PART IV

Neuropsychological and Linguistic Framework, Reading-Related Characteristics, Screening for Dyslexia, and a Variant View

Dyslexia in Chinese: Clues from Cognitive Neuropsychology

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In this review, we describe a series of cognitive neuropsychological studies of Chinese speaking aphasic patients that reveal subtypes of acquired dyslexia and dysgraphia in Chinese. These subtypes can be understood with reference to a cognitive framework that assumes reading and writing to dictation in Chinese depends on the division of labor between two pathways: a lexical-semantic pathway and a direct or nonsemantic *pathway. This framework generates a number of predictions about the types of literacy problems that might be observed in native Chinese speakers who are learning to read and write. We argue that the language environment, and specifically the type of script used to read and write, will play a role in determining the phenotype of dyslexia in Chinese. We conclude that dyslexia in Chinese can be caused by psycholinguistic impairments at multiple levels including orthographic, semantic (morphological), and phonological processing.*

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We know very little about dyslexia in Chinese. This is probably because the linguistic features of Chinese place a constraint on interpretation of reading and writing within established conceptual frameworks. This problem is compounded by linguistic differences between Chinese languages themselves; that is, Cantonese, Min, and Mandarin, or *Putonghua*. Despite this, research shows that dyslexia is a concern in Chinese speaking environments and that the language environment, or more precisely the *type of script*, plays a critical role in determining the phenotype of dyslexia in Chinese (Chan & Siegel, 2001; Leong, 1999; Ho, Chan, Tsang, & Lee, 2002; Ho, Wong & Chan, 1999; Ho, Law, & Ng, 2000; Woo & Hoosain, 1984). In our view, progress in the understanding of Chinese developmental dyslexia requires a conceptual framework that can, firstly, accommodate reported reading and writing problems in Chinese, and secondly, generate new predictions about the likely causes of dyslexia in Chinese. This approach has been fruitful in English (e.g. Coltheart, 1978; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996).

The aim of this paper is to present a new framework for understanding reading and writing in Chinese that is derived from studies of aphasic Chinese speakers. This cognitive neuropsychological approach to understanding reading and writing in Chinese is based on the assumption that carefully controlled studies of aphasic speakers can reveal the functional architecture of the normal reading and writing system (Coltheart, Rastle, Perry, Langdon, & Zeigler, 2001). Our focus will be on dyslexia in Putonghua speakers from Mainland China. We will review data from cognitive neuropsychological studies of premorbidly literate adults who become dyslexic and/or dysgraphic following brain damage. We will then link data from studies of developmental dyslexia among children in Hong Kong and new data from dyslexic children in Beijing to this framework.

The paper is divided into three parts. In the first part, we describe the linguistic features of spoken and written Putonghua. This is unusual for a paper on dyslexia but we consider this necessary to understand the phenotypes of dyslexia that may be observed in different Chinese speaking environments (Hong Kong, Mainland China, Singapore, and Taiwan). In the second part, we describe our cognitive framework of normal and impaired reading and writing in Chinese. We describe this framework in detail because we believe progress in the diagnosis and treatment of dyslexia in Chinese will be enhanced using this framework, and models stimulate ideas about the remediation of dyslexia (Weekes & Coltheart, 1996). In the final part of the paper, we link this model to developmental dyslexia in Chinese and we report preliminary results from our study of the prevalence of dyslexia in Beijing. One feature of instruction in mainland China is a method of teaching words using an alphabetic script called *pinyin*. Pinyin is taught to preliterate speakers to enhance character learning and is routine in schools throughout China (but is not used in Hong Kong). We will show that dyslexia in Chinese is a significant problem in Mainland China, and that there are differences in the prevalence of reading and writing problems for Chinese character and pinyin reading.

CHINESE LANGUAGES

Chinese languages contain a relatively small number of syllables that can be used in isolation or in combination to represent a single morpheme or multi-morphemic word, although the concept of a word in Chinese is controversial[1]. There are approximately 400 syllables in spoken Putonghua. However, as syllables can be marked by changes in tone, there are 1200 "functional" syllables (Zhou, 1978). The onset of each syllable is invariant but the rime (i.e., the vowel plus the final consonant combination) can be pronounced in several different ways. This allows for polysemy among syllables. Chinese syllables are typically made up of an onset that is a single consonant (note that some syllables, e.g., ai, have no consonantal onset) followed by a short or a long vowel that is then followed by a coda comprising at least one consonant. One unique feature of Chinese languages is that there are no consonantal blends or clusters before or after the nuclear vowel. A total of 22 onsets and 37 rimes can be identified in the Chinese syllabary and only two consonants ever follow the vowel in the rime of a syllable (velar and alveolar nasal consonants). This feature of Chinese means that ho-

[1]The majority of Chinese morphemes are monosyllabic, but most Chinese words are, in fact, disyllabic or polysyllabic, and are made up of free morphemes. Some polysyllabic words are binding words whose constituents must co-occur and do not combine with other morphemes to form words (e.g., jau1 jan5 earthworm). As such, compounding is productive in Chinese. In most languages, compounds refer to a type of word made up of two or more existing words. In Chinese, a compound is made up of two or more morphemes combined to form a word.

mophony is prevalent. Homophonic syllables in Chinese are distinguished by supra-segmental changes in tone and these occur at the level of the vowel. Tones change the morphemic content of each syllable. In Putonghua, there are four tones, and in Cantonese, there are eight (at least). This feature of Chinese morphemes makes the skill of phonological awareness, specifically at the level of the onset and the rime, a critical part of learning spoken and written Chinese words (Leong & Tan, 2002). Phoneme awareness is also a predictor of reading and writing ability for Chinese speakers in Mainland China (Siok & Fletcher, 2001), however, this may depend on whether there is exposure to an alphabetic script during beginning reading (see Huang & Hanley, 1994).

