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The Cognitive Neuropsychology of Reading and Writing in Chinese*

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Cognitive neuropsychological studies of patients with acquired reading and writing disorders in alphabetic languages have influenced our understanding of how mappings between orthography and phonology are learned, represented, and processed by the brain. This methodology has been extended to understanding reading and writing in Chinese during the past decade, leading to new insights about language processing and dyslexia and dysgraphia in Chinese. We review the key findings in this field and highlight some of the predictions that follow from a triangle framework of reading and writing in Chinese. Our conclusion is that the cognitive architecture for reading and writing is common across different scripts. However the unique features of Chinese script determine how the brain processes characters in normal and impaired reading and writing.

Key words: cognitive neuropsychology, sinographic dyslexia, dysgraphia

1. Introduction

How does the human brain process written words? During the past thirty years, cognitive models of the functional architecture of the reading system have led to new insights about reading and dyslexia in alphabetic languages (see Coltheart, Rastle, Perry, Langdon & Ziegler 2001). The study of patients with selective impairment to reading and/or writing to dictation has contributed much to the development of models of reading in English and other languages. To understand this, consider the dissociation between acquired surface dyslexia and phonological/deep dyslexia. Acquired **surface** dyslexia refers to impaired oral reading of irregular words in English such as *yacht* accompanied by preserved oral reading of regular words such as *patch* and nonwords such as *zint*. An irregular word will be regularized, e.g., *yacht* read as *yachted*. These errors are called

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regularizations, although they can be considered **legitimate alternative readings of components** (or LARC) responses (Patterson et al. 1995). An impaired ability to read nonwords accompanied by preserved reading of irregular and regular words, is acquired **phonological** dyslexia. A severe form of phonological dyslexia wherein patients make semantic errors reading abstract, low imageability words (e.g., *justice* read as *peace*) in addition to poor reading of nonwords is labelled acquired **deep dyslexia**. Analogous symptoms are seen in patients who have surface, phonological, and deep dsygraphia. These disorders are observed in Dutch, French, Italian, Japanese, and Spanish (Diesfeldt 1992, Goldblum 1985, Iribarren, Jarema & Lecours 1996, Patterson, Suzuki, Wydell & Sasanuma 1995, see Weekes 2005 for a review) although the pattern of impairment depends on features of the language; e.g., surface dyslexia in Italian refers to problems with stress assignment (Miceli & Caramazza 1992). The motivation for this paper is to illustrate the functional architecture of the reading and writing system in Chinese. Our approach is to review patients who have acquired dyslexia and dysgraphia in Chinese.

2. Models of single-word recognition/production in alphabetic writing systems

Coltheart et al. (2001) developed a "triple route" model of oral reading, which assumes that reading aloud known words is achieved using a **lexical semantic** pathway as well as a **direct lexical** pathway, the latter pathway reading words without contacting any meaning. A different model developed by Plaut, Seidenberg, McClelland & Patterson (1996) assumes that two pathways are available for normal reading, however these are labelled **semantic** and **phonological** instead of lexical semantic and direct lexical respectively. These models differ in two ways: in how many pathways are used to read words and nonwords and whether nonword reading requires rules or subword representations. One difference between the models is that a third nonlexical reading pathway with a sequential, rule-based, grapheme-to-phoneme reading strategy is assumed by Coltheart et al. and not by Plaut et al. Coltheart et al. (2001) assume that a nonlexical grapheme-to-phoneme (GPC) pathway is used to read nonwords and regular words, but cannot read irregular words correctly. Coltheart et al. (2001) also assume rules are required to link grapheme and phoneme representations and that GPC correspondences allow the correct pronunciation of nonwords in English by skilled readers. By contrast Plaut et al. (1996) do not assume that GPC rules are necessary to read nonwords. Instead, reading of nonwords is achieved via the phonological pathway, which reads novel letter strings by analogy with subword (onset, vowel, and coda) representations. These representations include the rime, defined as the orthographic or phonological unit including the vowel or vowel combination plus the final consonant or consonant cluster of a monosyllable which is an important functional unit when decoding words in English (see also Glushko 1979). Thus, the Plaut et al. (1996) model does not contain lexical whole-word representations and instead reads all letter strings via subword components only without assuming grapheme-to-phoneme rule-based correspondences.

The patterns of reading impairment in English can be explained by making hypotheses about different loci of deficits in these cognitive models as the models offer different accounts of surface and phonological dyslexia. According to Plaut et al. (1996) surface dyslexia results from damage to the semantic pathway because of impairment to the mappings between semantic and phonological representations or damage to semantic memory representations leading to reliance on the phonological pathway (see also Patterson & Hodges 1992). Phonological dyslexia results from relatively mild damage to the phonological pathway and deep dyslexia from severe damage to the phonological pathway. By contrast, Coltheart et al. (2001) argue that surface dyslexia can result from damage to one or more points along the direct lexical or lexical semantic pathways leading to over-reliance on the nonlexical route for reading aloud. This explains the phenomenon of regularized irregular words. Phonological dyslexia arises from damage to the nonlexical route, which results in poor nonword reading, but the direct lexical and lexical semantic pathways are intact. Deep dyslexia could result from damage to lexical <u>and</u> nonlexical pathways.

One question of interest is whether either model can explain reading in other languages. This will depend on the type of script. For example, the logographic nature of sinograms makes it likely that lexical knowledge (orthographic and phonological) will be vital for reading characters correctly. Because the Plaut et al. model contains no lexical representations (only subword components) it is not easy to see how the model would explain oral reading in Chinese although functional units such as the rime may be important for reading in both scripts. Coltheart et al.'s (2001) nonlexical pathway is redundant for oral reading in Chinese. Graphemes are orthographic representations of phonemes in an alphabet. By this definition grapheme representations may not exist in Chinese. Moreover, the logographic nature of Chinese characters makes it difficult to test nonword and pseudocharacter reading in the same way in alphabetic and non-alphabetic scripts.

