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Cross-linguistic Analysis of Developmental Dyslexia—Does Phonology Matter in Learning to Read Chinese?*

Jun Ren Lee[12], Daisy L. Hung[12], and Ovid J. L. Tzeng[23]
[1] *National Central University*
[2] *National Yang Ming University*
[3] *Academia Sinica*

Phonological processing deficit has been ascertained to be the core cognitive deficit of developmental dyslexia—in alphabetic languages at least. Measures of phonological processing typically include three components: phonemic awareness, phonological working memory, and rapid automatic naming. Among the three tasks, phonemic awareness was the most powerful predictor of reading abilities. Because the Chinese language has no explicit rules for mapping from the orthographic constituent to the phonological form of a Chinese character, it has been argued that phonological awareness plays no role in reading acquisition in Chinese. We point out that phonological awareness is a metalinguistic understanding that spoken words can be decomposed into functional phonological units and that orthographic-to-phonological mapping in a script is not a necessary condition for determining the effects of phonological awareness on reading acquisition. We contend that orthographic-to-phonological mapping only acts as a secondary processing for representing phonological segments and self-teaching, and that phonetic symbols used in Chinese can fulfill the function of this secondary processing. We present comparisons between Chinese and English that suggest a universal structure for reading and reading acquisition.

Key words: phonological awareness, dyslexia, Chinese reading acquisition

1. Introduction

Developmental dyslexia, a disorder of reading, is a disorder affecting children with normal intelligence and educational opportunity and no history of visual or auditory impairment, but who have problems in learning to read. The prevalence rate is about 5-17% in the United States (Shaywitz 1998). Although the exact etiology of the disorder is not clear, evidence indicates that dyslexia is genetically-linked (Grigorenko 2001,

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Vellutino, Fletcher, Snowling & Scanlon 2004) with data from behavioral genetic studies, indicating that a genetic factor can explain up to 70% of the variance in word recognition and cognitive components related to reading (DeFries, Singer, Foch & Lewitter 1978, DeFries, Fulker & LaBuda 1987, Gayan & Olson 2003). Moreover, phonological and surface subtypes of developmental dyslexia (Coltheart 1987, Castles, Datta, Gayan & Olson 1999) and phonological processing measures (e.g., phoneme deletion and serial rapid naming; Davis, Gayan, Knopik, Smith, Cardon, Pennington, Olson & DeFries 2001) have genes identified or weighted influence of genetic heritage.

Functional neuroimaging studies have also shown that dyslexics produce different brain activation patterns compared to non-impaired readers during reading-related tasks. Relative to non-impaired readers, dyslexics produce more activation in bi-hemispheric inferior frontal regions and less activation in left hemisphere (LH) temporo-parietal sites (Wernicke's area) and the occipital-temporal junction (visual word form area; VWFA) (Pugh, Mencl, Jenner, Katz, Frost, Lee, Shaywitz & Shaywitz 2001). Critically, the activation of the VWFA has been shown to be correlated with reading skill (Shaywitz, Shaywitz, Pugh, Mencl, Fulbright, Skudlarski, Constable, Marchione, Fletcher, Lyon & Gore 2002) and the reduced activation in the VWFA for dyslexics has been found (Paulesu, Demonet, Fazio, McCrory, Chanoine, Brunswick, Cappa, Cossu, Habib, Frith & Frith 2001, Siok, Perfetti, Jin & Tan 2004).

Data from behavioral studies of reading over the past thirty years suggests that a core difficulty in reading manifests itself as a deficiency within the language system and, in particular, a deficiency at the level of phonological processing (Liberman, Shankweiler, Fischer & Carter 1974, Stanovich, Cunningham, Cramer 1984, Wagner & Torgesen 1987). Measures of phonological processing typically include three components: phonemic awareness, phonological working memory, and rapid automatic naming; and the issue of whether each different phonological processing task explains unique variance in reading performance is still debated. Among the three tasks, phonemic awareness was the most power predictor of reading abilities, at least for an alphabetic writing system (Grigorenko 2001, Vellutino, Fletcher, Snowling & Scanlon 2004).

The interrelation and interaction of genes, functional neuroanatomy, behavior, and social environment makes dyslexia research extremely complicated (Grigorenko 2001, Vellutino et al. 2004). Due to the complexity of the reading, addressing genetic-environmental interactions in dyslexia is more complicated than for many diseases such as diabetes or heart disease. The varieties of languages and scripts in the world, each varying in the reliability of the mapping between the spoken and written form, all make this issue difficult to resolve. Therefore, cross-linguistic comparisons provide an important avenue for assessing universal and language-specific principles that govern the mechanism of reading acquisition (Perfetti 2003, Ziegler & Goswami 2005).