The English alphabetic script is a systematic method for mapping print to sound with an arbitrary system for mapping print to meaning. This means a literate speaker can derive a pronunciation (i.e., one not in their lexical vocabulary) from a printed nonword (e.g., *nar)* using nonarbitrary print to sound mappings. A key feature of dyslexia in English is impaired processing of nonwords in reading, spelling, writing, and repetition suggesting that, at a minimum, print to sound mappings are compromised. Also, English irregular words (e.g., yacht) make the attainment of reading and spelling skills difficult for dyslexic readers.

All Chinese languages use a *nonalphabetic* script. A nonalphabetic script is a relatively arbitrary system for mapping orthography to phonology. All Chinese characters are composed of strokes formed into components that are written together into a square shape to form a single character. The traditional script contains over 40,000 characters although the modern reader needs to learn only the most common 3,000 characters to become literate. All characters represent one morpheme in Chinese. This makes the script "morphographic" (i.e., the smallest pronounceable unit is associated with a monosyllable) (Leong, 1999). As most morphemes are homophonous, and because each morpheme is represented by a character, Chinese characters can be called *heterographic homophones.*

The Chinese writing system has been defined as *logographic* (Henderson, 1982). This means that each written form is associated with a morpheme in the spoken language, unlike the letters in an alphabet that do not ordinarily represent meaning. Many ancient Chinese characters were *pictographic* because the written character portrayed the form of the object that it represented. So, for example, to some the character for horse, 马 "ma" suggests an abstract figure galloping across the page (e.g., Wang, 1973).

However, the notion that written Chinese is a simple logography can be challenged. De Francis (1989) argued that there are four different types of characters in modern use: (1) pictographic characters that represent a specific object (e.g., 日 "ri" meaning sun); (2) indicative characters that represent abstract meanings that cannot be easily sketched (e.g., 本 "ben" which means base and is derived from 木 "mu" meaning tree); (3) associative characters that combine existing characters to produce a new meaning (e.g., 尘 "chen" which means dust and is derived from 小 "xiao" meaning small and 土 "tu" meaning earth); and (4) phonetic-compound characters that are constructed from a meaning component called the semantic radical and a pronunciation component called the phonetic component (e.g., 狐 "hu" meaning fox which contains the semantic radical for animal on the left and the phonetic component pronounced "hu" on the right). Approximately 80 percent to 90 percent of characters are compounds. An important point to note is that the phonetic component of a compound is itself often a character (and thus represents a syllable). It can, therefore, potentially provide information about the pronunciation of the whole compound via a lexical reading process. Also, the semantic component can often give the reader a clue to the semantic properties of the character (e.g., an animal) although the radical is not always a reliable cue for meaning (Chen, 1996; Tzeng & Wang, 1983).

One feature of compound characters is that the "phonetic" information contained in the compound is usually an unreliable guide to its pronunciation. Yin (1991) estimated that no more than 38 percent of compound characters contain a phonetic radical that is a consistent guide to the correct oral reading of the whole character. Furthermore, it is usually not possible to read aloud a compound character correctly by decoding its component parts, unlike alphabetic scripts where it is possible to read aloud many words by decoding their constituent letters. This point can be illustrated by considering two facts about Chinese orthography. First, phonetic radicals can be positioned to the left or to the right (or the top or the bottom) of a character. For example, the phonetic radical "qi" 其 is on the right for the character 棋 which means chess, but it is on the left for the character 期 which means a period of time. Second, character components can act as both the phonetic radical and the semantic radical in different words. For example, the character 木 which means "wood" is a semantic radical in over 1500 Chinese characters, including 棋 "qi"; however, it is also the phonetic radical in the character 沐 "mu" which means wash. This means that it is impossible to know which component in a compound character is the phonetic (or which is the semantic) from orthographic information alone. To read aloud a character correctly, the reader must know the pronunciation of the character as a whole. This means that oral reading in Chinese is always a lexical event.

Some psycholinguists have distinguished between regular and irregular characters (Ho & Bryant, 1997a, 1997b; Yin & Butterworth, 1992). A regular compound contains a phonetic component that is congruent with the pronunciation of the character as a whole. However, as shown above, the majority of compounds are irregular because of the unpredictable correspondences between their components and the pronunciation of the whole character. One feature of irregular characters is that they can be read aloud "legitimately" in more than one way. This leads to a tendency for inexperienced readers to read the character according to a legitimate though incorrect pronunciation. Weekes and Chen (1999) called this type of error a Legitimate Alternative Reading of Components or LARC error. A LARC error takes the form of producing an incorrect pronunciation with an irregular character that is appropriate to other characters containing the same component. In order to read an irregular character aloud correctly, the reader must know the pronunciation of the whole character and inhibit the legitimate (though incorrect) alternative pronunciations of character components. Ho and Bryant (1997b) classified compounds as *high regularity* if they contained a phonetic that was homophonic with the compound itself; *medium regularity* if they contained a phonetic that shared the same onset and rime with the compound but was pronounced in a different tone; and *low regularity* if they had a phonetic with a different onset, rime, and tone. They found an advantage for regular over irregular characters in the reading performance of Hong Kong children who produced LARC errors when reading low frequency irregular characters.

