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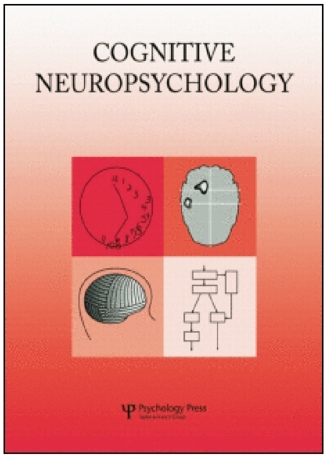

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The orthographic buffer in writing Chinese characters: Evidence from a dysgraphic patient

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We investigated the postlexical processes in writing Chinese characters by studying the delayed copying performance of a Chinese dysgraphic patient, W.L.Z. His delayed copying difficulty could not be attributed to peripheral motor deficit and could not be readily explained by lexical or semantic factors. Instead, the copying performance was sensitive to a word length variable (number of logographemes), and the most prevalent errors were logographeme substitutions. Furthermore, in the substitution errors, the target logographemes and responses tended to share visual/motoric attributes. We propose that the delayed copying difficulty reflects a deficit to the buffering component in writing (coined "logographeme output buffer"), and the universality and language-specific features of the output buffer in writing are discussed.

Chinese characters are complex things. Writing them involves spatial arrangement of strokes into a two-dimensional square in complicated ways. Take the character "脑"(brain, /*nao3*/[1]) for example, strokes are connected in various directions (亅, 凵), placed in various relationships (二, 亠, 乂), and so on. What guides the writing of these structures? Is there a closed set of stroke combinations in Chinese that are comparable to letters or graphemes in alphabetic scripts? Importantly, can models developed for writing alphabetic words be applied to writing Chinese characters? The current article tries to investigate the postlexical processes in writing by studying a Chinese dysgraphic patient.

Research on writing in alphabetic languages has revealed that writing involves multiple stages (see Figure 1). First, the orthographic properties of a

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[1] Within the slashes are the phonetic transcripts of the Chinese words, following the *pinyin* system. The number denotes the tone for the preceding syllable. There are four tones in Mandarin. The number 0 represents an unstressed syllable.

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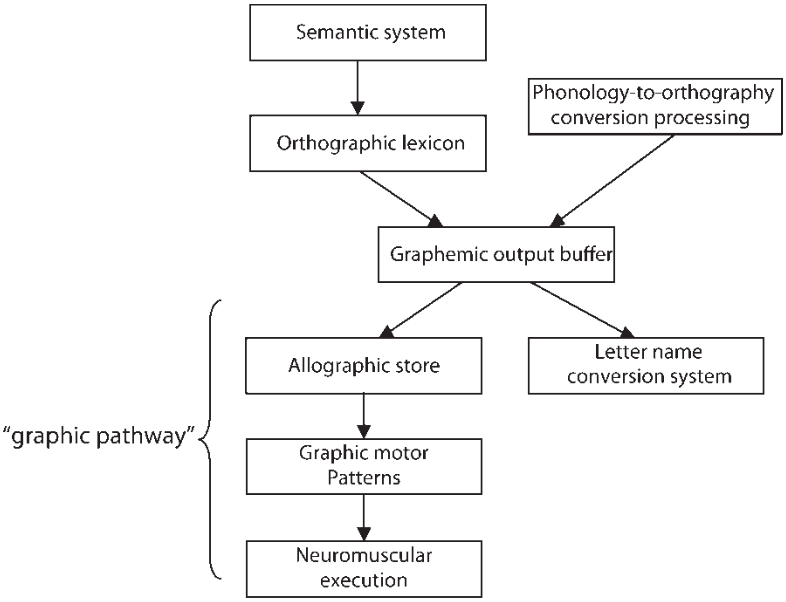

Figure 1. *A model of writing in alphabetic language (Adapted from Rapp & Caramazza, 1997).*

word could either be retrieved from memory directly, or could be computed from the phoneme–grapheme conversion mechanism. Once the orthographic information is retrieved, it is held in an amodal "graphemic output buffer" awaiting further processing. In written spelling, the "graphemes" in this buffer are converted into letter shapes (e.g., allographic representation and graphic motor pattern), including the correct case and font properties, after which the corresponding effector-specific motor system is employed (e.g., Ellis, 1982, 1988; Margolin, 1984; Rapp & Caramazza, 1997). In oral spelling, the "graphemes" in the buffer are converted into letter names and then are produced orally (e.g., Bub & Kertesz, 1982).