Chinese, as a morphosyllabic script (also called logographic), has a special role in reading/dyslexia research. Chinese is special, not only for the opaque relationship between the spoken and written form, which has been discussed abundantly, but also for the varieties of dialects mapping to only one written script, for the different instructional methods, for the difference of phonetic symbolic systems, and for different forms of characters (DeFrancis 1986, Hung & Tzeng 1981, Wang 1973). For example, people from Hong Kong speak and read traditional Chinese characters in Cantonese and use the whole-word method to teach reading, and no commonly-used system of phonetic symbols is used to label the pronunciation of sinograms. In contrast, people in Taiwan speak and read traditional Chinese characters in Mandarin and use *Zhùyīn Fúhào*, a symbol system for labeling character sounds based on onset-rime segregation. *Zhùyīn Fúhào* is taught to children in Taiwan during their first ten weeks of the first grade. In addition, people from Mainland China speak Mandarin and their local dialects, read simplified Chinese in Mandarin, and use the *Hànyŭ Pīnyīn* system to label character sounds. The instructional method and procedure in Mainland China is quite similar to that in Taiwan, except that *Hànyŭ Pīnyīn* uses Roman letters to represent traditional phonology, whereas *Zhùyīn Fúhào* uses specially designed simplified symbols as indicators to represent traditional phonology.

The diversity of language backgrounds, character forms (simplified or traditional/ full-form), instructional methods (whole language or phonics), spoken forms (Mandarin or local dialects), and phonetic symbols (*Hànyŭ Pīnyīn* or *Zhùyīn Fúhào*) provide a special opportunity for examining the mechanisms of reading in Chinese.

In studies of reading and dyslexia in Chinese, the visual-spatial configuration property of Chinese has been emphasized. That is, although findings from studies in alphabetic orthographies have linked dyslexia to phonological processing deficits, it has been argued that dyslexia in Chinese may arise from deficits in visual-spatial analysis (Huang & Hanley 1995, Siok et al. 2004, Tan, Spinks, Eden, Perfetti & Siok 2005). For example, recent functional imaging studies have found a critical region for development of reading in Chinese in the left middle frontal gyrus (MFG); the authors attributed this finding to the unique role of visual-spatial analysis in reading Chinese and suggested that it posed a major challenge to the unity theory of dyslexia (Tan, Liu, Perfetti, Spinks, Fox, & Gao 2001, Siok et al. 2004).

In the following section, we consider the extent to which skilled reading and reading acquisition in Chinese differ fundamentally from alphabetic writing systems in which phonology constrains visual word recognition. We argue that a universal reading theory for different writing systems is possible, and indeed, may even be inevitable (Liberman 1996, Perfetti 2003). That is, the limited mapping between phonology and orthography in Chinese does not preclude the possibility that phonological processing is critical in reading Chinese because the fundamental requirement for reading is the same across languages and orthographies: mapping from the written form to the linguistic primitives of language, the phonemes and syllables that comprise the units of speech (Liberman 1996). Therefore, we argue that phonological processing serves the critical role of facilitating the connection between a well-established spoken word system and the retrieval and operation upon written forms (Sandak, Mencl, Frost, Rueckl, Katz & Pugh 2004). Importantly, although the requirements for successful reading are the same across languages and orthographies, a unitary theory of reading does not require that the detailed operational mechanism be identical across different writing systems, nor does it require the exact same neural response to reading across different writing systems. We suggest that these details vary according to adaptation pressure from the structure of a writing system; though overall the neurocircuitry should be largely overlapping.

2. Reading: speech constraints

In the field of reading, one central question is whether different languages and orthographies engage the same underlying mechanisms. One theory that provides for a unitary theory of reading has been developed at Haskins Laboratories following an evolutionary viewpoint that highlights the connections between spoken and written forms of language. Although spoken language is, at least to a large degree, a biological specialization, the (arbitrary) representation of phonemes by printed symbols lacks the evolutionary basis of spoken language and, as such, does not have its own biological specialization (Liberman 1996). If reading is not based on specializations that were specifically selected for, the most parsimonious solution is to maximize contact with processes that do have a biological specialization, the mechanisms underlying speech perception and production. This biological constraint would have to be universal across cultures and languages, making universal rules/grammar possible (Hung & Tzeng 1981, Liberman 1996, Perfetti 2003).

