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Commentary

Brain-behavior relations in reading and dyslexia: Implications of Chinese results

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It is ironic that our recent report on the neural correlates of Chinese dyslexia (Siok, Perfetti, Jin, & Tan, 2004) raises a concern by Ziegler (2006) that this report could undermine an agreed-upon conclusion favoring a phonological deficit as the cause of reading disability. Our past research over 20 years in English (Perfetti, 1985) and Chinese (Perfetti, Liu, & Tan, 2005; Pollatsek, Tan, & Rayner, 2000; Tan & Perfetti, 1998) has argued that phonological processes are intrinsic to word reading and universal across writing systems, and we certainly have no reason to minimize the importance of these processes for understanding reading disability. We address Ziegler's concern by making two observations. (1) The Siok et al. evidence supporting a role for the left middle frontal gyrus (LMFG) instead of the left posterior temporoparietal regions found in alphabetic research does not undermine the consensus on the universality of phonology. Instead this evidence shows that the implementation of phonology depends on language and writing systems, a conclusion also reached through behavioral evidence (Perfetti et al., 2005). (2) The detailed neural basis of dyslexia remains an open question, rather than accepted wisdom.

On the first point, Siok et al. did not conclude that phonology plays no role in Chinese reading disability and Ziegler's critique recognizes this. Indeed, the evidence in favor of a phonological basis for dyslexia in alphabetic writing has accumulated impressively over 20 years, from a time at which the prevailing views emphasized visual problems as the cause of dyslexia. This evidence comes from neurobiological (Brunswick, McCrory, Price, Frith, & Frith, 1999; Eden et al., 2004; Price & Mechelli, 2005; Richards, Aylward, & Berninger, 2006; Shaywitz et al., 1998; Temple et al., 2003), cognitive (Bruck, 1992; Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004; Stanovich & Siegel, 1994; Vellutino, Fletcher, Snowling, & Scanlon, 2004), and genetic perspectives (Taipale et al., 2003). The more biologically specific form of the phonological hypothesis is that dyslexia is universally associated with functional disruption of the left temporoparietal brain regions (Paulesu et al., 2001). It is this hypothesis that is falsified by Siok et al. (2004).

To summarize briefly, using homophone and lexical decision tasks, we found that reading difficulty in Chinese is associated not only with a weakness in mapping of a character's orthography to pronunciation (as measured by the homophone decision task), but also with a substandard connection between orthography and meaning (as indexed by the lexical decision paradigm). Importantly, these two deficits were characterized by dysfunction of the left middle frontal gyrus. The left temporoparietal brain regions associated with disabled reading in English and other alphabets were not involved in the reading of Chinese children. Thus, either Chinese reading disability does not have a phonological component or the phonological component in Chinese does not involve the left temporoparietal regions. Because the Siok et al. behavioral data showed weakness in phonological processing, the conclusion is that this weakness is associated with some other neural substrate. The left middle frontal gyrus, which was under activated in Chinese dyslexics, is a likely candidate.

However, this is not the end of the story, but the beginning. The research goal becomes to understand the function of the LMFG in reading. It is not obvious that the LMFG, whatever its more general role in cognitive func-

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tioning, is a simple support for mapping between graphic form and phonology in Chinese. One possibility, which we proposed tentatively, is that the left middle frontal system is recruited to coordinate and integrate the visual-orthographic, phonological, and semantic information that is demanded by the processing of Chinese characters. This "coordination and integration" function may be part of central executive processes in verbal and spatial working memory mediated by left dorsal frontal areas. This function may result from the syllable-level unit required by Chinese (Perfetti et al., 2005; Siok, Jin, Fletcher, & Tan, 2003). But it may also result from the parallel mapping of the character to both meaning and pronunciation, which has been proposed in cognitive models of Chinese reading (e.g., Perfetti et al., 2005). On this account, a Chinese reader needs to briefly retain the graphic form (the character) while retrieving meaning and pronunciation. The possibility in alphabetic reading of "relinquishing" the visual form once phonological recoding has occurred is not an option for effective Chinese reading. Chinese has too many homophones for this recoding strategy to be effective.