The proposal specifying these representations and processes is based not only on computational needs but also on empirical evidence, especially the observations of dysgraphic patients. Take the graphemic output buffer for example. Given its position within the writing architecture depicted in Figure 1, Caramazza, Miceli, Villa, and Romani (1987) reasoned that a series of behavioural patterns should associate with the selective disruption of this element. Because it is a postlexical constituent, it should not be influenced by lexical and semantic factors (such as frequency, concreteness, or grammatical class), lexicality (words vs. nonwords), the input modalities (e.g., writing to dictation, written naming), or the output modalities (e.g., written spelling, oral spelling, or typing). The number of writing errors should increase as a function of the word length, due to the greater difficulty in retaining longer letter sequences. Furthermore, because letters (or graphemes) are basic processing units in this buffer, the writing errors should occur on letters. Patients fitting this profile have indeed been reported in various alphabetic languages, including Italian, English, and French (e.g., Annoni, Lemay, de Mattos Pimenta, & Lecours, 1998; Caramazza & Miceli, 1990; Caramazza, et al., 1987; Cipolotti, Bird, Glasspool, & Shallice, 2004; Hillis & Caramazza, 1989; McCloskey, Badecker, Goodman-Schulman, & Ajiminosa, 1994; Rapp & Kong, 2002). Furthermore, detailed analyses of the errors produced by patients with selective graphemic output buffer impairment have shown that the structure of representations held in the buffer is rather rich, including the identity and order of letters, the consonant/vowel status of letters (Buchwald & Rapp, 2006; Caramazza & Miceli, 1990; Cotelli, Abutalebi, Zorzi, & Cappa, 2003; Ward & Romani, 2000), the morphemic structure (Badecker, Hillis, & Caramazza, 1990; Orliaguet & Boë, 1993; Schiller, Greenhall, Shelton, & Caramazza, 2001), the graphosyllabic structure (Caramazza & Miceli, 1990; Zesiger, Orliaguet, Boë, & Moundoud, 1994), letter doubling (Caramazza & Miceli, 1990; Tainturier & Caramazza, 1996), and digraphs (Tainturier & Rapp, 2004).

Dysgraphic patients have also been reported who are assumed to have deficits located at processing stages beyond the graphemic output buffer and prior to the effector-specific peripheral motor systems (see the "allographic representation" and "graphic motor pattern" in Figure 1; e.g., Ellis, 1982, 1988; Margolin, 1984). Errors produced by these patients are similar to graphemic output buffer patients in that they all make well-formed letter substitution errors and that their writing performance is not affected by lexical factors or input modalities. However, different from the buffer deficit patients, they do not show any length effect, the impairment is specific to written production leaving oral spelling intact, and their substitutions are sensitive not to consonant/vowel categories but to "stroke features" (e.g., Rapp & Caramazza, 1997). Although controversies remain regarding whether properties like case and font are captured by having different representations or are realized through some dynamic mechanism (e.g., case conversion; Ellis, 1982, 1988; Margolin, 1984; Rapp & Caramazza, 1997; Zesiger, Martory, & Mayer, 1997), and whether letter shapes are represented by visual-spatial properties or stroke features properties, the idea of this kind of "letter shape" representation is both theoretically and empirically justified.

By contrast, we know far less about the cognitive processes involved in writing logographic languages, such as Chinese. By studying different writing systems, not only could we learn about how language-specific features shape the structure of each representation, we could also examine what cognitive processes in writing are universal. In other words, it is an open question whether particular cognitive components in writing alphabetic languages are theoretical and empirically justified for writing Chinese. For example, one characteristic of a selective deficit to the output buffer in alphabetic languages is that the error patterns are highly similar in oral spelling and written spelling because the buffer is shared by these two modalities. However, oral spelling of a Chinese character is impossible for almost all characters due to the lack of an exhaustive set of pronounceable subcharacter components. On the other hand, in the writing process of all languages, the output units of the orthographic lexicon are usually of larger size than the units that the more peripheral motor system employs. Therefore, a buffer-like component to hold the to-be-processed information should be universal. It should be noted that there are debates about the *lexical* processes of orthographic representation retrieval in writing Chinese words, such as whether two routes (a semantic pathway and a nonsemantic pathway) are involved, the nature of the nonsemantic pathway, and the interaction between the two pathways (e.g., Graham, Patterson, & Hodges, 1997; Law & Or, 2001; Reich, Chou, & Patterson, 2003; Weekes, Yin, Su, & Chen, 2006). These issues are beyond the scope of the current article, and the focus here is on the processes after the orthographic representation is retrieved.