3. Differences between alphabetic and non-alphabetic scripts

Alphabetic scripts use a finite number of symbols that can be combined to produce an infinite number of words. French, German, Spanish, and Turkish all use printed letters or letter clusters to convey the pronunciation of words. All Chinese languages use a non-alphabetic script. A non-alphabetic script is a relatively arbitrary system for mapping orthography to phonology. Non-alphabetic scripts are usually defined as logographic since the basic unit of writing is associated with a unit of meaning (the morpheme) in the spoken language. The great majority of characters represent one morpheme in Chinese. This makes the script **morphographic**, meaning the smallest pronounceable unit in a character is associated with a monosyllable. This means that each written form is associated with a morpheme in the spoken language. This contrasts with letters in an alphabet that do not represent meaning. Chinese scripts use a large number of symbols called characters (there are over 50,000 Chinese characters) that uniquely represent an individual word or small number of words. As printed letters are not available to convey the pronunciation of words, mappings between orthography and phonology are opaque (although there are some phonetic radicals that denote a common pronunciation across characters). Another feature of non-alphabetic scripts is that the mappings between orthography and meaning are transparent in many characters, whereas mappings between orthography and meaning in alphabetic scripts are relatively opaque. 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 3,000 characters to be literate. Ancient Chinese characters were pictographic because the written character portrayed the form of the object that it symbolized. So for example, the character for horse, 馬 *mǎ*, suggests a figure galloping across a page [36]. However few are used today.

There are four different types of character in modern use: (1) Pictographic characters represent an object, e.g., 口 *kǒu* meaning ‘mouth’. (2) Indicative characters represent abstract meanings that cannot be easily sketched, e.g., 本 *běn*, which means ‘base’ and is derived from 木 *mù* ‘tree’. (3) Associative characters combine existing characters to produce a new meaning, e.g., 塵 *chén* ‘dust’ derived from 小 *xiǎo* ‘small’ and 土 *tǔ* ‘earth’. And (4) phonetic-compound characters that are constructed from a meaning component called the semantic radical and a pronunciation component called the phonetic; e.g., 狐 *hú* ‘fox’ contains a semantic radical denoting animal on the left and a phonetic component pronounced “hu” on the right. Approximately 80% of characters are compounds. An important point is that the phonetic component of a compound is itself often a character (and thus represents a syllable). For example, the pronunciation of the character 清 *qīng* ‘clear’ is given by the component to the right of the character. This component can therefore provide information about the pronunciation of the whole compound. Similarly, the semantic component can often give the reader a clue to the category membership of a character (e.g., an animal) although the radical is not always a reliable cue for interpreting meaning. One feature of compound characters is that the phonetic information is often an unreliable guide to its pronunciation. For example the character 猜 'guess' which contains the component *qīng* on the right side is pronounced *cāi*. Yin [42] estimated that only 38% of compound characters contain a phonetic radical that is a consistent guide to the correct oral reading of the whole character. Yin [42] characterized this as regularity of characters [see also 40, 45]. A character can be defined as regular if the name of any character component, e.g., 青 *qīng* has the same name as the character as a whole, e.g., 清 *qīng*. However, if no component has the same name as the character, then it is irregular, e.g., 猜 *cāi*. Most Chinese characters are therefore irregular for reading.

One important difference between alphabetic and non-alphabetic scripts is that it is not possible to read aloud a compound by decoding the component parts in non-alphabetic scripts, but it is possible to read aloud many words by decoding constituent letters in alphabetic scripts. This point can be illustrated by considering two facts about Chinese orthography. (1) Phonetic radicals can be positioned to the left or to the right (or top or bottom) of a character. For example, the phonetic radical 其 *qí* is on the right in the character 棋 *qí* which means 'chess', but it is on the left for the character 期 *qí*, which means 'a period of time'. (2) Character components can act as both the phonetic radical and the semantic radical in different words. For example, the character 木 *mù* 'wood' is a semantic radical in over 1,500 Chinese characters, including 棋 *qí.* However, it is also the phonetic in the character 沐 *mù*, which means 'to wash'. This means it is difficult to know which component in a compound character is the phonetic (or semantic) prior to lexical access or 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 correct oral reading in Chinese is typically a lexical process [5].

Another important difference is that a Chinese speaker must pronounce a nonword using extant phonological representations of monosyllables from the lexicon. A non-word can be made in Chinese by manipulating existing syllables into a compound that has no meaning and these can be depicted as characters. The components in isolation have a lexical representation but will make no sense in combination. A pseudocharacter is a combination of character components into a stimulus that does not exist in print. A Chinese speaker is unlikely to read a pseudocharacter with a nonextant syllable, i.e., not in their vocabulary. The likely response is a monosyllable that is an existing syllable, i.e., a component of the pseudocharacter. However, this is not equivalent to the pronunciation that is generated for a nonword like *zint*, because that is a nonextant syllable.

4. A cognitive neuropsychological framework for explaining reading and writing in Chinese

Eminent linguists such as Wang (1973) and others (e.g., Yin & Rohsenow 1994) have proposed that the morphographic nature of Chinese means that a lexical semantic reading system would be sufficient to support normal oral reading in Chinese. This makes intuitive sense given that the relationship between orthography and phonology is —for most characters—quite arbitrary. Although a lexical-semantic pathway must be used for normal oral reading in Chinese (as in all languages), it might be possible to read aloud a character via a nonsemantic pathway such as that assumed to be available for reading in English by Coltheart et al. (2001) and Plaut et al. (1996).

Cognitive neuropsychological investigations of aphasic patients show that a nonsemantic pathway can be used to read in Chinese. Weekes, Chen & Yin (1997) described a *pǔtōnghuà* speaker called YQS with cerebrovascular disease who displayed intact oral reading of characters co-incident with impaired confrontation naming and reduced category fluency (anomia). YQS was unable to name pictured objects (e.g., an orange) but could read the printed characters of the same names perfectly. Anomia is assumed to reflect the operation of a lexical semantic system in models of language processing. Therefore, the pattern of **anomia without dyslexia** in Chinese shows that even if a lexical semantic pathway is impaired it is possible to read aloud in Chinese.

Weekes et al. (1997) argued that normal oral reading in Chinese can proceed via at least two pathways: a **lexical semantic pathway** that allows reading for meaning; and a **nonsemantic pathway** that directly links orthographic representations, i.e., strokes, radicals, and characters to phonological representations, i.e., syllables and tones. This framework is shown in Figure 1. This model can also explain writing to dictation through access from semantics to orthography, if it is assumed that the mappings between orthography and phonology are bidirectional. Note that the nonsemantic pathway can be referred to as a **direct lexical pathway** in keeping with the Coltheart et al. (2001) model. Weekes et al. (1997) argued that preserved reading in anomia is achieved using the nonsemantic pathway because it connects orthography to phonological output directly, i.e., bypassing representations of semantic knowledge. The pattern of poor picture naming with superior oral reading of characters displayed by YQS was replicated by Weekes & Chen (1999) in a *pǔtōnghuà* speaker (LJG) and in Cantonese (Law & Or 2001, Law, Wong & Chiu 2005).

