological decoding; Wimmer, 1993; Ziegler et al., 2003). Given this behavioral evidence, and given the evidence for common circuits in different written languages, we might expect language-invariant neurobiological signatures to be associated with reading disability as well. The evidence to date from alphabetic languages is supportive of this expectation (Paulesu et al., 2001; Salmelin et al., 1996; Shaywitz et al., 2002). Functional disruptions in LH posterior cortex (particularly the occipitotemporal region) in RD individuals performing reading tasks during neuroimaging have been found in several languages varying in orthographic depth (English, Finnish, German, French, Italian). This common neurobiological signature, within a largely language-invariant circuitry for reading in the LH, reinforces the need to understand reading development and reading remediation from a cross-linguistic perspective. A recent study of Chinese RD readers (Siok, Perfetti, Jin, & Tan, 2004) reported a language-specific difference in the RD signature (specifically diminished activation of middle frontal regions for RD readers relative to controls). This finding has not been reported in alphabetic languages. However, these authors also found diminished activation in RD readers at the same LH occipitotemporal region previously reported by Paulesu and others in RD within alphabetic languages (Brunswick et al., 1999; Paulesu et al., 2001; Salmelin et al., 1996; Shaywitz et al., 2002). More studies need to be done in non-alphabetic writing systems to examine the implications of both the similarities and the differences with respect to RD; such studies will be critical in establishing the generality neurobiological profiles of RD.

Neurobiological effects of successful reading remediation. Converging evidence from other studies supports the notion that gains in reading skill resulting from intense reading intervention are associated with a more “normalized” localization of reading processes in the brain. In a recent MEG study, eight young children with severe reading difficulties underwent a brief but intensive phonics-based remediation program (Simos et al., 2002). After intervention, the most salient change observed on a case-by-case basis was a robust increase in the apparent

engagement of the LH temporoparietal region, accompanied by a moderate reduction in the activation of the RH temporoparietal areas. Similarly, Temple et al. (2003) used fMRI to examine the effects of an intervention (FastForward) on the cortical circuitry of a group of 8- to 12-year-old children with reading difficulties. After intervention, increased LH temporoparietal and inferior frontal increases were observed. Moreover, the LH increases correlated significantly with increased reading scores. In a recent collaborative study with Dr. Benita Blachman of Syracuse University, we examined three groups of young children (average age was 6.5 years at Time 1) with fMRI and behavioral indices (Shaywitz et al., 2004). A treatment RD group received nine months of an intensive phonologically-analytic intervention (Blachman et al., 1999), and there were two control groups: a typically developing and an untreated RD group. Relative to RD controls, RD treatment participants showed reliable gains on reading measures (particularly on fluency-related measures). Pre- and post-treatment fMRI employed a simple cross modal (auditory/visual) forced choice letter match task. When RD groups were compared at post-treatment (Time 2), reliably greater activation increases in LH reading related sites were seen in the treatment group. When Time 2 and Time 1 activation profiles were directly contrasted for each group it was evident that both RD treatment and typically developing, but not RD controls, showed reliable increases in LH reading related sites. Prominent differences were seen in LH IFG, and importantly in LH ventral skill zone. These changes were quite similar to the NI controls as they also learned to read. Importantly, the treatment group returned one year post-treatment for a follow up fMRI scan and progressive LH ventral increases along with decreasing RH activation patterns were observed even one year after treatment was concluded. All these initial neuroimaging treatment studies suggest that a critical neurobiological signature of successful intervention, at least in younger children, appears to be increased engagement of major LH reading-related circuits, and reduced compensatory reliance on RH homologues.