The approach we take here is to study a Chinese dysgraphic patient whose writing errors are not due to a peripheral motor deficit and are not merely attributable to lexical factors. We start from the generic framework in Figure 1 and assume that our patient's errors originated from the stage(s) that are comparable to the levels between the orthographic lexicon and the neuromuscular execution—the graphemic output buffer, the allographic store, and the graphic motor pattern—which are referred to here as the "graphic pathway" for the sake of brevity. Then we investigate the detailed origins of our patient's writing deficits within this pathway and explore the characteristics of that impaired component. The answers to these questions will inform us whether particular components in Figure 1 are universal and how language-specific parameters in Chinese are realized in such a cognitive theory. Before elaborating on our case study, we first briefly introduce the characteristics of Chinese writing scripts.[2]

Characteristics of Chinese scripts

Chinese is a logographic language, and the basic writing units are characters (e.g., Wang, 1973). Each character corresponds to a syllable in sound and almost always a morpheme. While some highly frequent words are monosyllabic, 88% of Chinese words are compounds that are composed of multiple morphemes (characters), and the majority (74%) are two-morpheme/character compounds (ILTR, 1986). Within a written compound word, the characters are linearly arranged in a left-to-right fashion, each occupying a space-independent square. For example, the word, 心理学 (psychology, */xin1 li3 xue2/*) is composed of three characters, 心 (heart, */xin1/*), 理 (reason, */li3/*) and 学 (research, */xue2/*).

There are more than 20,000 characters in modern Chinese language, including about 3,000 commonly used characters. A character can be spatially analysed into a hierarchical structure involving several different-size units, conventionally including the radical layer, the logographeme layer, and the strokes (see Standards Press of China, 1994; State Language Commission, 1998). Strokes are combined in rich spatial relationships to form characters, but their combination is not random. For instance, a 丿 never occurs right below a 丶.

More than 80% of characters are so-called semantic-phonetic composite characters (Shu, 2003). A composite character (e.g., 蝗, locust, */huang2/*) includes two parts: the semantic radical (虫, insect, */chong2/*), which provides clues to the meaning of the character, and the phonetic radical (皇, emperor, */huang2/*), which may give clues to the pronunciation of the character. Most, but not all, phonetic radicals are also existing characters when they stand alone. A smaller percentage of semantic radicals are also used as independent characters, and when they are, they often undergo slight form alternation (e.g., 朩→木). Neither the semantic radicals nor the phonetic radicals are very reliable indexes but they have been shown to affect the processing of Chinese characters in comprehension and reading (e.g., Bi, Han, Weekes, & Shu, in press; Law, 2004; Law, Yeung, Wong, & Chiu, 2005). Their roles in writing characters are less certain.

Some linguists and psycholinguists (e.g., Fu, 1991; Law & Leung, 2000; Su, 1994; Zhang, 1984) have proposed an intermediate level between strokes and radicals in visual Chinese characters—logographemes—based on spatial-visual principles. Logographemes,[3] a term coined by Law and Leung (2000), are the smallest units in a character that are spatially separated. For instance, the three parts (虫, 白, and 王) in 蝗 are spatially separate from each other (as opposed to being crossed) and are therefore considered as different logographemes. Such visual units are productive in that they appear in many characters. For example, the part "日" is found in characters 旦, 但, 曾, 僧, 旺, 驲, 钼, 暗, 暑, 晶, and so on. Only the smallest blocks that cannot be further disassembled into other logographemes are considered logographemes. Hence, many phonetic radicals (e.g., the "皇" in 蝗) could be further analysed into two or more logographemes (白 and 王). Based on these principals, *The Chinese Character Component Standard of*

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[2] While Chinese is rich in spoken dialects that are different by various degrees, there are currently two kinds of Chinese written scripts used—the traditional fonts used in Taiwan and Hong Kong regions and the simplified fonts used in mainland China. The traditional fonts are usually more complex than simplified fonts, while the structural principals are comparable. Here in our paper we focus primarily on the simplified fonts.