Recently, a picture-naming study collected from seven languages showed that the reaction time in one language can predict the reaction time in another language (Bates, D'Amico, Jacobsen, Szekely, Andonova, Devescovi, Herron, Lu, Pechmann, Pleh, Wicha, Federmeier, Gerdjikova, Gutierrez, Hung, Hsu, Iyer, Kohnert, Mehotcheva, Orozco-Figueroa, Tzeng & Tzeng 2003). This shows that even different languages have different "surface structures"; due to the adaptive pressure of living, the internal lexicon structure is quite the same.

The uniqueness of the human speech processing is in phonological computation. Here phonological computation means phonological representation and transformation of phonological representation. Evidence showed that infants pick up the processing of phonological processing shortly after their birth, and the phonological information helps to enhance the development of sensitivity to syntactic properties of words (Mehler, Dupoux, Pallier & Dehaene-Lambertz 1994, Christophe, Dupoux, Bertoncini & Mehler 1994). Connectionist modeling also shows that the impairment of input phonological representation nodes will jeopardize the development of syntactic competence (McClelland & Patterson 2002). Many lines of evidence support the importance of phonological computation in verbal language development. Speech is natural; most people can acquire verbal language without difficulty. When the story turns to reading, it changes dramatically. Speech signal is continuous. The "coarticulatory" characteristics of speech imply that every single phoneme has very different physical attributes if it were following or followed by a different phoneme. In *key* [ki] and *coo* [ku], the [k]-sounds are produced differently. Human beings can attune to the coarticulatory characteristics of speech easily, but they do have problems when forced to segment it without further instruction (Liberman et al. 1974). Reading acquisition demands a very specific kind of transformation of the phonological representation: to become aware that the continuous speech signal can be segmented into a fixed number of small units, the phones, and then, by reading instruction, with explicit symbols representing the fine-grained phonological information, the phonemes. Through phonological coding of a word, people can retrieve a word efficiently; it also paves the way to connecting these codes with the mental vocabulary which is already well established for a child (Sandak et al. 2004).

With respect to word recognition in skilled adult readers, cross-linguistic studies show that phonological recoding is mandatorily or likely prelexical in nature (Frost 1998). The phenomenon has been demonstrated not only in shallow orthographies but also in a deep orthography. (For instance, even in Chinese, phonological recoding has been demonstrated.) Spinks, Liu, Perfetti & Tan (2000) employed a Stroop color naming paradigm to address the issue of mandatory phonological recoding in Chinese. They asked whether a homophone of a Chinese color character under an incongruent situation would generate a typical Stroop interference effect. They found that the homophone (洪 *Hóng*, a Chinese surname) of an incongruent color character (紅 *hóng* 'red') slowed down color naming ('green'), a typical Stroop color naming interference effect. The Stroop color naming studies employed by Spinks revealed the universal mandatory phonological processing in word recognition (Spinks, Liu, Perfetti & Tan 2000).

To be clear, emphasis on phonological processing does not imply that it is exactly the same operating mechanism across different writing systems. Different languages vary in the adaptive utility of different phonological units or grain sizes (Ziegler & Goswami 2005). The phonological computation in language and reading acquisition is necessary (in our view), and is universal, but the complexity of phonological structure, the physical arrangement of written symbols to represent speech, and the method of instruction do create some variation in different writing systems. Speech is the core for verbal language development, reading is based on verbal language, and hence there is the possibility of a unitary theory of reading acquisition. The universality of phonological process impinging on reading acquisition forms the theoretical foundation of this paper; we strongly argue therefore that Chinese is not an exception. In this paper, we shall start by pinpointing the importance of fluency index in the definition of reading abilities in Chinese dyslexia research. We then briefly evaluate different theories of dyslexia related to phonological processing. The reminder of this paper tries to provide possible mechanisms for why phonemic awareness is of value in learning to read Chinese.

2.1 Reading abilities in Chinese

In alphabetic languages, people now understand that single word identification is the most critical component or impediment in reading development, and the reason that children cannot develop normal, single-word identification is mainly due to a phonological processing deficit or bottleneck (Snow, Burns & Griffin 1998). While there might be a small percentage of children who cannot develop normal reading because of their visual/sensory motor problems, phonological processing deficit is the core deficit for developmental dyslexia (Snow et al. 1998, Vellutino et al. 2004).

Single-word identification is the bottleneck for dyslexia in English (Shaywitz 1998). What about Chinese? Is the processing bottleneck in Chinese dyslexic children shown in character identification? Since most words are two-character combinations in Chinese, we can ask whether the processing bottleneck operates in the integration of characters into words? Is character/word identification the main deficiency in Chinese dyslexia? Or is there no problem in character/word identification? Is comprehension the only obstacle in Chinese?

There seems no consensus about how to define reading abilities in Chinese. Employing different definitions of reading ability would screen out different types of dyslexic reading groups. Mixing different etiology groups of subjects who have reading difficulties would have the risk of either diminishing effect or making a given experiment non-replicable.