The nonalphabetic nature of characters means it is impossible for a speaker to produce a nonextant syllable (i.e., one not already in their oral vocabulary) for a printed pseudocharacter. A pseudocharacter is formed by combining the components of existing characters to create a written form that has never been encountered in printed Chinese. However, the only possible oral reading response to a pseudocharacter is a monosyllable that represents an existing word (i.e., one component of the pseudocharacter). This is not equivalent to the pronunciation that is generated for a nonword like *zint* because that pronunciation is novel. Polysyllabic nonwords are formed by combining characters to create a written form that has no meaning in Chinese. These components in isolation will have a lexical representation but in combination they make no sense. However, a Chinese speaker must pronounce a nonword using phonological representations of monosyllables already stored in the lexicon, each of which represents one component of the nonword.

The *Pinyin* script uses the Roman alphabet with inflectional symbols (marked stress) that are assigned to represent multiple pronunciations of Chinese syllables. Pinyin was introduced in the 1970s in Mainland China to enhance teaching of literacy among beginning readers and is now compulsory in all elementary schools. Pinyin words are learned during the first stages of literacy and are then later paired with characters that link orthographic units (strokes, radicals, characters) with phonology (syllables, onsets, rimes, and tones). Pinyin is used extensively for writing in Mainland China possibly because most literate Chinese speakers write characters with an electronic format by typing syllables into an alphabetic keyboard that are mapped to a choice of characters presented on screen. Pinyin is not compulsory in Hong Kong and is not taught in Taiwan where an alternative script called *Zhuyin Fuhao* is used as an adjunct to teach traditional characters.

INTERIM SUMMARY

All Chinese speakers must learn a large number of characters in order to become literate. Most characters represent a monosyllable that is homophonous with many other characters. The prevalence of homophony in spoken Chinese means that phonological awareness is a requisite skill for distinguishing between the meanings of spoken Chinese words. An intriguing hypothesis is that literacy may help language learners to distinguish between the many homophonous syllables in spoken Chinese and thus lead to better vocabulary development. In other words, literacy in Chinese might enhance phonological awareness of Chinese spoken words. This is unlike English where we know phonological awareness enhances the development of literacy in an alphabetic script. In the following pages, we will review two current models of word recognition and oral reading in English. The purpose of doing this is to illustrate their utility by showing how each model explains both acquired and developmental dyslexia in English, but also to show that neither model can readily explain what we know about normal or impaired oral reading in Chinese.

MODELS OF READING

Much progress in our understanding of developmental dyslexia in English has come from cognitive modeling of the oral reading system (Castles & Coltheart, 1993; Coltheart, et al., 2001; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Plaut, McClelland, Seidenberg, & Patterson, 1996). Verbal models (Coltheart, 1978) and sophisticated computational modeling have been developed through studying aphasic patients who have a selective impairment when reading and/or writing to dictation (Plaut, et al., 1996; Coltheart, et al., 2001). The critical dissociation between acquired surface and phonological dyslexia illustrates this point.

Acquired *surface dyslexia* in English refers to impairment in the reading aloud of irregular words, particularly if the words are low frequency and abstract in meaning (such as "indict") with a spared ability to read regular words and nonwords. Surface dyslexics produce LARC errors at the subword level when reading irregular words (e.g., *yacht* as *yatched)* just as Chinese children make LARC errors when learning to read characters (although errors produced by surface dyslexics are usually called *regularization errors*). Acquired *phonological dyslexia* is an impairment when reading aloud nonwords with a spared ability to read aloud irregular words and regular words. Some patients with phonological dyslexia also show an effect of imageability on reading whereby concrete nouns such as *dog* are read better than abstract words such as *justice*. Acquired *deep dyslexia* is an extreme form of phonological dyslexia whereby patients additionally make semantic errors when reading words aloud, particularly if the word is abstract (e.g. *justice* read as *peace*). Cases of acquired surface, phonological, and deep dyslexic patients have been reported in many languages including French, Spanish, Italian, Dutch, and Japanese.

Coltheart et al. (2001) developed a "multi-route" model of oral reading in English that assumes there is a lexical semantic pathway available for reading aloud all known words as well as a direct lexical pathway that can read words aloud without contacting the meaning of the word itself. The Coltheart et al. (2001) model further assumes a third nonlexical grapheme to phoneme route that is available for reading aloud regular words correctly—but not irregular words—and that is mandatory for oral reading of nonwords such as *zint*. Graphemes are the orthographic representations of the phonemes used in spoken English and can be single or multiple letter representations. Note that grapheme representations can be different in the same language (compare the Cyrillic and Roman alphabets used in Serbo-Croatian). Coltheart et al.'s (2001) model assumes that grapheme and phoneme representations are linked via a set of rules learned during the development of reading and writing skill, and these allow for the correct pronunciation of nonwords.

Plaut et al. (1996) proposed a model that also assumes semantic and orthography to phonology pathways are available for normal reading in English, but their model differs from Coltheart et al.'s because it is based on connectionist principles of subsymbolic processing. Connectionist models assume that subword components at the level of the onset, vowel, and coda allow oral reading in English, and they explicitly reject the notion of lexical or whole word representations. Thus, the labels lexical-semantic and nonlexical grapheme to phoneme that are used by Coltheart are called *semantic* and *orthography to phonology* pathways by Plaut et al. (1996). The key distinction between dual-route and connectionist models is that dual route theory proposes that there are lexical and semantic pathways that are independent at some level, whereas connectionist models do not. Unlike Coltheart et al. (2001), Plaut et al. (1996) also assume that reading of nonwords proceeds via the orthography to phonology pathway by a process of analogy with existing subword representations.