Identifying RD in Diverse Populations

To address the question of how neuroimaging might help to identify markers of RD within ELL and culturally diverse populations, we begin by considering the language-invariant disruption of LH ventral cortex reported thus far (e.g., Paulesu et al., 2001; Rumsey et al., 1997; Salmelin et al., 1996; Shaywitz et al., 1998, 2002). However, because this ventral system, critical in fluent reading skills, appears to be relatively late-emerging for typically developing readers (Shaywitz et al., 2002), for beginning ELL readers (or any population of reading novices) patterns of activation in this region might not be terribly diagnostic of RD at the onset of literacy instruction. But, measuring success or failure in training-up this system (over time) and determining how this varies with type of reading instruction focus on the ventral system might provide a means of better understanding individual differences in developmental trajectories within ELL cohorts.

The apparent disruption of LH temporoparietal regions with the

corresponding RH shift during language tasks (Sarkari et al., 2002; Shaywitz et al., 2002; Simos et al., 2000) might be more diagnostic of RD, even in beginning ELL readers, and this should be investigated carefully. The disruption of the those LH temporoparietal regions critical for learning to integrate orthography, phonology, and semantics, has been observed even in beginning readers (Simos et al., 2002) and is evident even during performance of spoken language tasks (Rumsey et al., 1997; Temple et al., 2003). Thus, a RH shift within the temporoparietal system for L1 and or L2 might be diagnostic of RD in ELL children even during the earliest stages of reading instruction (Simos et al., 2001). Indeed, the degree to which adequate integration and distinctiveness is developed for the spoken forms of L1 and L2, likely depends on intact temporoparietal function from the outset; therefore we hypothesize that anomalies in activation patterns in this system might be the key neurobiological variable predicting success or failure in developing an optimized LH reading circuitry over time in these children. Longitudinal studies will be crucial in testing this hypothesis.

With a goal of identifying latent RD in ELL and culturally diverse children, diagnostic markers for RD outside of the language domain should be examined as well. For example, several studies have observed anomalous responses to simple visual motion detection in MT/V5 for RD readers (Demb, Boynton, & Heeger, 1998; Eden, VanMeter, Rumsey, Maisog, Woods, & Zeffiro, 1996). This type of non-language neurobiological marker might help to identify at-risk children early, even for populations where matching on language experience is not possible. In addition, many technologies are available to examine structural and neurochemical factors in RD, and many intriguing findings regarding some RD markers have been reported at these levels of analysis (Klingberg et al., 2000; Habib, 2000). These sorts of neurophysiological indices might be extremely helpful in identifying latent RD in struggling populations of ELL children, where functional imaging is complicated by performance variation.

We might also begin to search for potential anomalies in the neurobiological circuits supporting more complex cognitive operations such as attentional control, response inhibition, and verbal working memory; these domains are likely critical to success both in language switching and language integration in ELL readers. There is little guidance from the existing studies thus far on how these variables might relate to latent RD, but given the unique demands that bilingualism places on brain systems, research of this sort has real potential to broaden our understanding of ELL development in general.

Finally, beyond the question of identifying RD within ELL populations, functional neuroimaging can be particularly helpful in assessing the efficacy of different approaches to the teaching of reading in ELL (Simos et al., 2002). As seen in recent remediation studies in monolinguals (Simos et al., 2002; Shaywitz et al., 2004; Temple et al., 2003), successful training approaches have profound effects of normalizing LH trajectories in struggling readers. Reduced RH reliance and increased LH activation following training has been seen in all of these remediation studies (each compared pre and post intervention activation profiles).

These studies converge to indicate that development of the LH posterior reading system constitutes an important neurobiological outcome variable associated with successful instruction and remediation. Thus, functional neuroimaging might be used in this manner to help in evaluating the sorts of reading instruction that work best for ELL children whether at risk for RD or not. Finding a neurobiological signature of successful intervention/instruction (e.g., LH posterior increases) can help to discriminate between “better or worse” approaches that might all produce some transient gains in reading performance. Indeed, neurobiological measures allow in principle for outcome measures (increased LH response) that would be expected with successful training in any written language; thus cross language comparisons such as those demanded in evaluating the innovative immersion programs discussed at this meeting, will be helped by developing good neurobiological targeted effects.