Word decoding is the working definition of reading abilities in alphabetic scripts (Snow et al. 1998). From a functional viewpoint, let us temporarily take character identification as a comparable reading index in Chinese, similar to single word identification in English, since the function is the same, that is, sounding out the written symbols.

2.2 Accuracy and automaticity

Cross-linguistic studies show that dyslexic children in the deep orthographic scripts have problems both in accuracy and automaticity, dyslexic children in the shallow orthographic scripts have problems mainly in automaticity. What is the case in Chinese? For Chinese, there is no transparent relationship between written symbol and speech code. The GPC rules do not apply to the Chinese writing system. Only an opaque and weak orthography-to-phonology analogy rule can be found with the phono-semantic compound type of characters (i.e., the *xíngshēng zì*), which covers 80% of modern daily-use characters. But the higher the frequency, the weaker the regularity (Zhou 1978, DeFrancis 1986, Perfetti 2003). It is no wonder that people keep questioning whether the phonological deficit hypothesis holds in Chinese, and even more, questioning whether there is developmental dyslexia in Chinese. However, let us keep in mind the following: (1) The first 1,000 high-frequency characters cover 90% of those used in a daily newspaper. (2) Children can recognize more than 1,500 characters by the end of their second school year (Hue, Ko & Lee 2004). This of course does not mean that children can comprehend 90% of the content of a daily newspaper; it means that a second grader can sound out 90% of the characters in a daily newspaper. Because the units needed to be decoded in a Chinese text are fewer than in English, children who have serious problems in sounding out characters accurately (assuming normal intelligence) are rare (Yin & Weekes 2003). This might be the reason why a lower prevalence rate of dyslexia has been found for Chinese. But accurately sounding out the characters is not enough for comprehension. The problem in single-word identification is two-fold: one is in accurately sounding out words; the other is in processing words automatically. With the same rationale, character-identification automaticity should be taken seriously in Chinese dyslexia research. But the automaticity index is seldom found in defining Chinese dyslexia. In composite tests of word identification and comprehension, Stevenson, Stigler, Lucker, Lee, Hsu & Kitamuraet showed a similar prevalence rate of dyslexia in Taiwan as in the U.S. (Stevenson, Stigler, Lucker, Lee, Hsu & Kitamura 1982). This could be indirect evidence for the universal impediment of dyslexic children in different languages.

3. Theories about dyslexia

Reading behavior starts from retina coding the visual written material information and then the visual information transforms into linguistic codes. People process the linguistic codes to understand underlying semantic meaning. Theories about reading disorders indicate that these complex processes vary from focusing on the visual process, phonological processing, semantic processing, or any possible combination of these features. Given the focus of this paper, we shall here focus on those theories related to the phonological processing deficiency.

3.1 The phonological processing deficiency hypothesis

In the past thirty years, there has been overwhelming evidence supporting the idea that the phonological processing deficit hypothesis was behind core deficits of dyslexia. Phonemic awareness, phonological working memory, and serial-confrontation naming were the three constructs actively used to indicate phonological processing. Among the three constructs, phonemic awareness is the most powerful construct to predict reading development (Fletcher, Shaywitz, Shankweiler, Katz, Liberman, Stuebing, Francis, Fowler & Shaywitz 1994). Empirical results showed a strong correlation between phonemic awareness tasks and reading abilities in Chinese and English, even with statistical controls for IQ, parent's education, and socio-economic status (for English, Snow et al. 1998, Vellutino et al. 2004; for Chinese, Ho & Bryant 1997, Lee 1999, Siok & Fletcher 2001, McBride-Chang & Kail 2002). In a reading age match design, younger children, with the same reading age as the dyslexic group, showed better performance in phonemic awareness abilities than older dyslexic readers (Lee 1999). That evidence indicates that phonemic awareness may be not the effect of poor reading abilities, but is the cause of poor reading abilities.

Additionally, in remediation studies, phonemic awareness training has been found to improve children's reading abilities (Blachman, Schatschneider, Fletcher, Francis, Clonan, Shaywitz & Shaywitz 2004). But to make phonemic awareness training work, it needs to be done aside from text reading; direct instruction about segments of speech words, letter and letter-name correspondence, and synthesis of phonemes is needed; teachers need to be well trained and children must take remediation early in their schooling (Snow et al. 1998). Dr. Reid Lyon, chief of Child Development and Behavior Branch, National Institute of Child Health and Human Development, National Institutes of Health (Lyon 1999) notes:

> *Specifically, early intervention that includes the systematic and direct explicit instruction in phoneme awareness, phonics skills, and reading comprehension strategies within a literature-rich context appears to be critical to fluent word and text reading and comprehension.*