These models give contrasting accounts of surface and phonological dyslexia. According to Coltheart et al. (2001), surface dyslexia results from damage to the direct lexical and lexical semantic pathways leading to an overreliance on the nonlexical route for reading aloud. This explains a tendency to regularize irregular words using grapheme and phoneme representations. Phonological dyslexia results from an impairment to the nonlexical pathway with spared direct lexical and lexical semantic pathways. This explains the inability to read nonwords. Deep dyslexia could arise from the loss of both the lexical and nonlexical pathways so that reading aloud is exclusively semantic (hence semantic errors are observed). By contrast, according to Plaut et al. (1996), surface dyslexia results from damage to a semantic pathway either because of impairment to semantic memory representations or impairment to the mappings between semantic and phonological representations. This causes a tendency to rely on the phonological pathway for oral reading (see also Patterson & Hodges, 1992). Phonological dyslexia and deep dyslexia fall on a continuum as both result from damage to the phonological pathway. Although both models assume there can be damage to two independent reading pathways allowing a plurality of acquired dyslexias and developmental dyslexias (Castles & Coltheart, 1993; Manis, et al., 1996), they make different predictions about the locus of impairment in acquired and developmental dyslexia, at least in English speakers.

Castles and Coltheart (1993) reported two subtypes of developmental dyslexia in English (from Australia), and argued these types are homologous with acquired phonological and acquired surface dyslexia. They found that although developmental phonological dyslexia was quite common (consistent with reports of poor nonword reading in dyslexia), some dyslexic children could read nonwords within the normal range but they could not read irregular words. Castles and Coltheart (1996) argued these subtypes are compatible with dual route theory. They reasoned that developmental phonological dyslexia results from a problem acquiring nonlexical grapheme to phoneme knowledge whereas developmental surface dyslexia results from a lexical reading route problem (Castles & Coltheart, 1996).

Manis et al. (1996) also reported subtypes of phonological and surface dyslexia in English speakers (from the United States). But they argued that whereas developmental phonological dyslexia results mainly from phonological processing problems, the smaller proportion of dyslexic children who show a pattern of developmental surface dyslexia results from a global developmental reading deficit. Specifically, they argued that too few hidden units in the oral reading system lead to poor reading of exception words and nonword reading problems. This is the pattern observed in most cases of developmental surface dyslexia as well as reading age matched (i.e., younger) readers. Manis et al. (1996) also argued that a global deficit can arise because of a visual-perceptual deficit affecting all types of words.

It is not obvious how the Coltheart et al. (2001) model or the Plaut et al. (1996) model would explain oral reading in Chinese since both models were devised to explain reading in alphabetic scripts. There is no motivation for a GPC route in Chinese because graphemes do not exist in that script. Also, the morphographic nature of characters means that a lexical-semantic reading process is likely even though subsymbolic or analogical reading processes may also be possible in a computational model of Chinese reading.

Indeed, some writers have argued that reading in Chinese is always mediated by semantics (Wang, 1973; Yin & Rohsenow, 1994). It could be assumed, therefore, that a lexical semantic reading process is sufficient to support normal oral reading in Chinese. This makes intuitive sense given that the majority of characters have a relatively arbitrary relationship between orthography and phonology. Despite this, and given that Coltheart et al. (2001) and Plaut et al. (1996) both assume a *nonsemantic* oral reading pathway, it is reasonable to ask whether characters can be read via a nonsemantic pathway in addition to the lexical-semantic pathway that must be used for oral reading in Chinese.

Evidence from cognitive neuropsychological investigations of aphasic patients suggests a nonsemantic pathway is available to Chinese speakers for reading and writing. Lyman, Kwan, and Chao (1938) reported a bilingual (Chinese-English) patient with a large occipito-parietal tumor in the left hemisphere who was dyslexic in Chinese but not in English. Impaired reading of characters was accompanied by fluent speech in Chinese and English and intact verbal comprehension in both languages. These data suggest name production and oral reading are dissociable skills in Chinese. The dissociation between naming and reading in Chinese shows that, if it is assumed that spoken word production in Chinese proceeds via a pathway that links semantics with phonological output, then a lexical semantic pathway is not sufficient to support oral reading in Chinese (but may support reading of English words in bilingual speakers). However, these data taken on their own do not prove that oral reading and writing to dictation in Chinese can proceed via a nonsemantic pathway. That type of evidence would come from a patient who could not use the lexical-semantic pathway but who could read aloud characters correctly; in other words, the opposite or *double dissociation* of the patient reported by Lyman et al. (1938).

Weekes, Chen and Yin (1997a) described a Putonghua speaking patient, YQS, who displayed intact reading of characters coincidental with impaired confrontation naming and reduced category fluency (anomia). YQS was unable to name pictured objects (e.g., an apple) but could, nevertheless, read aloud the printed names (characters) of the same objects perfectly well. Anomia is universally assumed to reflect the operation of a lexical semantic system in models of language processing. Therefore, the pattern of *anomia without dyslexia* in Chinese displayed by YQS shows that if the lexical semantic pathway is impaired, it is possible to read aloud in Chinese via a nonsemantic pathway connecting orthography directly to phonological output and bypassing semantic representations. On the basis of these data, Weekes et al. (1997a, b) argued that normal oral reading and writing to dictation in Chinese can proceed via at least two *bi-directional* pathways: a lexical semantic pathway that allows reading and writing for meaning, and a nonsemantic pathway that directly links all orthographic representations (i.e., strokes, radicals, and characters) to all phonological representations (i.e., syllables, rimes, and tones). This "triangle model" is displayed in figure 1.[2] The pattern of superior reading of characters compared with poor naming of pictures in Chinese observed with YQS has subsequently been replicated by Weekes and Chen (1999) in another Putonghua speaking patient, LJG, and by Law and Orr (2001) reporting a Cantonese speaking patient called CML.