[3] The same concept has been addressed as 部件, */bu4jian4/* (components or subcomponents) in earlier linguistic references (e.g., CCCSGCSIP, State Language Commission, 1998).

GB13000.1 Character Set for Information Processing (CCCSGCSIP; State Language Commission, 1998) listed 560 logographemes that constructed the 20,902 characters in the *UCS Chinese Character Database* (Standards Press of China, 1994). This logographeme database will be the one used throughout the article.

Previous research on writing in logographic languages

The above description shows that Chinese characters could be analysed into various levels: strokes, logographemes, radicals, and whole characters. What then are the basic functional units in writing Chinese characters? How are they represented and retrieved? Insights on these issues have mainly come from the errors that patients with brain damage make. Kokubo, Suzuki, Yamadori, and Satou (2001) reported a Japanese brain-damaged patient who suffered from selective impairment in the "orthographic output buffer" in writing Kana (syllabogram) characters and was normal in writing Kanji (logogram) characters. Based on such observations the authors proposed that there exist two separate graphemic buffers for Kanji and Kana words in writing Japanese and that their patient had selective impairment to the buffer used for Kana words.

Law and colleagues (Law, 1994; 2004; Law & Caramazza, 1995; Law & Leung, 2000; Law et al., 2005) reported a series of case studies on the writing performance of Chinese dysgraphic patients who were Cantonese speakers using traditional characters. One group of patients (Law, 1994; 2004; Law & Caramazza, 1995; Law et al., 2005) made many writing errors on the radical level, where semantic and phonetic radicals were replaced (e.g., 踼 → 揚), deleted (e.g., [illegible] → 加), or added (e.g., 摩 → [illegible]), suggesting that the semantic/phonetic radical might be a processing level that could be impaired selectively in character writing. One particularly relevant case (S.F.T.) had a preponderance of writing errors on the logographeme level in a delayed copy task, leading the authors to conclude that logographemes are functional units in writing as well (Law & Leung, 2000). However, this conclusion is premature because logographemes and radicals were confounded in a large proportion of the errors—that is, the errors could be classified either as a logographeme error or as a radical error. Furthermore, many of the errors resulted in real characters, and therefore lexical factors might be at play. Most critically, while S.F.T. was poor at delayed copying (40%[4]), she was also impaired with direct copying (53%), raising the possibility that her copying errors may actually lie in peripheral visual or motor systems.

Our article reports a case that has a disrupted ability in delayed copying with preserved direct copying ability. His overall profile in delayed copy shared similarities in certain aspects with previous patients in alphabetic languages with deficits ascribed to "the graphic pathway". We present detailed analyses of his writing errors to address the following questions: (a) What deficit causes the delayed copying difficulties? (b) What are the functional units in the impaired representation? (c) What structural characteristics does that representation have?

Case background

W.L.Z. is a 36-year-old, right-handed, Mandarin-speaking male with a college education. Prior to a stroke, he worked in a foreign clothing company and had normal language abilities. In May 2004, he was admitted to a hospital due to a severe headache and difficulty in speaking. A computed tomography (CT) scan at the acute stage revealed a haemorrhage at the left temporal lobe. Evaluations from the Chinese version of *Western Aphasia Battery* (Gao et al., 1993; Kertesz, 1982) categorized him as suffering from sensory aphasia. A magnetic resonance imaging (MRI) scan performed in June 2004 indicated the assimilation stage of left tempo-occipital

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[4] Unless otherwise noted, the numbers given are correct percentages.

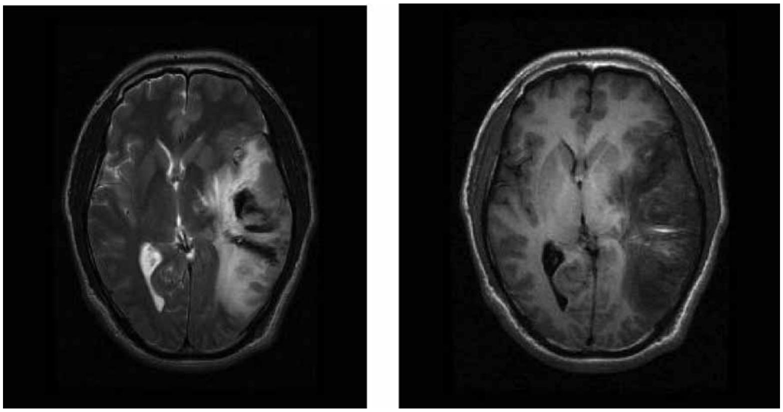

Figure 2. *MRI scans for W.L.Z.*

haematoma, with the possibility of hidden vascular malformation (see Figure 2). In that same month, a Transcranial Doppler (TCD) technique disclosed a weak blood signal in the temporal window and decreased blood flow of the left vertebrobasilar artery.