Although phonological processing deficit was a dominant theory and there was overwhelming evidence supporting the theory, still some questions have been raised in challenge. Castle & Coltheart (2004) examined studies supporting phonological awareness as a precursor to reading and claimed that there was no single convincing study showing that phonological awareness was a factor in reading development. Every study lacked control of initial letter knowledge and/or reading ability. The perceived cause might well, in fact, have been the consequence. Specifically, the cause in reading may not have been the processing related to phonological awareness itself; rather the phonological awareness task may have picked up on non-essential operations and may be of limited value since it may benefit from orthographic knowledge to code phonological representation. As for the first question of cause or effect, a Finish longitudinal study recruiting at-risk dyslexia participants and matching controls from their infancy was a project fitting the requirements proposed by Castle & Coltheart (2004). Up till now, the evidence supports the contention that, compared to the controls, at-risk pre-readers had different behavioral and ERPs patterns from basic speech perception and had delayed language development. It fits the pattern that the phonological processing deficit hypothesis would predict (Lyytinen, Ahonen, Eklund, Guttorm, Laakso, Leinonen, Leppanen, Poikkeus, Puolakanaho, Richardson & Viholainen 2001, Leppanen, Richardson, Pihko, Eklund, Guttorm, Aro, Lyytinen 2002, Richardson, Leppanen, Leiwo & Lyytinen 2003). As for the orthographic issue, Chinese was a perfect case for refuting the hypothesis, since there is no grapheme in Chinese, only opaque mapping between orthography and phonology. Yet, the evidence supported a correlation between phonological awareness and reading (Ho & Bryant 1997, Lee 1999, Siok & Fletcher 2001). Although this issue is still hotly debated, we suggest that phonological competence is a more likely a cause rather than a consequence of reading development.

3.2 Magnocellular pathway deficit hypothesis and temporal processing deficit

Recently, an emerging theory about reading disorder is the magnocellular deficiency hypothesis, also known as the transit system deficiency hypothesis (Lovegrove 1996, Stein & Walsh 1997). Evidence shows that poor readers have lower sensitivity in detecting transit stimulus, like sine wave grating, or a moving dots pattern. Several brain imaging studies also indicate that poor readers have lower activation in detecting moving patterns in the MT area, which belong to the magnocellular pathway, known as the major brain region for detecting motion detection in human and animal studies (Eden, VanMeter, Rumsey, Maisog, Woods & Zeffiro 1996, Demb, Boynton & Heeger 1997). But the empirical results are not consistent. It is interesting that experiments in shallow orthography language showed negative results and experiments in deep orthography language showed positive results (Chen 2000). The reason is not clear yet.

The problem of magnocellular pathway deficit is not only in its reliability but also in its operating mechanism. The stimuli in most studies with positive evidence for the transit system deficits are actually not in the range of the "transit system stimulus", most of them are in the range of the parvocellular system (Skottun 2000). Sperling, Lu, Manis & Seidenberg (2005) also demonstrated that the problem for dyslexia was in noise exclusion instead of magnocellular stimuli processing. They found that dyslexics performed equally well as the controls when there was no noise for magnocellular or parvocellular visual stimuli, but dyslexics did show elevated threshold when there was noise added. The argument for the deficiency magnocellular system might not have been justified.

The temporal coding deficit hypothesis was proposed to integrate the phonological processing deficit hypothesis and magnocellular pathway deficit hypothesis. The core concept of the temporal coding hypothesis is that dyslexic children have problems in differentiating similar but different short duration stimuli and/or in individualizing two consecutively presented stimuli with short intervals, no matter whether the modality of stimulus was visual or auditory (Tallal 1980, Tallal, Sainburg & Jernigan 1991, Farmer & Klein 1995). For example, dyslexic children have problems in differentiating the /ba/ and /da/ sounds, which are only different in the initial transition of the second and third formant, which is a difference of milliseconds. Dyslexic children also have reduced sensitivity to low contrast, low spatial frequency and high temporal frequency visual grating stimulus (Farmer & Klein 1995). The remediation studies showed that training in differentiating auditory temporal stimulus can improve the reading abilities of dyslexics and shape their brains to be more like those of normal readers (Temple, Deutsch, Poldrack, Miller, Tallal, Merzenich & Gabrieli 2003). But evidence has also shown that dyslexic children have a temporal coding problem in acoustically similar speech stimulus, [ba]/[pa], but not in the acoustically non-similar speech stimulus, [ba]/[ga] (Studdert-Kennedy & Mody 1995). The temporal processing deficit account seems to be limited to speech-related stimuli instead of across all modalities. Whether it can account for general reading development is questionable.