The triangle model can accommodate cases of acquired dyslexia and dysgraphia in Chinese. The model assumes the lexical semantic and a nonsemantic pathway are functionally independent, and hence can be selectively impaired or else develop at different rates in beginning readers. The pathways are linked via a set of bi-directional connections allowing feed-forward and feedback connections between orthographic and phonological representations. When a reader is presented with a character, the orthographic representation will activate several different representations via the lexical semantic pathway, each of which is related in meaning to the target and thus equally likely to be produced as a response. However, semantic errors are not usually produced in normal reading and writing (see Moser, 1994, for examples of these errors). According to the model, this is because additional input from the nonsemantic pathway is available to inhibit the semantically related (incorrect) reading or writing response. Damage to the nonsemantic pathway should, therefore, result in acquired deep dyslexia in Chinese because the input from the nonsemantic pathway that is normally used to select correct phonological output is unavailable. Reliance on the semantic pathway will cause imageability effects on reading and semantic errors, as well as difficulty in reading nouns compared with verbs since nouns tend to be more imageable than verbs. Exactly the reverse set of processes would arise when writing characters to dictation. The lexical semantic and nonsemantic pathways are

[2]Note that the nonsemantic pathway could be referred to as a phonological or as a direct pathway in keeping with either the Plaut et al. (1996) or Coltheart et al. (2001) models, but this does not imply that nonsemantic reading in Chinese can be simulated by either model, given that both were devised to read alphabetic scripts. Note also that the framework in figure 1 is a verbal model only and should not be regarded as computational. It may provide a basis for a computational model when we understand better the processes used for reading and writing Chinese as well as the statistical properties of different Chinese language environments.

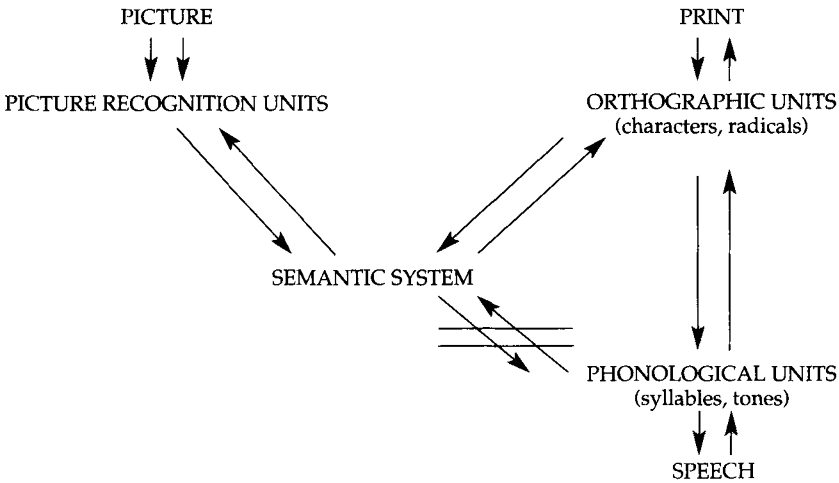

Figure 1. *A model of lexical processing in Chinese (from Weekes, et al., 1997a). The breaks in the lines between semantic system and phonological units show the point of impairment in anomia as displayed by patient YQS.*

assumed to derive correct orthographic representations for writing to dictation from phonological input. However, in the absence of a nonsemantic pathway, writing performance can only be generated via the lexical semantic pathway. As there is no constraint over production of semantic errors via this pathway, semantic writing errors are inevitable.

Yin (1991) and Yin and Butterworth (1992) were the first to report detailed experimental analyses of dyslexia in individual Putonghua speakers from Beijing. They reported several aphasic patients who displayed patterns of impaired and preserved oral reading that resembled features of deep and surface dyslexia in English. For example, one group showed a tendency toward semantic errors on character reading and writing tasks, and produced more errors with low imageability characters than high imageability characters matched for word frequency. Yin and Butterworth (1992) called this phenomenon *deep dyslexia in Chinese* (see also Yamada, 1995).[3] A second group

[3]Note that acquired phonological dyslexia has never been reported in Chinese. This is because phonological dyslexia in English is defined as poor oral reading of nonwords and these are defined as stimuli with no lexical representation (Coltheart, et al., 2001). As it is impossible to read a printed nonword in Chinese without contacting some lexical representation, phonological dyslexia in this strict sense cannot be observed in Chinese.

made a large number of regularization errors or more precisely LARC errors when reading irregular characters but they could read regular characters matched for word frequency. They called this phenomenon *surface dyslexia in Chinese.*[4]

Acquired dyslexia in Chinese is not restricted to Putonghua speakers. Law and Orr (2001) reported a Cantonese speaking patient, CML, who displayed a pattern of *tonal dyslexia* whereby the correct monosyllable was preserved on reading tasks but the tonal stress assigned to the syllable was incorrect. Eng and Obler (2002) reported the same phenomenon in a biscriptal Cantonese English speaker who coincidently made semantic errors in oral reading. In addition to tonal reading errors, CML produced tonal writing errors as well as homophone writing errors when asked to write characters from dictation and when asked to write the names of pictures (a written naming task). Such errors have been observed in other Cantonese speakers reported by Law (Law, 1994; Law & Caramazza, 1995; Law & Leung, 2000).