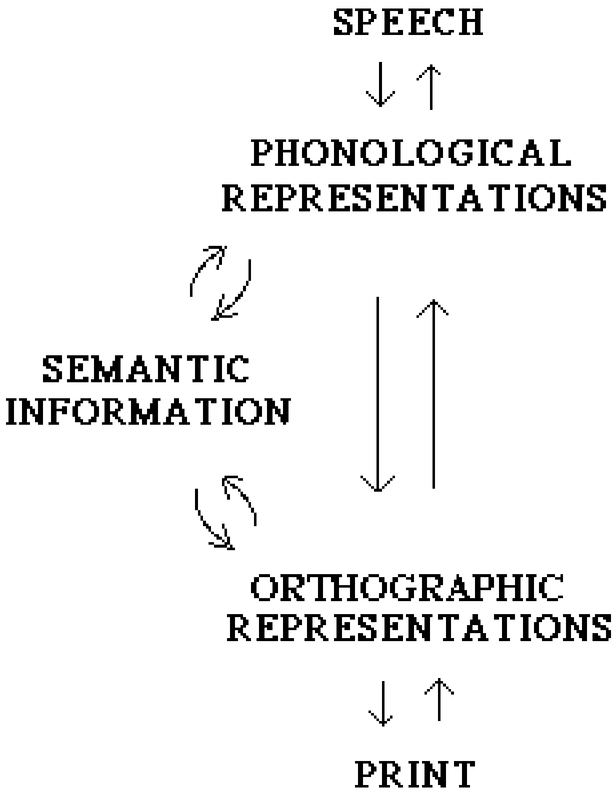

Figure 1: Functional model of reading and writing in Chinese

Our framework allows cognitive neuropsychologists to compare disorders of reading and writing in Chinese to other languages and to accommodate unique features of the Chinese script. The framework assumes that a character will be processed in both pathways in normal reading and writing. This means that during reading an orthographic representation will activate lexical representations related by meaning via the lexical semantic pathway and also by sound via the nonsemantic pathway (the same in reverse for writing to dictation). Any of these representations may be produced as a response. However, errors are not normally observed in Chinese reading and writing—although they have been reported (Moser 1994). This is because input from the nonsemantic pathway can inhibit semantically related (although incorrect) reading and writing responses and input from the lexical semantic pathway inhibits the production of LARC errors.

Yin (1991) and Yin & Butterworth (1992a, b) were the first to report impaired reading that resembled acquired dyslexia in alphabetic languages. One group of patients produced LARC errors (e.g., *qīng* when reading **irregular** characters 猜 *cāi*), but who could read **regular** characters (清 *qīng*) correctly. Reading errors were more common for low imageability, low frequency characters—a pattern that is also observed in patients with surface dyslexia in English (Breedin, Saffran & Coslett 1994, Bub, Cancelliere & Kertesz 1985), Dutch (Diesfeldt 1992), Italian (Miceli & Caramazza 1993), and Japanese (Patterson et al. 1995). They also described patients who made semantic errors on reading and writing tasks and produced more errors with low imageability than high imageability characters, as do deep dyslexic patients in English and French. According to our framework, if the input from the nonsemantic pathway that is normally used to inhibit incorrect phonological output becomes unavailable due to brain damage, semantic reading and writing errors will be the result. Evidence that loss of the nonsemantic pathway results in semantic reading errors comes from Cantonese speaking aphasic patients. Law (2004b) describes the spoken production of a patient who had intact comprehension and made semantic errors in reading (and naming) but produced no LARC errors in reading. Law (2004b) argued that absence of LARC errors (which reflect operation of the nonsemantic pathway) and deficits to phonological processes in the lexical semantic pathway result in semantic reading errors. Law (2004c) also reported patient LKK who produced more semantic errors in picture naming than in reading, suggesting that semantic reading errors can be inhibited with sufficient input from the nonsemantic reading pathway. This account of semantic errors in reading is compatible with the summation hypothesis (Hillis & Caramazza 1995), which assumes that normal reading depends on pooled activation at the level of phonological output from the semantic and direct pathways.

The patients identified in these reports are similar but not identical to acquired deep and surface dyslexic patients in alphabetic languages. In fact acquired dyslexia in Chinese cannot be identical to alphabetic languages for two reasons. First, nonlexical stimuli such as *zint* cannot be constructed in Chinese. Thus, it will never be possible to identify exactly the reported symptoms of phonological and deep dyslexia (impaired nonlexical reading) nor surface dyslexia (preserved nonlexical reading) in non-alphabetic languages. Second, regularity in alphabetic languages—which refers to whether subword components conform to GPC rules—is irrelevant since Chinese has no graphemes and thus strictly speaking irregular characters do not exist (Coltheart 1984).

Despite this, the psychological processes that reflect the regularity of words in alphabetic languages can be captured in normal and impaired oral reading in Chinese. We know that the **predictability** of character components has an impact on normal oral reading in Chinese (Zhou & Marslen-Wilson 1999). If the name of a character component, e.g., 青 *qīng* has the same name as the whole character, then the target can be defined as predictable (e.g., 清 *qīng*). If no component has the same name as the character then the target can be defined as unpredictable (e.g., 猜 *cāi*). Like regularity, predictability refers to whether there is agreement between the pronunciation of the character and its components.

One reason to examine the effect of predictability on reading in surface dyslexia is to test the **semantic glue hypothesis** (Graham, Hodges & Patterson 1994, Patterson & Hodges 1992, Patterson, Graham & Hodges 1994, Patterson & Lambon-Ralph 2000, Plaut et al. 1996). This holds that the normal system will inhibit competing and more common pronunciations of subword components at the level of phonological output preventing LARC errors. The system will settle on the correct but atypical pronunciation of an unpredictable word using input from semantic memory. Without support, the more common pronunciations of components dominate the computation of phonology from orthography. One prediction of this hypothesis is that impairment to semantic memory will lead to surface dyslexia (and dysgraphia) (see papers Patterson et al. for reports in English and Japanese). Evidence to support this prediction comes from Yin (1991) who reported an association between impairment on tests of semantic memory and production of LARC errors in Chinese reading. For example, patient LQF, who produced a large number of LARC errors (over 90%) when reading unpredictable characters, had poor word comprehension, spoken word production, and word-picture matching. Weekes & Chen (1999) reported patient LJG who produced LARC errors when unpredictable characters that were low in frequency and abstract. Since these symptoms are comparable to the patterns reported in patients with surface dyslexia in other languages, LQF and LJG were labelled surface dyslexia. Of course, preserved nonword reading cannot be demonstrated. Weekes & Chen (1999) suggest that reading of unpredictable characters is prone to error after damage to the lexical-semantic pathway due to loss of semantic support leading to response competition and reduced inhibition of competitors at the level of phonological output (also Weekes 2000).