4. Phonological awareness and reading development in Chinese

4.1 Phonological awareness does matter, but why?

The correlation studies, reading age matched design studies, and the educational remediation studies all point out that the phonological processing deficit is the reason "why Johnny can't read" (Rayner, Foorman, Perfetti, Pesetsky & Seidenberg 2001, Vellutino et al. 2004). Not only in English but also in Chinese, the phonological variable was found to be the strongest variable in predicting reading abilities development (Ho & Bryant 1997 in Hong Kong; Lee 1999 in Taiwan; Shu, Anderson & Wu 2000 on Mainland China; for different results, please see Ho, Chan, Tsang & Lee 2002, Tan et al.

2005). Ho & Bryant (1997) found that the rhyme-detection ability at three years of age can predict reading ability two-to-three years later. This research demonstrated that long before children learn to read, rhyme-detection ability has an impact on later character identification in an opaque script. Lee (1999) found that, when intelligence and mental vocabulary are statistically controlled, there were differences found between a fifth-grade dyslexia group and third-grade reading age controls in tasks of *Zhùyīn Fúhào* synthesis and initial phoneme deletion respectively. Moreover, when the performance in the initial deletion task is also statistically controlled, there is still variance in the word identification performance that was explained by the performance in the *Zhùyīn Fúhào* synthesis task (Lee 1999). These findings are important in supporting the argument that phonological core processing plays an essential role in Chinese. Particularly, it is noteworthy that different instructional methods (e.g., look-and-say, phonics) for reading Chinese and different Chinese written symbols (i.e., traditional and simplified characters) are employed in those regions. Empirical evidence has shown a correlation, or even causal relationship between phonological awareness and reading acquisition in Chinese. An important question is, from where does this relationship originate? Given that the mapping rule between grapheme and phoneme is not valid in Chinese, people have argued that it is pragmatically impossible for the function of phonological awareness. We argue that phonological awareness influences reading acquisition through two mechanisms: one for the explicitness of phonological representation and the other for the mapping between orthography and phonology.

Phonological awareness refers to segmentation, representation, and manipulation of phonological information. What are the mechanisms that make phonological awareness essential for reading acquisition? The continuous speech signal can be decomposed into segments, and these segments are finite elements in the core processing of the first mechanism of phonological awareness. Odd-man out, rhyme detection, phoneme segmentation, phoneme synthesis, phoneme deletion, spoonerism are the operational definitions of phonological awareness. These tasks are related to speech perception and to the awareness that the continuous speech signal can be segmented (Liberman 1996). People who have problems in speech categorical perception prone to failing phonological awareness tasks; so will those who cannot segment the speech signal.

Evidence has shown that infants with and without family-related risk for dyslexia showed different ERPs patterns to categorical speech sound (Leppanen et al. 2002); adult dyslexia could have problems in differentiating very low level perceptual stimuli (Sperling et al. 2005). This part of phonological awareness is relatively independent of scripts. To be clear that the first mechanism of phonological awareness on reading is distal, it provides the possibility of efficient learning about relations between orthography and phonology. It does not directly act on the "decoding" processing.

It should also be noted that a segment does not necessary mean a phoneme. Instead, a segment refers to the functional unit relevant to specific writing system in a spoken language. In English, a segment might be a phoneme, in Japanese it might be a mora, and in Chinese it might be the initials and rhymes (Yin & Weeks 2003). Once children master the segmentation of the speech signal, the second mechanism starts to function. Written codes, either letters in alphabetic scripts or phonetic symbols in Chinese, help to represent the phonological information explicitly. The symbols help learners to manipulate the phonological information in an economical and effective way (Liberman et al. 1974). Once children master the segmentation of the speech signal, the second mechanism of phonological awareness plays its role. For the second mechanism, the functional unit of phonological information is language-specific. The information validity of mapping rules between orthography and phonology also relates to the second mechanism, which further influences the processing of self-teaching (Share 1985, Ziegler & Goswami 2005, for a review about the function of different grain sizes in different languages). This is a way to explain why phonological awareness matters in reading acquisition for all languages, albeit phonological awareness varies in its effectiveness across languages. We speculate that, for Chinese, the first mechanism is to segment the characters into initials and rhymes, whereas the second mechanism is to represent the phonological information with phonetic symbols. Those cognitive abilities are the bases for Chinese children to learn characters, either by self-teaching or by implicit rule behind orthography and phonology. Ho & Bryant's (1997) study showed that the function of rhyme played a role in reading acquisition; the effect was beyond orthography and phonology mapping. Lee (1999) found that phoneme synthesis had uniqueness explaining variance of reading, while intelligence, vocabulary, and even phoneme deletion were controlled; this study showed the self-teaching function in reading acquisition from phonetic symbols, at least in Taiwan.