Law and Orr (2001) suggested that tonal errors in reading and writing could be informative about the structure of phonological representations of Chinese words. They argued that the phonological representations of Chinese words have a nonlinear structure with separate syllabic, segmental (onset and rime), and suprasegmental layers. Impairment to these layers leads to dissociation between segmental and suprasegmental information stored in the phonological lexicon causing both tonal reading and writing errors. As noted above, CML displayed superior oral reading of characters compared with picture naming, and this pattern was observed in her writing performance, too (i.e., writing to dictation was better than written picture naming). These dissociations were taken as evidence that CML used a nonsemantic route for the production of spoken words on reading tasks and when writing characters. One account of CML's writing is that in addition to feed-forward connections between orthography and phonology for oral reading depicted in figure 1, *feedback connections* are also available between phonology and orthography in the nonsemantic pathway.

[4]Weekes and Chen (1999) later showed that reading performance is more impaired for low imageability, low frequency irregular characters in Chinese surface dyslexic patients (see also Weekes, 2000), a pattern that is observed among surface dyslexic patients in English (Breedin, Saffran, & Coslett, 1994), Dutch (Diesfeldt, 1992), Italian (Miceli & Caramazza, 1993) and Japanese (Patterson, Suzuki, Wydell, & Sasanuma, 1995).

One prediction of our model is that impairments to mappings between orthography and phonology can impact on reading and writing in a graded fashion. If access to phonology from print is severely impaired, then deep dyslexia will result. However, mild damage to the nonsemantic pathway might reveal imageability effects (owing to the use of the semantic pathway) but may not be sufficient to cause semantic errors if some input from the nonsemantic pathway is available. This would lead to a type of phonological dyslexia in Chinese. Although this type of patient has never been reported, if such a patient were found, it would be an important finding because some writers (Coltheart, et al., 2001; Weekes, Coltheart, & Gordon, 1997) argue that phonological (and deep) dyslexia requires impairment to a GPC reading route, and since a GPC route cannot exist in Chinese, phonological dyslexia in Chinese is not expected.

Weekes and Chen (1999) made the prediction that selective damage to the lexical semantic pathway will lead to surface dyslexia. The rationale for this prediction comes from the *semantic glue hypothesis* (see Graham, Hodges, & Patterson, 1994; Patterson & Hodges, 1992; Patterson, Graham, & Hodges, 1994; Patterson & Lambon-Ralph, 1999; Plaut, et al., 1996; Strain, Patterson, & Seidenberg, 1995) which holds that in order to prevent LARC errors in English, the oral reading system normally inhibits the competing and perhaps more common pronunciation of word components during phonological output. This process of inhibition occurs via activation of representations in semantic memory so that the system will normally settle on the correct but atypical pronunciation of an irregular word. According to the semantic glue hypothesis, alternative and more common pronunciations of word components will dominate the computation from orthography to phonology without support from semantic memory.

If this hypothesis is correct, then visuo-semantic memory impairment should be associated with surface dyslexia in Chinese (see Patterson & Hodges, 1992 for many examples in English). There is evidence from Chinese patients to support this hypothesis. Yin (1991) reported an association between impairment on tests of semantic memory and production of LARC errors in Chinese. For example, patient LQF was impaired on tests of word comprehension, spoken word production, and word-picture matching, and he produced a large number (over 90 percent) of LARC errors when reading irregular characters aloud. Weekes and Chen (1999) also found that Chinese surface dyslexia was accompanied by impaired written word and spoken word comprehension, and they argued that oral reading of irregular characters is more prone to error than reading of regular Chinese characters because of response competition at the level of phonological output following damage to the lexical semantic pathway (see also Weekes, 2000).

According to the triangle model, damage to the lexical semantic pathway should result in homophone errors on writing tasks. Law and Orr (2001) did not characterize the homophone errors produced by CML in character writing as surface dysgraphia in Chinese, but this type of error is a hallmark of surface dysgraphia in other languages (see Weekes & Coltheart, 1996). An isolated lexical semantic pathway will generate semantic errors in writing. By contrast, the isolated nonsemantic pathway will generate candidates for orthographic output that are homophonic with the target and, in the absence of the lexical semantic pathway, there will be no constraint over production of homophonic responses in writing to dictation. One point to note is that CML did not generate semantic errors on writing tasks, consistent with the claim that she writes without access to the lexical semantic pathway for writing (Law & Orr, 2001).

DEVELOPMENTAL DYSLEXIA IN CHINESE

Studies in Hong Kong show that a proportion of children with at least an average IQ struggle to attain literacy in Chinese (Lam, 1999; Leong, 1999; Leong, Cheng, & Lam, 2000). Clinicians from the Department of Health in Hong Kong and colleagues from the University of Hong Kong have preliminary data based on clinic referrals and also from schools to suggest that the prevalence of dyslexia in Hong Kong is high, and could be at least around 5 percent. Leong (personal communication) estimates that between 3 percent and 5 percent of children may have dyslexia in Hong Kong (see also Ho, et al., 2002; Leong, et al., 2000).