The term **surface dyslexia in Chinese** is controversial. Coltheart & Perry (1998) argued that to assume similarity in selective disorders of reading between English and other languages (including Chinese) is a “kind of scientific cultural imperialism that runs the risk of obscuring important differences between scripts” (p.55). They argued this approach to understanding reading and writing disorders may preclude important insights about the unique characteristics of reading across languages. Although this view is not universally shared (e.g., Beland & Mimouni 2001, Eng & Obler 2002, Law 2000, 2003, Law & Or 2001, Raman & Weekes 2005, Patterson 1990, Patterson et al. 1995, Patterson & Lambon-Ralph 1999), it is important to uncover the features of the Chinese language that may impact upon the reading of surface dyslexic patients.

In fact Coltheart (1984) was the first to point out that surface dyslexia might be observed in Chinese. He argued indirect lexical access to semantics via lexically obtained phonological representations in Chinese was—in principle—possible, as Weekes et al. (1997) found for patient YQS. Coltheart argued that surface dyslexia in Chinese would be characterized by homophone confusions in comprehension. He drew an analogy between reading in Chinese and reading of irregular homophonic words, e.g., *bury* in English, by reasoning that in order to understand the correct meaning of *bury*, it is necessary to derive the correct pronunciation via direct lexical access. Surface dyslexic patients can produce homophone confusions in reading comprehension with irregularly spelled words in English; e.g., *bury* was defined as a fruit on a tree (*berry*) by patient NW (Weekes & Coltheart 1996, see also Coltheart et al. 1983). Hence, one question is whether homophone confusions are a feature of surface dyslexia in Chinese.

Weekes & Chen (1999) reported that when presented with a character-picture matching task including pictorial distractors that were phonologically related to the target (i.e., target and distractor shared one syllable), LJG performed poorly. This suggests he had difficulty retrieving semantic information from print. Moreover his errors were all phonological, so he had difficulty accessing the meaning of a character when there was a phonological competitor. For example, when asked to match the printed character 貓 *māo* 'cat' with the picture of a cat, an anchor, an elephant, or an apple, he pointed at the picture of an anchor, which has the sinogram 錨 *máo*. Notice that 貓 and 錨 are both orthographically and phonologically similar. LJG's errors suggest that he could access word meaning from print via phonological activation. However, because LJG had some difficulty accessing spoken names of objects, it is not clear whether the effect of phonological interference resulted from poor retrieval of semantics from print or because of his difficulty accessing phonology from semantics.

These unique characteristics of the Chinese script make it possible to isolate the locus of phonological confusions in acquired dyslexia with some precision. The Chinese script has many **heterographic** homophones in addition to visually similar characters. Also, there are visually similar characters that are not homophonous. Leck, Weekes & Chen (1995) exploited this phenomenon to test the hypothesis that retrieval of meaning from print in Chinese can be mediated by phonology using a semantic categorization task via presentation of homophones (foils) that varied in visual and phonological similarity. They found independent effects of visual and phonological interference on character recognition, suggesting that access to meaning from orthography can be mediated by phonological activation. This is compatible with Coltheart (1984) and with the lexical constituency model of reading in Chinese (Perfetti & Tan 2005).

If phonological confusions are due to damaged orthography, visually similar characters should cause most interference in reading comprehension. However, if these confusions are due to phonological activation, there should be little difference in the interference caused by visually similar and visually dissimilar homophones. This can be tested in the tasks shown in Table 1.

Table 1: Items used in tests of reading comprehension (Tasks 1 and 2)

Picture	Target	P+V-	P-V+	P-V-	Picture	Target	P-V+	P+V-	P+V+	P-V-
	嘴	最	嘀	伸		床	庆	创	疮	掰
	锚	毛	锡	逸		船	铅	串	舡	春
	虾	夏	独	点		碗	碱	顽	娩	幕
	鸟	脲	鸪	肌		糖	粹	躺	搪	新
	鱼	揄	笛	末		云	亏	允	运	半
	腿	颓	膀	捎		狗	拘	垢	佝	帛
	马	嘛	驴	僵		鼓	彭	辜	故	零
	熊	雄	烈	申		花	苻	划	化	应
	手	寿	撑	旦		脚	卿	焦	胶	离
	鹿	卤	庞	接		枪	构	墙	抢	昏
	旗	起	痒	舞		针	叶	枕	镇	临
	门	懑	闪	方		鹰	腐	影	膺	壁
	锁	所	镣	愁		梨	染	理	犁	善
	伞	三	全	孑		猪	赌	柱	著	晨
	球	丘	浆	价		锯	镇	菊	据	崩
	书	术	十	公		鞋	蛙	谢	斜	墨
	钟	重	针	网		蛇	舵	社	射	寄
	驴	率	吗	茶		剑	敛	茧	检	另
	象	项	芋	查		树	椒	殊	枢	都

Key
P-V+ refers to phonologically unrelated and visually related distractors.
P+V- refers to phonologically related and visually unrelated distractors.
P+V+ refers to phonologically related and visually related distractors.
P-V- refers to phonologically unrelated and visually unrelated distractors.

In Task 1, four characters surround the picture of an object. The characters are the printed name of the object (target) and three characters acting as distractors: one phonologically similar (the same syllable) but visually dissimilar character (assessed by Chinese undergraduates); and two phonologically dissimilar characters, one visually similar and the other visually dissimilar to the target. Participants are asked to select the character that matches the picture without reading aloud. In Task 2, five characters surround the picture of an object. These are the printed name of the object (target) and four characters acting as distractors: one phonologically similar and visually similar character; one phonologically similar but visually dissimilar character; and two nonhomophonic characters, one visually similar and the other visually dissimilar to the target. The purpose of the condition with phonologically similar and visually similar characters is to test the possibility that phonological interference and orthographic interference have additive effects on performance—as items in this condition seem the most difficult to discriminate from targets.