For Chinese, the mapping between orthography and phonology is opaque compared to alphabetic writing systems. But there are mechanisms to compensate for this rather weak mapping. In Taiwan, most of the school reading materials for children below the fifth grade have *Zhùyīn Fúhào* printed alongside the character. As long as children know how to synthesize *Zhùyīn Fúhào*, they can sound out an unknown/unfamiliar character. In Mainland China, *Hànyǔ Pīnyīn* plays the same role as *Zhùyīn Fúhào* in Taiwan. One might argue that there are no phonetic symbols used in Hong Kong to label the character sounds. However, the lack of phonetic symbols does not imply that there is no categorization of character sounds. The categorization of character sounds and the use of symbols to represent sounds are not new in Chinese. For more than two thousand years Chinese people have used *zhíyīn* 直音 and *fǎnqiè* 反切 to represent character sounds. There are lots of homophones in Chinese. *Zhíyīn* involves using the pronunciation of high frequency characters to represent the sounds of unknown characters. *Fǎnqiè* involves taking the initial of one character and the rhyme of a second to represent the pronunciation of a third, less familiar character. *Fǎnqiè* is the foundation of *Hànyǔ Pīnyīn* and *Zhùyīn Fúhào*. Even though *Hànyǔ Pīnyīn* and *Zhùyīn Fúhào* use different symbols, they actually represent the same basic sound structure of Chinese, with 21 initials and 16 rhymes (based on *Zhùyīn Fúhào*). Hong Kong children might have developed the same way of implicitly representing phonological information via *zhíyīn* and *fǎnqiè*. Otherwise there is no way to explain the relationship between phonological awareness and reading acquisition found in Hong Kong.

4.2 Chinese visual-spatial, but not phonological processing?

People often equate visual-spatial analysis with orthographic analysis in Chinese. However, orthographic analysis is linguistic analysis, but visual-spatial analysis is not. Orthography refers to the mapping rule between written symbol and speech phonology (Perfetti 2003). Since orthography has a rule-governed relation to phonology, it is constrained by phonology. Reading starts from visual analysis which is not controversial. (Braille reading, of course, being an exception). The critical question is not whether there is visual-spatial analysis in reading, but when it turns into linguistic analysis. We speculate that the moment was at the structure of a character, the constituent (semantic or phonetic radicals) of a character and the position of the constituents. A kindergartener in Hong Kong can differentiate real Chinese characters from non-characters created by exchanging the positions of radicals in a character (Chan & Nunes 1998). The radicals in a Chinese character were decomposed, and the position of radical and degree of transparent relatedness determined their processing dimension, depth, and duration (Fang & Wu 1989, Taft, Zhu & Peng 1999). Consistency effect has been demonstrated in Chinese character naming (Lee, Tsai, Su, Tzeng & Hung 2005). A second-grader in Taiwan can decode more than 1,500 Chinese characters (Hue et al. 2004). All these phenomena reveal that there are rules behind Chinese characters, and children can learn the rules quickly. A simple mapping between character and semantic meaning can neither afford the complexity nor can it be learned in such a short time. The most convenient and effective way to access semantic meaning from script is though speech (Liberman 1996, Sandak et al. 2004). A writing system without explicit GPC rules does not necessarily imply that there is no role for phonology in word recognition. Besides, the explanation of visual-spatial analysis in learning to reading Chinese will not work, since literate people will not decode written symbols as purely visual-spatial information.

However, recently visual-spatial analysis was emphasized in Chinese imaging studies (Tan et al. 2001, Tan et al. 2005) and homophone characteristics (Perfetti 2003) were proposed for failure to provide the adaptive utility for phonological awareness/mediation.

In the visual-spatial analysis issue, the activation of LH MFG was proposed as uniqueness in Chinese reading and its function was speculated to be the specific visual-spatial analysis requirement specific to reading Chinese (Tan et al. 2001). To be clear, most of the papers mentioned the possibility that the difference found between Chinese and English might be (1) visual-spatial analysis in Chinese, (2) visual-spatial analysis binding with phonological processing, and (3) the phonological structure might be different between Chinese and English. Here we disagree with the visual-spatial analysis count only. From an empirical point of view, the activation in the LH MFG did not eliminate the possibility of phonological processing (Ziegler 2005). Actually by meta-analysis of phonological tasks in Chinese, a study showed consistent activation in the LH MFG (Tan, Laird, Li & Fox 2005). Besides, the phonological structure of Chinese might be the reason why imaging studies showed more dorsal MFG and less in the inferior frontal gyrus (Tan, Spinks, Feng, Siok, Perfetti, Xiong, Fox & Gao 2003). From a theoretical point of view, reading is a sophisticated cognitive behavior; the frequent exposures of print make the written symbols a compact structure. Only processing a compact structure of written symbols could render efficient reading. It should be the linguistic analysis which decides whether the chaotic visual-spatial pattern could become a compact structure. A Westerner who knows no Chinese needs visual-spatial cognitive efforts to analyze Chinese; a Chinese who does not know English also needs visual-spatial cognitive efforts to analyze English. The complexity of visual analysis depends on language background instead of the writing system.