W.L.Z. was first administered the *Mandarin Clinical Language Screening Battery* that was adapted by author YB from the *Harvard CNLab Language Screening Battery*. Control data were collected from normal participants who were matched to W.L.Z. on gender (male), education (college), handedness (right), and age (mean: 26 years; range: 22–36). The control group were perfect on all tasks unless reported below. Worth noting is that control participants who had the same occupation and age were on the high end of the control group performance.

W.L.Z. was perfect at the bucco-facial apraxia task (15/15), picture copying (2/2), phoneme discrimination (40/40), and repetition (words with syllable number varying from one to four, 35/35; nonwords, 5/5). He was moderately impaired at auditory digit span (forward, 4; backward, 2; control group mean: forward, 8.25; backward, 6.25).

W.L.Z.'s lexical recognition and comprehension skills were impaired. He scored 12/20 on an auditory-word/visual-word matching task where he needed to match one spoken compound word to one of three visual words including one target and two related foils (semantic, orthographic, or phonological); 41/50 on an auditory-word/picture matching task where he matched one spoken word to one of two pictures (a target and a foil that was either semantically or visually related or unrelated to target); 41/50 on the visual version of the word/picture matching task; and 17/20 on an auditory lexical decision task where nonwords were created by combining two characters/syllables (e.g., "tea–row"; control group mean, 19.5/20).

W.L.Z.'s oral and written production were severely impaired. He was almost unable to read words (0/57, all no responses) or name pictures (11/82, mostly circumlocution errors; control group mean, 95%). He was unable to perform the writing to dictation task (0/10) and the written picture-naming task (0/11; control group mean, 95%), where all the writing errors were no responses. Nevertheless he had no difficulty copying the characters (20/20, for an example see Figure 3), where he had the target character in front of him during the copying. If the target characters were taken away for 2 s before he was instructed to write down what he saw (a delayed copy task), he was correct for 19/30 of the items (for an example see Figure 3). The responses here were all well formed, but only 2 out of the 11 errors he made resulted in another real character: 陆 (land, /*lu4*/) → 陪 (to accompany, /*pei2*/) and 楼 (building, /*lou2*/) → 搂 (to hug, /*lou3*/). The remaining 9 erroneous responses were all

Figure 3. *Samples of W.L.Z.'s writing performance (erroneous part/s being circled).*

noncharacters, all of which involve errors on the logographeme level—for example, 碗 (bowl, /*wan3*/) → 砾; 稿 (manuscript, /*gao3*/) → 积; 填 (add, /*tian2*/) → 坤; 徒 (apprentice, /*tu2*/) → 徃.

In summary, the screening tests revealed that W.L.Z. was impaired on a range of cognitive functions, including word and sentence comprehension, reading, and oral and written naming. Our study focuses primarily on his written production patterns using the delayed copy task, because of the observations that W.L.Z.'s delayed copy response patterns seemingly revealed a deficit along the "graphic pathway", and W.L.Z. was unable to perform written production from memory tasks (e.g., writing to dictation, written picture naming) and because oral spelling is hardly feasible in Chinese in most cases. In order to examine whether and how a deficit or deficits to these functional components along this pathway could account for W.L.Z.'s copying behaviour, and to investigate the structure of that component, we designed the following delayed copying experiment.

EXPERIMENT: DELAYED COPY

We mentioned in the Introduction that if a patient has a selective deficit along the "graphic pathway" for writing (see Figure 1), certain predictions could be derived about the patient's writing performance: It should not be influenced by lexical-semantic factors (frequency, concreteness, or grammatical class) and lexicality (words vs. nonwords) and should present the same pattern across different modalities. In an alphabetic language the errors should occur on the letter level, such as letter substitutions, deletions, insertions, or transpositions. If the deficit is located at a buffer-like component, the performance should be sensitive to word length (amount of information to be held in the buffer). If the errors are related to the targets by visual-spatial or stroke features, the origin of the errors is likely to be at a level that is more comparable to "allographic store" and/or "graphic motor pattern".