These tasks estimate a patient's ability to identify character meaning from orthographic knowledge and allow a test of the hypothesis that phonological knowledge is used to recognize character meaning. According to Figure One, surface dyslexia can arise from damage to multiple loci in the lexical semantic pathway (as in English), including semantic information, mappings between orthography and semantics (O→S), and the mappings between semantics and phonology (S→P); although in our experience, patients who make LARC errors in Chinese rarely fail on tasks in Table 1. This is because the majority of patients we see have damage to S→P mappings.

The framework in Figure 1 can also explain reports of acquired dysgraphia in Chinese. Reich, Chou & Patterson (2003) reported a Cantonese speaker, TUA, with acquired dysgraphia following a right hemisphere stroke. Their study was designed to identify the conditions under which TUA failed to produce the correct orthographic form of words. TUA made few errors when writing high-frequency words to dictation, but his error rates were as high as 60-70% on lower-frequency homophonic targets. The majority of errors were closely related phonologically to the target. Of particular interest was the fact that the deficit in writing to dictation was accompanied by good definition of the correct lower-frequency homophonic alternative. Thus, TUA's writing impairment had an orthographic locus. Reich et al. argued that TUA had an impairment activating low-frequency orthographic representations under conditions of response competition from a higher-frequency character with the same pronunciation. According to the framework in Figure 1 this could result from damage to the lexical semantic pathway and reliance on a nonsemantic pathway for writing.

Law & Or (2001) first proposed a nonsemantic pathway for writing in Chinese. They reported CML who also displayed superior writing to dictation compared with her written picture naming a pattern that was mirrored in better performance on tests of reading than picture naming (comparable to YQS reported by Weekes et al.). Law & Or (2001) argued that CML used a nonsemantic pathway to produce spoken words on reading tasks and a nonsemantic pathway to produce orthographic output when writing characters. CML also produced tonal and homophone errors (same syllable and tone) when writing from dictation and when writing the names of pictures (see also Law 2004a). According to Law & Or (2001), the nonsemantic pathway when isolated produces errors that are phonologically plausible (as in surface dysgraphia). In normal writing, both lexical semantic and nonsemantic pathways activate orthographic representations.

However as orthographic output from an isolated nonsemantic pathway is homophonic with the target, there is no constraint over homophone errors without support from the lexical semantic pathway (see also Graham, Hodges & Patterson 1997). Conversely, without input from the nonsemantic pathway, there will be no constraint over semantic errors in writing. CML's writing can also be understood with reference to Figure 1, if it is assumed that feedback connections exist in the nonsemantic pathway between phonological and orthographic representations (see also reports in Law 2003, 2004a). Note that reports of acquired dysgraphia in Chinese have led to a modification of that framework to include feedback connections (cf. Weekes et al. 1997). According to the framework in Figure 1, reduced output from both pathways could result in a pattern of semantic and homophone errors in writing. Reduced output in both pathways for writing to dictation may result from damage to the phonological lexicon (as in CML). This is the pattern of errors observed in many patients with acquired dyslexia and dysgraphia in Chinese (for examples of mixed reading errors in English see Gerhand, McCaffer & Barry 2000).

It is important to notice that both TUA and CML displayed better reading than writing performance. However, this does not necessarily imply any functional independence between the pathways connecting orthography and phonology; i.e., there is no requirement to posit separate unidirectional pathways for reading and writing. A more parsimonious explanation for better reading than writing in patients with dysgraphia is simply that writing is a recall task and is thus more difficult than word recognition and reading. More convincing evidence for unidirectional pathways would come from a patient who has better writing than reading (Weekes & Coltheart 1996). This can be observed in neuropsychological cases, though there are no reports in Chinese.

5. Structure of representations in the phonological and orthographic lexica

The pioneering work of Law and colleagues on dyslexia and dysgraphia in Cantonese has fostered a much better understanding of the architecture of the reading and writing systems in non-alphabetic scripts as well as the unique structure of orthographic and phonological lexica in Chinese (Law & Leung 2000, 2004a, Law, Yueng & Wong, in press). Their work also shows how acquired dyslexia and dysgraphia reveal information about the unique properties of Chinese script and their impact on reading and writing. This is best illustrated by Law & Or's (2001) observation of tonal dyslexia in patient CML whose reading included errors whereby the correct monosyllable was preserved but the tonal stress assigned to the syllable was incorrect (Eng & Obler (2002) subsequently reported the phenomenon in a bi-scriptal Cantonese-English speaker as did Luo and Weekes (2004) in a *pŭtōnghuà* speaker). CML also produced tonal errors and homophone errors (same syllable and tone) when writing from dictation and writing the names of pictures (also Law 2004a). Tonal errors in reading and writing are a unique feature of aphasia in Chinese. As such they can be informative to psycholinguists about the structure of phonological representations in the Chinese lexicon. For example, one view of phonological representations of Chinese words is that they have a nonlinear structure with separate syllabic, segmental (onset and rime), and suprasegmental layers. For Law & Or (2001), tonal reading and writing errors result from impairment to the tonal tier or to the association between tonal and segmental tiers which leads to a dissociation between segmental and suprasegmental information stored in the phonological lexicon. Law (2004a) reported a Cantonese speaker whose errors in writing-to-dictation and written naming were phonologically plausible and homophonous with or differed only in tone from the target. Interestingly, Law found that non-character responses, particularly those involving substitution of constituent(s), maintained the spatial configuration of the target. Law (2004a) proposed that the orthographic representations of characters contain information on the identity of components and structural information, which take the form of a template indicating the internal organization of the character or the specification for position of occurrence for each constituent within the character (see also Caramazza & Miceli 1990).

Law, Yeung & Wong (2005) report a Cantonese speaking patient with mild dyslexia and more severe dysgraphia who produced a large number of non-existing characters in writing. One feature of his errors was non-existing characters, including the substitution or insertion of semantic radicals whereby the non-target radical was semantically related to the target. Law et al. (2005) argued that their findings provided evidence for multiple levels of orthographic representation and that orthographic units of different sizes are accessed directly by the additional levels of representation. In addition, the observation that character structure was preserved in the majority of errors and substituting components appeared in their legal position supports the notion that spatial specification is a part of orthographic representations of Chinese characters. These findings have theoretical implications for the orthographic lexicon in Chinese since orthographic units of different sizes are arranged at the same level and semantic radicals are directly connected with semantic features.

6. Questions for further investigation in Chinese reading/writing disorders

There are many outstanding questions for research into the cognitive neuropsychology of reading and writing in Chinese. One question is how to characterize the representations that are assumed to be available in the nonsemantic pathway. Another question concerns the similarities between these representations and the mappings between orthography and phonology assumed to be available in alphabetic scripts such as subword units including the rime. Of course grapheme-to-phoneme units that are available for reading in English do not have an equivalent in Chinese.