This account is not the only one possible, of course. An alternative is suggested by a recent behavioral study that examined the relative contributions of phonological awareness and writing to Chinese reading ability (Tan, Spinks, Eden, Perfetti, & Siok, 2005). We administered a variety of tasks including reading, writing by copying, picture drawing, and phonological awareness to 131 Beijing school children aged 7–10. We found that writing skills heavily contributed to reading ability, whereas the contribution of phonological awareness was minor and secondary. Picture drawing skills were also associated with older Chinese children's reading. This study suggests an important contribution of visual-motor skills in learning to read and write Chinese. It is possible that the LMFG supports this visual-motor activity. Ziegler also suggests this link between LMFG and character writing.

Both of these hypotheses are specific instantiations of our more general hypothesis that language forms come to shape the cognitive procedures for reading and language, which, in turn, alter the neural circuits involved in language processing (Perfetti & Liu, 2005; Tan, Laird, Li, & Fox, 2005). According to our hypothesis, children learn to read alphabetic writing through the acquisition of letter-to-phoneme conversion skills, which are supported by phonemic awareness (and vice versa). Acquiring these skills results in a biological adaptation in which the neural systems for phonological processing in visual (reading) and auditory (listening) modalities are proximal to or even integrated into the left posterior temporoparietal systems. In contrast, the homophony in written Chinese, together with its visual-orthographic demands, requires that successful learning include mastery of specific character forms, for which repeated copying and writing of single characters is helpful. The extensive writing exercise serves to shape the cortical regions for Chinese reading in the posterior portion of the left middle frontal system that is near the motor cortex.

We now know that the brain areas supporting reading are only partly universal (Bolger, Perfetti, & Schneider, 2005; Pugh, Sandak, Frost, Moore, & Mencl, 2005), and trying to figure out the details of the non-universal components is important for a viable theory of the neural basis of reading. In the case of Chinese, that means understanding the function(s) of the LMFG and its connection with other brain regions. Our evidence goes beyond the Siok et al. study. In event-related potential experiments, we find time course and low-resolution cortical source differences between Chinese and English reading by Chinese bilinguals and English speakers learning to read Chinese (Perfetti & Liu, 2005). These differences are compatible with the data from fMRI studies. For both bilingual Chinese and English learners of Chinese, there are distinct Chinese language and English language patterns. In new fMRI studies, we find that English adult learners of Chinese show activation patterns during Chinese reading that are similar to those found by Siok et al. (Liu, Dunlap, Fiez, & Perfetti, 2005), and similar to the pattern observed in the meta-analysis of imaging studies of phonological processing of Chinese characters and alphabetic words by Tan and Spinks et al. (2005).

This brings us to our second point. We think it is premature to close the door on understanding the basis of dyslexia, including the role of phonology. The advances in research have been impressive in supporting the importance of a phonological processing as a causal factor. And the studies of brain imaging have contributed much to the overall progress. However, it is important to emphasize that a reference to a "biological origin" of dyslexia, as made by Ziegler and others, should carry some disclaimers. One is what we have emphasized: that the language and the writing system make a difference for the biological signature of dyslexia. A second, more general, disclaimer is that the brain areas that are associated with dyslexia do not necessarily constitute only biological causes. They may partly represent biological consequences. Studies of intervention effects suggest changes in brain activation patterns following interventions that are consistent with the functional roles assigned to left hemisphere reading areas (Eden et al., 2004; Shaywitz et al., 2004; Temple et al., 2003). Such studies allow varying interpretations of the brain-behavior relationships that are modified through instructional interventions. Certainly one possibility is that the intervention changes ineffective reading procedures that, in the dyslexic, had relied on brain regions outside the typical alphabetic reading network. Different reading procedures call on different brain resources, and when new procedures are learned they use the brain areas that support these procedures. This conclusion applies both to the different procedures that are produced by different writing systems and to the different (and variably effective) procedures that are learned by children within a given writing system.

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