It is obvious that our patient is not only impaired with the graphic pathway, but also has problems in the semantic system, the orthographic output lexicon, and the orthographic input lexicon among others. Our rationale here is to first examine whether the difficulties in this particular task—delayed copy—are due to impairment along the graphic pathway, and, if so, by looking at the error patterns we could gain insights into the structural characteristics of the representation(s) of interest.

The rationale of the experimental design and error analyses is as follows. First, to establish whether his delayed copying errors come from a deficit on the graphic pathway, we manipulated factors including *lexical frequency*, *orthography–phonology regularity*, *concreteness*, and *grammatical class* of the test characters and compared his copying performance on words to his performance on nonwords. If the errors in delayed copying indeed originate from the graphic pathway, these factors should not affect the copying performance. The word-length factors of the test characters (number of strokes and number of logographemes) were also manipulated to explore whether the impaired component has buffer-like properties. Then, based on the error corpus obtained in the experiment, we examined at what orthographic levels the errors occurred on (strokes, logographemes, or radicals), what potential factors might predict the performance (e.g., position inside of the test character), and what relationships the target and the erroneous units have (e.g., visual-spatial or stroke features). The results from these analyses would potentially answer these following interrelated questions: (a) What is an exact deficit point along "the graphic pathway" that best explains the error patterns—"the graphemic output buffer", the "allographic representation", or the "graphic motor pattern"? (b) What are the functional units in the impaired component? (c) What are the structural characteristics of that impaired component?

Method

Materials

To avoid further complications such as morphology, we only selected single-character (also single-syllable) words as test material.

Frequency and phonetic regularity. A total of 160 "composite" characters were subdivided into four 40-character lists: 2 (frequency: high, low) × 2 (regularity: regular, irregular). A *regular* composite character (e.g., 怖, horror, /*bu4*/) shares identical pronunciation with its phonetic radical (e.g., 布, cloth, /*bu4*/), whereas an *irregular* character (e.g., 错, wrong, /*cuo4*/) has a completely different pronunciation from that of its phonetic radical (e.g., 昔, past, /*xi1*/). The character frequency counts are from the *Frequency Dictionary of Modern Chinese* (ILTR, 1986). We matched the four kinds of characters on visual complexity measures including number of strokes and number of logographemes. The statistics for mean frequency, mean logographeme number, and mean stroke number in each category are the following: high-frequency regular (353 ± 171,[5] 2.93 ± 0.89, 10.25 ± 2.92); high-frequency irregular (353 ± 240, 2.63 ± 0.67, 10.25 ± 2.23), low-frequency regular (13 ± 9, 2.73 ± 0.64, 10.25 ± 2.38), and low-frequency irregular (13 ± 9, 2.83 ± 0.90, 10.25 ± 2.23).

Concreteness. A total of 44 characters were selected, half of which were semantically concrete (e.g., 灯, lamp), and the other half were semantically abstract (e.g., 宛, similar). The selected characters were given to 10 normal participants to rate their semantic concreteness/abstractness on a 7-point scale, with 1 being most concrete and 7 being most abstract. The mean ratings were 2.03 for the concrete characters and 5.17 for the abstract characters, and the difference was highly significant, $t(42) = -11.275$, $p < .0001$. These two lists of characters were matched on frequency, number of logographemes, and number of strokes (concrete, 76 ± 123, 2.82 ± 1.01, 9.54 ± 3.47; abstract, 76 ± 125, 2.86 ± 1.04, 10.00 ± 3.00, respectively).

Grammatical word class. The following three 33-character lists were chosen: concrete nouns (e.g., 狼, wolf), abstract nouns (e.g., 祸, disaster), and abstract verbs (e.g., 忘, forget). They were matched on frequency and number of strokes (concrete nouns, 396 ± 504, 9.64 ± 2.87; abstract nouns, 405 ± 404, 9.70 ± 2.72; abstract verbs, 414 ± 592, 9.61 ± 3.47). Care was also taken that equal number of items in each list were regular composite characters.

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[5] The first value is the condition mean and the second the standard deviation.