As for the homophonic issue, homophonic properties in Chinese may weaken the phonological information utility for differentiating semantic meaning as Perfetti argues (Perfetti 2003). But the first 1,000 high frequency characters could cover 90% of daily usage, divided by the 400 syllables in Chinese; it is not as dramatic as one might imagine. More than that, for different orthographic homophonic characters, the frequency weighting is also different. Besides, the homophone limitation is only at the level of single character. At the level of a two-character word, the number of homophones is very limited. Actually in Chinese, a two-character word does not necessary reveal the meaning of its constituent character. For example, 天花 *tiānhuā* means smallpox, the first character 天 *tiān* means 'sky' and the second 花 *huā* means 'flower'. If the association between the orthography and meaning of a character is too strong, it might interfere instead with semantic understanding of a word. As Perfetti argues, the writing system is a visual manifestation of spoken words (Perfetti 2003). The function of phonological processing in reading is to associate the written symbols to its well established mental vocabulary. A well established spoken word system is helping in constraining the identification. However, we do not mean that orthographic structure plays no role in

Chinese, for it does help. Just as in English, orthographic structure affects phonological judgment. But the main entry pathway, phonology, has to be built first, and then orthographic information further constrains (Stone, Vanhoy & Van Orden 1997).

We should also like to point out that the mapping rule between orthography and phonology in English is not as transparent as people imagine. Words like *pint* and *have* are good examples. To handle its notorious mapping, English developed two ways to constrain the mapping: the rhyme constraint and the frequency constraint. In English, the smaller phonological grain size, the more inconsistent it is for orthography to phonology mapping (Ziegler & Goswami 2005). Rhyme can constrain the mapping at certain levels. In English, high frequency words tend to be irregular/inconsistent words whereas low frequency words tend to be regular/consistent words. The design or evolution to equip high- and low-frequency words with memory- and rule- based mapping respectively lowers the cognitive load in reading. Such design also compensates for the lack of valid information between orthography and phonology. In short, the brain imaging studies up to now do not eliminate the possibility of phonological processing in Chinese; a unitary theory of phonological processing was not falsified (Ziegler 2005). The homophonic attribute in Chinese might not be a dead end for phonological processing.

5. Concluding remark

Phonology matters in reading acquisition, regardless of writing system. Analysis of reading acquisition cannot ignore the importance of phonological processing. Any theory or hypothesis built about reading acquisition/disorder must take phonological processing into account. Comparisons of Chinese and English reveal the universal structure of reading and its acquisition. After all, man has but one brain to adapt to the requirements of language acquisition.

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Jun Ren Lee
Institute of Cognitive Neuroscience
National Central University
300, Zhong-Da Road
Zhongli, Taoyuan 320, Taiwan
jrlee@cc.ncu.edu.tw

發展性閱讀障礙跨語言分析——聲韻處理影響中文閱讀發展嗎？

李俊仁[1,2]　洪　蘭[1,2]　曾志朗[2,3]

[1] 國立中央大學

[2] 國立陽明大學

[3] 中央研究院

在拼音文字中，研究證據顯示聲韻處理缺陷是造成閱讀障礙的主要原因。聲韻處理作業一般有三種定義：聲韻覺識、聲韻工作記憶以及快速唸名。其中，以聲韻覺識爲最有效的預測指標。鑑於漢字字形和字音的對應與拼音文字迥異，聲韻覺識於漢字閱讀發展的作用招致諸多懷疑。我們認爲聲韻覺識是對於抽象語言規則的覺知，主要的作用在於覺知連續的言語訊號是可分離的，字形字音的對應是輔助的作用，並非必要或充分條件。再者，對於初學者言，漢字字形字音的對應，可以透過標音系統達成。漢字的學習，還是涵蓋聲韻覺識的兩種機制。在論文中，以漢語、英語爲範例，討論跨語言聲韻處理作用影響閱讀發展的可能性。

關鍵詞：聲韻覺識，閱讀障礙，閱讀發展