In conclusion, the extant cross-language research on the brain organization for speech and reading in monolingual and bilingual populations suggests that, while the rate of acquisition may differ between these populations, the development of an optimal reading circuitry in ELL and culturally diverse children should follow a similar trajectory and a predictable course with respect to localization. Moreover, several potential neurobiological markers for RD have been identified (both language and non-language based) which we believe will be helpful in distinguishing latent RD from environmental factors in children in any language environment.

Kenneth R. Pugh is a research scientist at the Yale University School of Medicine (Pediatrics) and holds an appointment as Senior Scientist at the Haskins Laboratories, New Haven, CT. His primary research interests are in the areas of cognitive neuroscience and psycholinguistics. His current research examines the effects of training and remediation on the developing neurocircuitry associated with reading. Dr. Pugh is the director of the Yale Reading Study, an NIH-funded project examining reading development and disability in adolescence

Rebecca Sandak is Senior Scientist at Haskins Laboratories. Her research is focused on understanding the cognitive processes underlying skilled and impaired reading, reading acquisition, and successful reading instruction and remediation. In her recent work she has been employing functional neuroimaging (fMRI) to investigate how learning conditions, reading expertise, and reading strategies influence the cortical areas that are recruited for reading.

Stephen J. Frost is Senior Scientist at Haskins Laboratories, New Haven, CT. His research interests include the role of phonology in reading and whether the processing of spoken and written language is supported by a common phonology. Most recently, he has been using functional neuroimaging (fMRI) to extend this research to the understanding of the cortical systems supporting reading acquisition, development, and reading skill.

Dina Moore is an assistant professor in the Department of Psychology at Southern Connecticut State University and a Research Affiliate at Haskins Laboratories in New Haven, CT. Her current research focuses on cognitive and language development employing both behavioral and neuroimaging methodologies.

Einar Mencl is Director of Neuroimaging for Haskins Laboratories. His research integrates multi-modal neuroimaging with computational modelling in the study of language and general cognitive development. He received his Ph.D. in cognitive psychology from Dartmouth College.

References

- Abutalebi, J., Cappa, S. F., & Perani, D. (2001). The bilingual brain as revealed by functional neuroimaging. *Bilingualism: Language and Cognition*, 4(2), 179-190.
- Adams, M. J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge, MA: MIT Press.
- Aro, M., & Wimmer, H. (2003). Learning to read: English in comparison to six more regular orthographies. *Applied Psycholinguistics*, 24(4), 621-635.
- August, D., & Hakuta, K. (Eds.) (1998). *Educating language-minority children*. Committee on Developing a Research Agenda on the Education of Limited-English-Proficient and Bilingual Students, National Research Council and Institute of Medicine.
- Black, S. E., & Behrmann, M. (1994). Localization in alexia. In A. Kertesz (Ed.), *Localization and neuroimaging in neuropsychology* (pp. 331-376). New York: Academic Press.
- Booth, J. R., Burman, D. D., et al. (2001). The development of specialized brain systems in reading and oral-language. *Child Neuropsychology*, 7(3), 119-141.
- Bradley, L., & Bryant, P. (1985). *Rhyme and reason in reading and spelling*. Ann Arbor: Univ. of Michigan Press.
- Brunswick, N., McCrory, E., Price C., Frith, C. D., & Frith, U. (1999). Explicit and implicit processing of words and pseudowords by adult developmental dyslexics: A search for Wernicke's Wortschatz. *Brain*, 122(Pt 10), 901-1917.
- Carello, C., Turvey, M. T., & Lukatela, G. (1992). Can theories of word recognition remain stubbornly nonphonological? In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp 211-226). Oxford: North-Holland.
- Chee, M. W. L., Tan, E. W. L., & Thiel, T. (1999). Mandarin and English single word processing studied with functional magnetic resonance imaging. *The Journal of Neuroscience*, 19(8), 3050-3056.
- Cohen, L., Lehericy, S., Chochon, F., Lemer, C., Rivaud, S., & Dehaene, S. (2002). Language-specific tuning of visual cortex? Functional properties of the Visual Word Form Area. *Brain*, 125(Pt 5), 1054-1069.
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108(1), 204-256.
- Dehaene, S., Dupoux, E., Mehler, J., Cohen, L., Paulesu, E., Perani, D., van de Moortele, P. F., Lehericy, S., & Le Bihan, D. (1997). Anatomical variability in the cortical representation of first and second language. *Neuroreport*, 8(17), 3809-3815.
- Demb, J. B., Boynton, G. M., & Heeger, D. J. (1998). Functional magnetic resonance imaging of early visual pathways in dyslexia. *Journal of Neuroscience*, 18(17), 6939-6951.