We know from studies of children in Beijing, Canada, Hong Kong, and Taiwan that phonological awareness is a precursor to normal reading and writing in Chinese (Chan & Siegel, 2001; Ho, 1997; Ho & Bryant, 1997a, 1997b; Ho & Lai, 1999. Ho, et al., 2000; Ho, Lam, & Au, 2001; Huang & Hanley, 1994; Leong & Tan, 2002; Siok & Fletcher, 2001). Developmental studies of children who are learning to read and write in Hong Kong also find that phonological problems can lead to dyslexia in Chinese. Ho and Lai (1999) examined rapid naming-speed of dyslexic children on digit, color, picture, and character naming tasks, as well as phonological memory tasks (e.g., repetition). Naming speed was slower and performance on memory tasks was worse for dyslexics than matched controls, suggesting that phonological deficits may be core features of dyslexia across very different language environments. Ho et al. (2000) also reported that dyslexic children performed worse than controls on a variety of phonological processing tasks. However, they also found that individual dyslexic children can have a variety of deficits including visual, orthographic, and phonological deficits, and children with severe reading and writing problems have *multiple deficits* including problems with rapid naming.

The data from Hong Kong show that dyslexic children have deficiencies in naming and phonological memory similar to their peers from Indo-European language environments. Although we are hesitant to interpret these data post-hoc in terms of the framework in figure 1 for reading and writing in Chinese, it seems that a variety of different causes of dyslexia and multiple loci of causes is best explained by a model that assumes a separate level of representation for orthographic, phonological, and semantic processing, as well as bi-directional feedback between these levels of representation. If any one or a number of these processing routes is impaired, then reading and writing problems could emerge. Note that, like Ho and colleagues (2002) who argue for multiple deficits in dyslexia, we do not assume that there is a single cause of dyslexia in Chinese. Instead, it is quite likely that any given child with dyslexia will show one or more deficits to the processes shown in figure 1, but these deficits may be different from another child with dyslexia. Despite these differences, the same consequence (i.e., poor reading and writing in Chinese) is the presenting problem.

We believe that progress in understanding dyslexia in Chinese requires a battery of tests that are tailored for each individual to isolate impairments to one (or more) levels of processing depicted in figure 1. For example, a phonological problem with the units in the phonological processing system, may lead to a failure to acquire monosyllables with the additional consequence that reading and writing is impaired. This could be detected by tests of onset-rime awareness. According to figure 1, phonological awareness problems can arise from impairment to phonological units or to the mappings between speech and phonology. Note a phonological impairment could lead to reading problems with pinyin words as well as to dyslexia with Chinese characters. It is possible that awareness of subsyllabic phonological units will lead to dyslexia in both types of script.

DEVELOPMENTAL DYSLEXIA IN BEIJING

Little is known about the prevalence of dyslexia in Mainland China. A common assumption is that learning to read and write in Chinese may be easier than learning to read and write in English for children who are predisposed to dyslexia. For example, Rozin, Poritsky, and Sotsky (1971) demonstrated that the reading ability of U.S. children with dyslexia improved when they were taught to read English words printed as Chinese characters (using a visual memory strategy). This finding suggests that the unique properties of a script have the potential to diminish reading and writing problems in children predisposed to dyslexia, and that *type of script* can determine the phenotype of dyslexia in different language environments. Despite this, the data from Hong Kong show that dyslexia is as much of a concern for Chinese speakers as it is for English speakers.

We developed an ongoing survey study with elementary school pupils from Beijing in order to characterize the features of dyslexia in Mainland China. We have data from 8,106 pupils (4,184 males and 3,922 females) and our findings are summarised in table I. Inspection of table I suggests that the prevalence of reading difficulty is relatively low in China (1.92 percent). However, we need to interpret these very preliminary data with extreme caution. Our estimates are observational and we surveyed children from a relatively affluent part of Beijing. Therefore, it is likely that our data have underestimated the true prevalence of dyslexia in Chinese. We found more boys (2.63 percent) have reading difficulty than girls (1.17 percent), and reading difficulty is greater in left-handed (5.53 percent) than right-handed (1.83 percent) pupils. Pupils make a variety of errors including semantic, homophone, and LARC errors as reported by Ho and Bryant (1997b), as well as multiple difficulties such as learning the visual configuration of characters (consistent with Ho, et al., 2002).

One striking phenomenon that we have observed in Beijing is that Pinyin reading difficulties (e.g., a tendency to confuse b, d, p, and q) are more common than difficulties learning to read

TABLE I. Sex, Handedness, and Grade Differences in Dyslexia in Beijing.

	Boys	Girls
Number of pupils surveyed	4184	3922
Dyslexic pupils diagnosed	110 (2.63%)	46 (1.17%)
	Right-handed	**Left-handed**
Number of pupils surveyed	7889	217
Dyslexic pupils diagnosed	144 (1.83%)	12 (5.53%)
Grade	**Number of pupils being surveyed**	**Dyslexic pupils diagnosed**
2	1720	44 (2.56%)
3	1853	34 (1.83%)
4	1674	29 (1.73%)
5	1493	28 (1.88%)
6	1366	21 (1.54%)

characters. This suggests to us that reading and writing difficulties in Chinese can vary according to the type of script that is used in different Chinese speaking environments. This is compatible with what we know about alphabetic scripts whereby many of the well-established features of dyslexia in English (e.g., problems with phonological discrimination) interact with the unique properties of alphabetic scripts to produce varieties of dyslexia in different Indo-European languages (e.g., Goswami, 2002; Miles, 2000).