Weekes et al. (1997) assumed that the nonsemantic pathway contained the representations of strokes, radicals, and characters at the level of the orthographic input, lexicon and syllables, rimes and tones at the level of the phonological output lexicon. The mappings between representations are assumed to be bidirectional and to allow reading and writing without contacting the meaning of words. However, this framework can be refined using cognitive neuropsychological data. One possibility is to assume **rule based** representations for phonetic radicals between orthography and phonology. There are some compound characters whose phonetic radicals are not legitimate and these have been called independent phonograms (Peng, Yang & Chen 1994, Lee, Tsai, Su, Tzeng & Hung 2005). Some studies have shown that the phonological information in a radical of an independent phonogram (e.g., the right side of the character 噗 *pū*) has an impact on reading both characters and pseudocharacters, suggesting that pronunciation of a compound is not necessarily retrieved holistically from the lexicon, but rather the pronunciation can be influenced by pronunciation of other compounds that contain the same phonetic radical (Lee et al. 2005). However, this does not necessarily mean that phonetic radicals operate according to a rule-based mechanism. Pronunciation of radicals is possible by analogy with characters in the lexicon that contain the radical making this a lexical event. Also if there is a family of characters containing this radical and most members in this family map on to a particular syllable, then it is likely this syllable will be produced. It would be of interest to observe an aphasic patient who was able to produce the pronunciation of a phonetic radical in character reading, but unable to produce the same response in pseudocharacter reading. This would suggest a mechanism, normally available for reading phonetic radicals, could be abolished following brain damage. This would be similar to the loss of grapheme-to-phoneme rules observed in phonological dyslexia in alphabetic scripts. Thus one possible counterpart of phonological dyslexia in Chinese, specifically in relation to the reading of independent phonograms, is a patient who could read existing phonetic compound characters with non-free-standing phonetic radicals, but was unable to read either the phonetic radicals or pseudo-characters that contain these phonetic radicals. Note that a report of this type would be of interest independent of the question of a rule-based mechanism underlying reading in Chinese. However, there is no data from aphasia to suggest rule-based oral reading in Chinese.

Weekes et al. also did not specify the status of the mechanisms that link representations in the nonsemantic pathway. One possibility is that there are **subword** connections in this pathway and these influence reading and writing in acquired dyslexia and dysgraphia. Subword refers to units of representation below the level of a word in Chinese. As all Chinese characters represent a morpheme it is an open question whether there are additional links between the orthography of character components (that do not depict the character morpheme) and phonological output. In addition, it is an empirical question whether phonological units including the syllable, rime, and tone are represented as subword units in the lexicon (note that most Chinese words are disyllabic). There is evidence from studies of normal oral reading in Chinese to suggest that characters, components, and radicals have distinct representations in the orthographic lexicon and these have an impact on reading in Chinese via links to phonological output. Indeed, Taft and colleagues (1995, 1997, 1999) have proposed a model of word recognition in Chinese that assumes subword levels of representation. Note that subword representations do not imply that a nonlexical rule-based mechanism is used to read aloud in Chinese, nor that a nonlexical pathway is available. Effects of subword components on reading in acquired dyslexia in Chinese have been reported (Han, Bi, Shu & Weekes 2005, Luo & Weekes 2004, Weekes & Chen 1999). LARC errors in surface dyslexia are of subword component pronunciations that are of higher frequency than the name of the character itself. Similarly rime and tonal errors suggest subword level is necessary. Thus the data from cognitive neuropsychology can contribute to the development of the framework shown in Figure 1 by adducing evidence about word and subword representations in the nonsemantic pathway. However, of much greater importance is that the framework can be used to generate predictions about the types of errors that should be observed in acquired dyslexia and dysgraphia in Chinese. This is the main contribution of single-case reports from cognitive neuropsychology.

Another important question is the role of cognitive neuropsychology in the rehabilitation of reading and writing disorders in Chinese (Law & Wong 2005). Figure 1 generates predictions about the locus of impairment for a patient. For example, homophone confusions in character recognition tasks indicate problems with access from orthography to meaning and homophone errors in writing may result from impairment at the level of the mappings between semantics and orthographic output. Rehabilitation of reading and writing could then focus on these deficits. One way to treat homophone comprehension errors is to retrain the mappings between characters and meanings. This involves generating a pictorial mnemonic that matches the meaning of the homophonic character, then using a paired association learning technique to reinstate mappings between orthography and meaning. This method was used successfully to treat the irregular word reading performance of patient NW who had surface dyslexia in English (Weekes & Coltheart 1996) with the result that NW was able to read many irregular words after training. Of greatest interest, his improved reading included better reading of irregular words that were not trained. A generalization of treatment effects to the reading of untrained irregular words was attributed to the activation of interconnected units of orthography in the lexicon. One prediction from Figure 1 is that training characters for reading comprehension will have the effect of improving writing to dictation of homophonic characters, i.e., reducing homophone errors in writing. This is because the mappings for reading and writing are shared as orthographic representations used to perform both tasks. If rehabilitation of reading has no effect on writing performance this might suggest that separate representations of orthography in the lexicon are used for reading and writing so that training of reading comprehension would not be able to affect writing performance (and vice versa). This is consistent with the view that there are functionally independent pathways between semantics and orthography. It is also possible that two orthographic lexica are used for reading and writing in Chinese, instead of a single orthographic store as is assumed in Figure 1.

7. A key question in language and linguistics is how different languages are processed in the brain. Human brains in different language environments probably solved the problem of literacy in the same way—by grafting phylogenetically young skills (reading and writing) on to existing neural systems that were developed for vision, speech, and comprehension of language (Patterson & Lambon-Ralph 1999). However, the Chinese language environment is unique and, within the domain of reading and writing, alphabetic scripts evolved in quite a different way to logographic writing systems. Thus, it may not be appropriate to ask whether a common cognitive architecture is used to read and write in different language environments, and therefore quite inappropriate to compare acquired disorders of reading and writing in Chinese to alphabetic languages. However it has long been recognized that damage to the cognitive systems used to read and write within a language can produce different error types for a variety of reasons (Shallice & Warrington 1980). The same logic applies to understanding dyslexia and dysgraphia across different scripts. We have approached the question of how the brain processes Chinese by testing hypotheses derived from a cognitive model developed to understand oral reading <u>in</u> <u>Chinese</u>. That was the approach pioneered by Marshall & Newcombe (1966, 1973) in the early years of cognitive neuropsychology (see also Coltheart 1984). Our approach resonates with the more sophisticated computational models of word recognition in Chinese (e.g., Taft & Zhu 1997 a, b, Perfetti & Tan 2005).