- Demmert, W. (1995). Indian Nations at risk: An educational strategy for action. In L. I. Rendon & R. O. Hope (Eds.), *Educating a new majority* (pp. 231-262). Jossey-Bass Publishers: San Francisco.
- Eden, G. F., VanMeter, J. W., Rumsey, J. M., Maisog, J. M., Woods, R. P., & Zeffiro, T. A. (1996). Abnormal processing of visual motion in dyslexia revealed by function brain imaging. *Nature*, *382*(6586), 66-69.
- Ellis, N. C., Natsume, M., Stavropoulou, K., Hoxhallari, L., van Daal, V. H. P., Polyzoë, N., Tsipa, M., & Petalas, M. (2004). The effects of orthographic depth on learning to read alphabetic, syllabic, and logographic scripts. *Reading Research Quarterly*, *39*(4), 438-460.
- Fiebach, C. J., Friederici, A. D., Mueller, K., & von Cramon, D. Y. (2002). fMRI evidence for dual routes to the mental lexicon in visual word recognition. *Journal of Cognitive Neuroscience*, *14*(1), 11-23.
- Fiez, J. A., & Peterson, S. E. (1998). Neuroimaging studies of word reading. *Proceedings of the National Academy of Sciences*, *95*(3), 914-921.
- Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. Brady & D. P. Shankweiler (Eds.), *Phonological processes in literacy: A tribute to Isabelle Y. Liberman* (pp. 97-118). Hillsdale, NJ: Erlbaum.
- Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: a multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(1), 104-115.
- Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True issues and false trails. *Psychological Bulletin*, *123*(1), 71-99.
- Geschwind, N. (1965). Disconnexion syndromes in animals and man: Part 1. *Brain*, *88*, 237-294.
- Goswami, U. (2000). Phonological representations, reading development and dyslexia: Towards a cross-linguistic theoretical framework. *Dyslexia*, *6*(2), 133-151.
- Goswami, U., Ziegler, J. C., Dalton, L., & Schneider, W. (2003). Nonword reading across orthographies: How flexible is the choice of reading units? *Applied Psycholinguistics*, *24*(2), 235-247.
- Grigorenko, E. L., Wood, F. B., Meyer, M. S., Hart, L. A., Speed, W. C., Shuster, A., & Pauls, D. L. (1997). Susceptibility loci for distinct components of developmental dyslexia on chromosomes 6 and 15. *American Journal of Human Genetics*, *60*(1), 27-39.
- Habib, M. (2000). The neurological basis of developmental dyslexia: An overview and working hypothesis. *Brain*, *123*(Pt 12), 2372-2399.
- Harm, M. W., & Seidenberg, M. S. (2004). Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes. *Psychological Review*, *111*(3), 662-720.
- Horwitz, B., Rumsey, J. M., & Donohue, B. C. (1998). Functional connectivity of the angular gyrus in normal reading and dyslexia. *Proceedings of the National Academy of Sciences*, *95*(15), 8939-8944.
- Illes, J., Francis, W. S., Desmond, J. E., Gabrieli, J. D. E., Glover, G. H., Poldrack, R., Lee, C. J., & Wagner, A. D. (1999). Convergent cortical representation of semantic processing in bilinguals. *Brain and Language*, *70*(3), 347-363.
- Indefrey, P., & Levelt, W. J. M. (2004). The spatial and temporal signatures of word production components. *Cognition*, *92*(1-2), 101-144.
- Katz, L., & Frost, R. (1992). The reading process is different for different orthographies: The orthographic depth hypothesis. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning*. Oxford, England: North-Holland.
- Kim, H. S., Relkin, N. R., Lee, K. M., & Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature*, *388*(6638), 171-174.