FUTURE DIRECTIONS

Goswami's (2000) phonological representations hypothesis assumes dyslexics have pre-existing difficulties in the linguistic representations of the sequential sounds of speech leading to difficulties with printed word learning. This hypothesis is supported by cognitive, developmental, and brain imaging research of dyslexic reading and writing in Indo-European languages. In our opinion, the data from Beijing (and from Hong Kong) dyslexics can be explained by the phonological representations hypothesis. Phonological awareness, specifically at the level of the onset and rime for homophonous syllables in Chinese, is a predictor of vocabulary development and literacy in Beijing children (Siok & Fletcher, 2001). Therefore, just as for English speakers, a preliterate Chinese speaker's phonological awareness of syllable structure (segmental and supra-segmental phonology) should be a good predictor of later reading and writing impairments. There may also be a reciprocal relationship such that literacy in Chinese enhances vocabulary development in Chinese speakers. These hypotheses await further empirical investigation.

A different hypothesis is that visual and/or grapho-motor impairments are a cause of dyslexia in Chinese as they seem to be in English (Manis, et al., 1996). There is little evidence to support this hypothesis. Even though literacy in Chinese requires making fine distinctions between heterographic homophones there are few reports of visual problems in Chinese dyslexics (see Ho, et al., 2002). Woo and Hoosain (1984) reported that dyslexics did make visual errors but these errors were also linguistic; that is, substitutions, omissions, additions, and deletions of critical phonetic and semantic radical components (see also Kwan & Ho, 2002; Leong, Cheng, & Lam, 2000; Tzeng, Zhong, Hung, & Lee, 1995). The morphographic nature of characters makes it likely that mappings between orthographic units and semantic representations will be a useful strategy for acquiring literacy in Chinese. A deficit at this level might also lead to reading and writing problems with characters (see Leong, et al., 2000; Ho, et al., 2002). According to the framework in figure 1, putative visual problems could be due to impairment to orthographic units or to the mappings between print and orthography. Orthographic knowledge of characters (e.g., homophone identification) might predict surface dyslexic problems with characters for Chinese speakers (cf. Castles & Coltheart, 1996; Weekes & Coltheart, 1996).

A complete framework for understanding the causes of dyslexia in Chinese (for characters and pinyin script) needs to link the levels of cognitive processing we have highlighted in figure 1 with the behavioral and biological levels (cf. Frith, 1999). The last five years have seen a great deal of progress toward uncovering the brain regions that are involved in Chinese character recognition and reading (Chee, Weekes, Lee, Soon, Schreiber, Hoon, & Chee, 2000; Chen, Fu, Iversen, Smith, & Matthews, 2002; Tan, Spinks, Gao, Liu, Perfetti, Xiong, Stofer, Pu, Liu, & Fox, 2000; Tan, Feng, Fox, & Gao, 2001, Tan, Liu, Perfetti, Spinks, Fox, & Gao, 2001). Chen et al. (2002) report that a common brain network including inferior frontal, middle, and inferior temporal gyri, inferior and superior parietal lobules, and extrastriate areas are activated when reading characters and pinyin script. However, reading pinyin compared to characters leads to greater activation in the inferior parietal cortex bilaterally, the precuneus, and the anterior middle temporal gyrus in monolingual speakers. By contrast, reading Chinese characters leads to a greater activation in the left fusiform gyrus, the bilateral cuneus, the posterior middle temporal, the right inferior frontal gyrus, and the bilateral superior frontal gyrus. These data show that the type of script can have differential effects on brain activation, confirming that the type of script used must be considered in studies of Chinese dyslexia. Dyslexia with pinyin words is unlikely to have a different origin to dyslexia in alphabetic scripts such as English and probably involves the same brain regions (see Shaywitz, Shaywitz, Pugh, Fulbright, Mencl, Constable, Skudlarski, Fletcher, Lyon, & Gore, 2001). By contrast, problems with characters may have a different origin.

CONCLUSION

Dyslexia in Chinese speakers can take a variety of different forms. Acquired dyslexia and dysgraphia, including surface and deep dyslexia as well homophone and semantic errors in writing, have been reported in aphasic speakers following brain damage. These subtypes of dyslexia and dysgraphia can be explained by the framework in figure 1. This model assumes that proficient reading and writing in Chinese depends on a division of labor between the lexical-semantic and direct, nonsemantic pathways. Impairment to the lexical semantic pathway results in acquired surface dyslexia whereby regular characters are read better than irregular characters and homophone errors that will be produced on character writing tasks. By contrast, impairment to the nonsemantic pathway results in acquired deep dyslexia whereby semantic errors are made in reading and/or writing. The model predicts that without semantic support, there will be a tendency toward LARC errors in reading and homophone errors in writing. The model also predicts that loss of the direct, nonsemantic pathway (which could be manifest as phonological processing difficulties) will lead to semantic errors in reading. We know that normal readers (i.e., without known neurological impairment) produce each of these error types when they learn to read and write in Chinese (e.g., Ho & Bryant, 1997b). We take this as evidence that literacy in Chinese requires a division of labor between lexical semantic and nonsemantic pathways depicted in figure 1, and that these develop independently and at different rates for individual beginning readers. According to figure 1, developmental dyslexia could result from impairments at more than one level of processing. Dyslexia could result from failure to develop connections between orthographic and phonological representations via the lexical semantic pathway or in the terms coined by Leong (1999) via the morphographic features unique to nonalphabetic scripts. The morphographic nature of Chinese makes it likely that mappings between orthographic and semantic representations will be a useful strategy for acquiring literacy in Chinese. Therefore, a deficit at this level might lead to reading and writing problems (see Leong, et al., 2000). We submit that the phenotype of dyslexia in Chinese speakers depends on how the language environment—especially the type of script that is taught—is configured for acquiring literacy in different Chinese speaking environments. This necessarily means that progress in understanding Chinese dyslexia will depend on carefully distinguishing between the reports of dyslexia in different Chinese speaking environments as we have attempted to do here.

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