References

Beland, Renee, and Zohra Mimouni. 2001. Deep dyslexia in the two languages of an Arabic/French bilingual patient. *Cognition* 82.2:77-126.

Caramazza, Alfonzo, and Gabriele Miceli. 1990. The structure of graphemic representations. *Cognition* 37.3:243-297.

Cardebat, Daniel, Martine Puel, Jean-Francoise Demonet, and Jean-Luc Nespoulous. 1991. Les differentes “boites” de la repetition: analyse d’un case de dysphasie profonde. *Revue de Neuropsychologie* 1:215-232.

Coltheart, Max, and Conrad Perry. 1998. Reading Chinese: dual route theory and acquired dyslexia. *Advances in Theoretical Issues and Cognitive Neuroscience Research of the Chinese Language*, ed. by Henry Kao and Chen Lin. Hong Kong: The University of Hong Kong.

Coltheart, Max, Jackie Masterson, Sally Byng, Margot Prior, and Jane Riddoch. 1983. Surface dyslexia. *Quarterly Journal of Experimental Psychology* 35A:469-495.

Coltheart, Max. 1982. The psycholinguistic analysis of acquired dyslexias: some illustrations. *Philosophical Transactions of the Royal Society of London* B298: 151-164.

Coltheart, Max. 1984. Writing systems and reading disorders. *Orthographies and Reading: Perspectives from Cognitive Psychology, Neuropsychology, and Linguistics*, ed. by L. Henderson, 67-80. London: Lawrence Erlbaum Associates.

Diesfeldt, Henry. 1992. Impaired and preserved semantic memory functions in dementia. *Memory Functioning in Dementia*, ed. by L. Backman. Amsterdam: Elsevier Science Publishers.

Eng, Nancy, and Loraine Obler. 2002. Acquired dyslexia in a biscript reader following traumatic brain injury: a second case. *Topics in Language Disorders* 22.5:5-19.

Fiset, Daniel, Martin Arguin, Daniel Bub, Glyn Humphreys, and Jane Riddoch. (in press). How to make the word length effect disappear: letter by letter dyslexia is not letter by letter reading. *Psychological Science*.

Gerhand, Simon, Fay McCaffer, and Chris Barry. 2000. Surface or deep dyslexia? A report of a patient who makes both regularization and semantic errors in oral reading. *Neurocase* 6:393-401.

Goldblum, Marcel. 1985. Word comprehension in surface dyslexia. *Surface Dyslexia*, ed. by K. Patterson, J. Marshall, and M. Coltheart, 175-205. London: Lawrence Erlbaum Associates.

Graham, Kim, Karalyn Patterson, and John Hodges. 1997. Progressive dysgraphia: co-occurrence of central and peripheral impairments. *Cognitive Neuropsychology* 14.7:975-1005.

Han, Zaizhu, Yanchao Bi, Hua Shu, Brendan Weekes. (in press). The interaction between semantic and sublexical routes in reading: converging evidence from Chinese. *Brain and Language*.

Hillis, Argye, and Alfonso Caramazza. 1995. Converging evidence for the interaction of semantic and phonological information in accessing lexical information for spoken output. *Cognitive Neuropsychology* 12:187-227.

Iribarren, Carolina, Gonia Jarema, and Andre Lecours. 1996. The assessment of surface dyslexia in a regular orthography, Spanish: a case study. *Brain and Cognition* 32.2:196-198.

Law, Sam-Po, and Bella Or. 2000. Nonsemantic pathways of reading and writing Chinese: data from a Cantonese-speaking brain-damaged patient. *Brain and Language* 74.3:524-526.

Law, Sam-Po, and Bella Or. 2001. A case study of acquired dyslexia and dysgraphia in Cantonese: evidence for nonsemantic pathways for reading and writing in Chinese. *Cognitive Neuropsychology* 18.8:729-748.

Law, Sam-Po, Olivia Yeung, and Winsy Wong. (in press). Processing of semantic radicals in writing Chinese characters: data from a Chinese dysgraphic patient. *Cognitive Neuropsychology*.

Law, Sam-Po, R. Wong. 2005. A model-driven treatment of a Cantonese-speaking dyslexic patient with impairment to the semantic and nonsemantic pathways. *Cognitive Neuropsychology* 22.1:95-110.

Law, Sam-Po, Winsy Wong, and Karen Chiu. 2005. Preserved reading aloud with semantic deficits: evidence for a non-semantic lexical route for reading Chinese. *Neurocase* 11.3:167-175.

Law, Sam-Po. 2003. Written word production of a Cantonese dysgraphic patient. *Brain and Language* 87.1:148-49.

Law, Sam-Po. 2004a. Writing errors of a Cantonese dysgraphic patient and their theoretical implications. *Neurocase* 10.2:132-140.

Law, Sam-Po. 2004b. A morphological analysis of object naming and reading errors by a Cantonese dyslexic patient. *Language and Cognitive Processes* 19.4:473-501.

Law, Sam-Po. 2004c. Impairment to phonological processes in a Cantonese-speaking brain-damaged patient. *Aphasiology* 18.4:373-388.

Leck, Kwong Joo, Brendan Weekes, and May Jane Chen. 1995. Visual and phonological pathways to the lexicon: evidence from Chinese readers. *Memory and Cognition* 23.4:468-76.

Lee, C. Y., J. L. Tsai, E. C. I. Su, O. J. L. Tzeng, and D. L. Hung. 2005. Consistency, regularity and frequency effects in naming Chinese characters. *Language and Linguistics* 6.1:175-197.

Luo, Qian, and Brendan Weekes. 2004. Tonal dyslexia in Chinese. *Brain and Language* 91.1:102-103.

Majerus, Steve, Francoise Leku, Martial Van de Linden, and Eric Salmon. 2001. Deep dysphasia: further evidence on the relationship between phonological short term memory and language processing impairments. *Cognitive Neuropsychology* 18.5: 385-410.

Marshall, John, and Freda Newcombe. 1966. Syntactic and semantic errors in paralexia. *Neuropsychologia* 4.2:169-176.

Marshall, John, and Freda Newcombe. 1973. Patterns of paralexia: a psycholinguistic approach. *Journal of Psycholinguistic Research* 2.3:175-199.