- Klein, D., Milner, B., Zatorre, R. J., Meyer, E., & Evans, A. C. (1995). The neural substrates underlying word generation: A bilingual functional-imaging study. *Proceedings of the National Academy of Science*, 92(7), 2899-2903.
- Klingberg, T., Hedehus, M., Temple, E., Salz, T., Gabrieli, J. D., Moseley, M. E., & Poldrack, R. A. (2000). Microstructure of temporo-parietal white matter as a basis for reading ability: evidence from diffusion tensor magnetic resonance imaging. *Neuron*, 25(2), 493-500.
- Kuo, W. J., Yeh, T. C., Lee, C. Y., Wu, Y. T., Chou, C. C., Ho, L. T., Hung, D. L., Tzeng, O. J. L., & Hsieh, J. C. (2003). Frequency effects of Chinese character processing in the brain: an event-related fMRI study. *Neuroimage*, 18(3), 720-730.
- Lee, C., Hung, D. L., Tse, J. K., Lee, C., Tsai, J., & Tzeng, O. J. (2005). Processing of disyllabic compound words in Chinese aphasia: Evidence for the processing limitations account. *Brain and Language*, 92(2), 168-184.
- Liberman, A. M. (1992) The relation of speech to reading and writing. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 167-178). Amsterdam: Elsevier.
- Liu, In-M., Chen, S-C., & Sue, L-R. (2003). Regularity and Consistency Effects in Chinese Character Naming. *Chinese Journal of Psychology*, 45, 29-46.
- Liu, Y., & Perfetti, C. A. (2003). The time course of brain activity in reading English and Chinese: An ERP study of Chinese bilinguals. *Human Brain Mapping*, 18(3), 167-175.
- Lukatela, G., & Turvey, M. T. (1994a). Visual lexical access is initially phonological: 1. Evidence from associative priming by words, homophones, and pseudohomophones. *Journal of Experimental Psychology: General*, 123(2), 107-128.
- Lukatela, G., Savic, M., Urosevic, Z., & Turvey, M. T. (1997). Phonological ambiguity impairs identity priming in naming and lexical decision. *Journal of Memory and Language*, 36(3), 360-381.
- Lyytinen, H., Guttorm, T., Huttunen, T., Hamalainen, J., Leppanen, P. H. T., & Vesterinen, M. (in press). Psychophysiology of developmental dyslexia: A review of findings including studies of children at risk for dyslexia. *Journal of Neurolinguistics*.
- Lyytinen, H., Aro, M., Eklund, K., Erskine, J., Guttorm, T., Laakso, M., Leppanen, P. H. T., Lyytinen, P., Poikkeus, A., Richardson, U., & Torppa, M. (2004). The development of children at familial risk for dyslexia: Birth to early school age. *Annals of Dyslexia*, 54(2), 184-220.
- National Assessment of Educational Progress (2000). [On-line] Available: <http://nces.ed.gov>.
- Paulesu, E., McGrory, E., Fazio, F., Menoncello, L., Brunswick, N., Cappa, S. F., Cotelli, M., Cossu, G., Corte, F., Lorusso, M., Pesenti, S., Gallagher, A., Perani, D., Price, C., Frith, C. D., & Frith, U. (2000). A cultural effect on brain function. *Nature Neuroscience*, 3(1), 91-96.
- Paulesu, E., Demonet, J. F., Fazio, F., McCrory, E., Chanoine, V., Brunswick, N., Cappa, S. F., Cossu, G., Habib, M., Frith, C. D., & Frith, U. (2001). Dyslexia: Cultural diversity and biological unity. *Science*, 291(5511), 2165-2167.
- Perani, D., Paulesu, E., Galles, N. S., Dupoux, E., Dehaene, S., Bettinardi, V., Cappa, S. F., Fazio, F., & Mehler, J. (1998). The bilingual brain: Proficiency and age of acquisition of the second language. *Brain*, 121(Pt 10), 19-32.
- Perfetti, C. A. (1985). *Reading Ability*. New York: Oxford University Press.
- Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a "universal" phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227-248). Amsterdam: Elsevier.
- Perfetti, C. A. (2003). The universal grammar of reading. *Scientific Studies of Reading*, 7(1), 3-24.

- Poldrack, R. A., Wagner, A. D., Prull, M. W., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. (1999). Functional specialization for semantic and phonological processing in the left inferior prefrontal cortex. *Neuroimage*, *10*(1), 15-35.
- Price, C. J., Green, D. W., & von Studnitz, R. (1999). A functional imaging study of translation and language switching. *Brain*, *122*(Pt 12), 2221-2235.
- Price, C. J. (2000). The anatomy of language: contributions from functional neuroimaging. *Journal of Anatomy*, *197*(Pt 3), 335-359.
- Price, C. J., Winterburn, D., Giraud, A. L., Moore, C. J., & Noppeney, U. (2003). Cortical localization of the visual and auditory word form areas: A reconsideration of the evidence. *Brain and Language*, *86*(2), 272-286.
- Pugh, K. R., Mencl, W. E., Jenner, A. R., Katz, L., Frost, S. J., Lee, J. R., Shaywitz, S. E., & Shaywitz, B. A. (2000a). Functional neuroimaging studies of reading and reading disability (developmental dyslexia). *Mental Retardation & Developmental Disabilities Research Reviews*, *6*(3), 207-213.
- Pugh, K., Mencl, W. E., Shaywitz, B. A., Shaywitz, S. E., Fulbright, R. K., Skudlarski, P., Constable, R. T., Marchione, K., Jenner, A.R., Shankweiler, D. P., Katz, L., Fletcher, J. M., Lacadie, C., & Gore, J. C. (2000b). The angular gyrus in developmental dyslexia: Task-specific differences in functional connectivity in posterior cortex. *Psychological Science*, *11*(1), 51-59.
- Rumsey, J. M., Nace, K., Donohue, B., Wise, D., Maisog, J. M., & Andreason, P. (1997). A positron emission tomographic study of impaired word recognition and phonological processing in dyslexic men. *Archives of Neurology*, *54*(5), 562-573.
- Salmelin, R., Service, E., Kiesila, P., Uutela, K., & Salonen, O. (1996). Impaired visual word processing in dyslexia revealed with magnetoencephalography. *Annals of Neurology*, *40*(2), 157-162.
- Sarkari, S., Simos, P. G., Fletcher, J. M., Castillo, E. M., Breier, J. I., & Papanicolaou, A. C. (2002). The emergence and treatment of developmental reading disability: Contributions of functional brain imaging. *Seminars in Pediatric Neurology*, *9*(3), 227-236.
- Seymour, P. H., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, *94*(Pt 2), 143-174.
- Shaywitz, S. E., Shaywitz, B. A., Pugh, K. R., Fulbright, R. K., Constable, R. T., Mencl, W. E., Shankweiler, D. P., Liberman, A. M., Skudlarski, P., Fletcher, J. M., Katz, L., Marchione, K. E., Lacadie, C., Gatenby, C., & Gore, J. C. (1998). Functional disruption in the organization of the brain for reading in dyslexia. *Proceedings of the National Academy of Sciences*, *95*(5), 2636-2641.
- Shaywitz, S. E., Shaywitz, B. A., Fulbright, R. K., Skudlarski, P., Mencl, W. E., Constable, R. T., Pugh, K. R., Holahan, J. M., Marchione, K. E., Fletcher, J. M., Lyon, G. R., & Gore, J. C. (2002). Disruption of posterior brain systems for reading in children with developmental dyslexia. *Biological Psychiatry*, *52*(2), 101-110.
- Shaywitz, B., Shaywitz, S., Blachman, B., Pugh, K. R., Fulbright, R., Skudlarski, P., Mencl, W. E., Constable, T., Holahan, J., Marchione, K., Fletcher, J., Lyon, R., & Gore, J. (2004). Development of left occipitotemporal systems for skilled reading following a phonologically based intervention in children. *Biological Psychiatry*, *55*(9), 926-933.
- Simos, P. G., Breier, J. I., Wheless, J. W., Maggio, W. W., Fletcher, J. M., Castillo, E., & Papanicolaou, A. C. (2000). Brain mechanisms for reading: The role of the superior temporal gyrus in word and pseudoword naming. *Neuroreport*, *11*(11), 2443-2447.
- Simos, P. G., Fletcher, J. M., Bergman, E., Breier, J. I., Foorman, B. R., Castillo, E. M., Davis, R. N., Fitzgerald, M., & Papanicolaou, A. C. (2002). Dyslexia-specific brain activation profile becomes normal following successful remedial training. *Neurology*, *58*(8), 1203-13.
- Simos, P. G., Breier, J. I., Fletcher, J. M., Foorman, B. R., Castillo, E. M., & Papanicolaou, A. C. (2002). Brain mechanisms for reading words and pseudowords: an integrated approach. *Cerebral Cortex*, *12*(3), 297-305.