Miceli, Gabriele, and Alfonso Caramazza. 1993. The assignment of word stress in oral reading: evidence from a case of acquired dyslexia. *Cognitive Neuropsychology* 10.3:273-296.

Moser, David. 1991[1994]. Phonetic processes in writing Chinese: evidence from written errors. *Information Processing of Chinese Language*, ed. by Q. C. Jing et al. Beijing: Beijing Normal University Press.

Patterson, Karalyn, and John Hodges. 1992. Deterioration of word meaning: implications for reading. *Neuropsychologia* 30.12:1025-1040.

Patterson, Karalyn, and Matthew Lambon-Ralph. 1999. Selective disorders of reading? *Current Opinion in Neurobiology* 9.2:235-239.

Patterson, Karalyn, Taka Suzuki, Taeko Wydell, and Sumiko Sasanuma. 1995. Progressive aphasia and surface alexia in Japanese. *Neurocase* 1:155-165.

Patterson, Karalyn. 1990. Basic processes of reading: do they differ in Japanese and English? *Japanese Journal of Neuropsychology* 6:4-14.

Peng, Danling, H. Yang, and Y. Chen. 1994. Consistency and phonetic independency effects in naming task of Chinese phonograms. *Information Processing of Chinese Language*, ed. by Q. C. Jing et al., 26-41. Beijing: Beijing Normal University Press.

Perfetti, Charles, Y. Liu, and L. H. Tan. 2005. The lexical constituency model: some implications of research on Chinese for general theories of reading. *Psychological Review* 112.1:43-59.

Plaut, David, James McClelland, Mark Seidenberg, and Karalyn Patterson. 1996. Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological Review* 103.1:56-115.

Raman, Ilhan, and Brendan Weekes. 2005. Acquired dyslexia and dysgraphia in a biscriptal Turkish-English reader. *Annals of Dyslexia* 55.1:71-96.

Reich, S., T. L. Chou, and Karalyn Patterson. 2003. Acquired dysgraphia in Chinese: further evidence on the links between phonology and orthography. *Aphasiology* 17.6-7:585-604.

Sasanuma, Sumiko. 1985. Surface dyslexia and dysgraphia: how are they manifested in Japanese? *Surface Dyslexia*, ed. by K. Patterson, J. Marshall, and M. Coltheart, 225-248. London: Lawrence Erlbaum Associates.

Shallice, Tim, and Elizabeth Warrington. 1980. Single and multiple component central dyslexic syndromes. *Deep Dyslexia*, ed. by Max Coltheart, Karalyn Patterson, and John Marshall. London: Routledge and Keegan Paul.

Taft, Marcus, and Xiaoping Zhu. 1995. The representation of bound morphemes in the lexicon: a Chinese study. *Morphological Aspects of Language Processing*, ed. by Laurie Beth Feldman, 293-316. Hillsdale: Lawrence Erlbaum Associates.

Taft, Marcus, and Xiaoping Zhu. 1997a. Submorphemic processing in reading Chinese. *Journal of Experimental Psychology: Learning, Memory and Cognition* 23.3:761-775.

Taft, Marcus, and Xiaoping Zhu. 1997b. Using masked priming to examine lexical storage of Chinese compound words. *Cognitive Processing of Chinese and Related Asian Languages*, ed. by H. C. Chen, 233-241. Hong Kong: The Chinese University Press.

Taft, Marcus, Ying Liu, and Xiaoping Zhu. 1999. Morphemic processing in reading Chinese. *Reading Chinese Script: A Cognitive Analysis*, ed. by J. Wang, A. W. Inhoff, and H. C. Chen, 91-113. Mahwah: Lawrence Erlbaum Associates.

Tan, L. H., and C. A. Perfetti. 1999. Phonological activation in visual identification of Chinese two-character words. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25.2:382-93.

Weekes, Brendan, and Gail Robinson. 1997. Semantic anomia without surface dyslexia. *Aphasiology* 11.8:813-825.

Weekes, Brendan, and Hui Qin Chen. 1999. Surface dyslexia in Chinese. *Neurocase* 5.2: 161-72.

Weekes, Brendan, and Max Coltheart. 1996. Surface dyslexia and surface dysgraphia: treatment studies and their theoretical implications. *Cognitive Neuropsychology* 13: 277-315.

Weekes, Brendan, May Jane Chen, and Bolin Yu. 1998. Differential effects of phonological priming on Chinese word recognition. *Reading and Writing: An Interdisciplinary Journal* 10.3-5:47-68.

Weekes, Brendan, May Jane Chen, and Wengang Yin. 1997. Anomia without dyslexia in Chinese. *Neurocase* 3:51-60.

Weekes, Brendan, May Jane Chen, Bolin Yu, Yue Xiao Xie, and Yao Cui. 1998. Anomia and dyslexia in Chinese: a familiar story? *Aphasiology* 12.1:77-98.

Weekes, Brendan. 2000. Oral reading in Chinese: evidence from dementia of the Alzheimer's type. *International Journal of Language Disorders* 35.4:543-59.

Weekes, Brendan. 2005. Acquired disorders of reading and writing: cross-script comparisons. *Behavioural Neurology* 16.2-3:51-57.

Yin, B., and J. S. Rohsenow. 1994. *Modern Chinese Characters*. Beijing: Sinolingua.

Yin, Wengang, and Brian Butterworth. 1992. Deep and surface dyslexia in Chinese. *Language Processing in Chinese*, ed. by H. C. Chen and O. J. L. Tzeng, 349-366. Amsterdam: North-Holland.

Yin, Wengang. 1991. *On Reading Chinese Characters*. London: University of College London dissertation.

Zhou, Xiaolin, and William Marslen-Wilson. 1999. The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25.4:819-37.

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漢語失讀和失寫：綜述

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對於拼音文字使用者中的失讀和失寫進行的認知神經心理學研究影響著我們關於人腦是如何學習字形和字音的匹配、對其進行表徵以及怎樣處理的認識。在過去的十年裡，認知神經心理學又拓展到漢字閱讀和書寫的研究，從而加深了我們對於中文語言處理過程以及閱讀障礙的理解。我們回顧了這個領域的主要發現，特別強調了那些支持漢語閱讀和書寫過程中的認知三角模型的資料。我們的結論是：雖然閱讀和書寫的認知框架對於不同文字系統來說基本上相同，但是漢字的特殊性則有可能決定著大腦如何具體處理這些資訊。

關鍵詞：認知神經心理學，失讀，失寫