- Siok, W. T., Perfetti, C. A., Jin, Z., & Tan, L. H. (2004). Biological abnormality of impaired reading is constrained by culture. *Nature*, *431*(7004), 71-76.
- Snow, C. E., Burns, M. S., & Griffin, P. (Eds.) (1998). *Preventing reading difficulties in young children*. Committee on the Prevention of Reading Difficulties in Young Children, Commission on Behavioral and Social Sciences and Education, National Research Council.
- Tagamets, M. A., Novick, J. M., Chalmers, M. L., & Friedman, R. B. (2000). A parametric approach of orthographic processing in the brain: an fMRI study. *Journal of Cognitive Neuroscience*, *12*(2), 281-297.
- Tan, L. H., Liu, H-L., Perfetti, C. A., Spinks, J. A., Fox, P. T., & Gao, J-H. (2001). The neural system underlying chinese logograph reading. *NeuroImage*, *13*(5), 836-846.
- Tarkiainen, A., Cornelissen, P. L., & Salmelin, R. (2003). Dynamics of visual feature analysis and object-level processing in face versus letter-string perception. *Brain*, *125*(Pt 5), 1125-1136.
- Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. E. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. *Proceedings of the National Academy of Sciences*, *100*(5), 2860-2865.
- Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A., & Eden, G. F. (2003). Development of neural mechanisms for reading. *Nature Neuroscience*, *6*(7), 767-773.
- Valaki, C. E., Maestu, F., Simos, P. G., Zhang, W., Fernandez, A., Amo, C. M., Ortiz, T. M., & Papanicolaou, A. C. (2004). Cortical organization for receptive language functions in Chinese, English, and Spanish: a cross-linguistic MEG study. *Neuropsychologia*, *42*(7), 967-979.
- Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review*, *97*(4), 488-522.
- Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin*, *101*(2), 192-212.
- Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied Psycholinguistics*, *14*(1), 1-33.
- Xu, B., Grafman, J., Gaillard, W. D., Ishii, K., Vega-Bermudez, F., Pietrini, P., Reeves-Tyer, P., DiCamillo, P., & Theodore, W. (2001). Conjoint and extended neural networks for the computation of speech codes: The neural basis of selective impairment in reading words and pseudowords. *Cerebral Cortex*, *11*(3), 267-277.
- Ziegler, J. C; Perry, C., Jacobs, A. M., & Braun, M. (2001). Identical words are read differently in different languages. *Psychological Science*, *12*(5), 379-384.
- Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., & Schulte-Korne, G. (2003). Developmental dyslexia in different languages: Language-specific or universal? *Journal of Experimental Child Psychology*, *86*(3), 169-193.
- Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin*, *131*(1), 3-29.