Lexicality. A total of 20 real characters were selected, and 20 (legal) noncharacters were generated by randomly pairing semantic radicals and phonetic radicals together. The two lists were matched on the number of strokes and logographemes (real characters, 8.1 ± 2.22 and 2.45 ± 0.60; noncharacters, 8.1 ± 2.43 and 2.45 ± 0.60, respectively).

Number of strokes. A total of 148 items were split equally into a "few-stroke" character list and a "many-stroke" character list (stroke number, 9.51 ± 0.73 vs. 14.38 ± 1.63). They were balanced on character frequency (56 ± 69.34 vs. 57 ± 60.22) and logographeme number (3.00 ± 1.01 vs. 3.03 ± 1.04).

Number of logographemes. In total 385 characters were selected including 140 two-, 140 three-, and 105 four-logographeme characters. We matched these three sets of characters on number of strokes (11.04 ± 6.65, 10.91 ± 6.25, 11.50 ± 6.67, respectively) and character frequency (186 ± 212, 151 ± 186, 173 ± 257, respectively).

Procedure

In each trial of the testing, the experimenter presented one visual character in the middle of a sheet of paper, and W.L.Z. was allowed to look at it for two seconds. The stimulus was then removed, and W.L.Z. was required to write it down. In fact, although we encouraged W.L.Z. to look at the target character for two seconds, he often wrote it after a quick glance. In that situation, we removed the target once he began to write. The presentation time did not seem to affect the copying performance. The testing was completed in nine sessions in 2004.

Results

The results section is organized according to the questions that we laid out at the beginning of the experiment. First we looked at the variables that we manipulated on the target characters. Then all the errors were compiled to see what the basic error units were, what characteristics of the units predicted his copying performance, and what relationships existed between the targets and responses.

Table 1. *Delayed copying performance as a function of the properties of the target characters*

Word type	*Significance*[a]	*Correct response*[b]
Word frequency and regularity effect	*ns*	
High frequency, regular		43 (17/40)
High frequency, irregular		33 (13/40)
Low frequency, regular		23 (9/40)
Low frequency, irregular		33 (13/40)
Concreteness effect	*ns*	
Concrete		14 (3/22)
Abstract		32 (7/22)
Grammatical class effect	*ns*	
Concrete noun		64 (21/33)
Abstract noun		76 (25/33)
Verb		67 (22/33)
Lexicality effect	*ns*	
Character		55 (11/20)
Noncharacter		45 (9/20)
Stroke number effect	*ns*	
Few strokes		29 (15/74)
More strokes		26 (19/74)
Logographeme number effect	***	
Two-logographeme character		48 (67/140)
Three-logographeme character		31 (44/140)
Four-logographeme character		24 (24/105)

[a] Chi-square test: *ns*: $p > .05$; $^{***}p < .001$. [b] In percentages, numbers in parentheses.

1. Various lists of the target characters

Table 1 displays W.L.Z.'s correct percentage for various effects in the delayed copy task. There were no significant effects of lexical variables, including frequency, $\chi^2(1) = 1.82$, $p = .18$, orthography–phonology regularity, $\chi^2(1) < 1$, concreteness, $\chi^2(1) = 2.07$, $p = .15$, and grammatical class, $\chi^2(2) = 1.22$, $p = .54$. His writing was not influenced by the lexicality factor either: There was no difference between the performance on real characters and noncharacters, $\chi^2(1) < 1$.

The picture with regard to the "word length" factors was more complicated. No effect of stroke number on copying performance was observed, $\chi^2(1) < 1$. There was a trend such that the more logographemes a character has, the more likely it is for errors to occur on the character, but the significance of the effect depends on the way in which it is evaluated. First, if the accuracy rate is calculated on the character level, the correct percentage in two-, three-, and four-logographeme characters were 48%, 31%, and 24%, respectively, $\chi^2(2) = 17.75$, $p < .0001$. To evaluate whether the probability of getting a logographeme correct is determined by the number of logographemes in the word, we calculated the logographeme error rates by calculating the percentage of mistaken logographeme instances divided by the total number of logographemes in each group. The corrected logographeme percentages in two-, three-, and four-logographeme characters were 77%, 68%, and 67%, respectively, $\chi^2(2) = 4.767$, $p = .09$. This marginally significant trend of the word length effect was further examined using regression analysis, and is shown in Section 3 of the Results section.

2. Error analyses: Stroke vs. logographeme vs. radicals

In the above analyses we looked at what factors of the test target affected the likelihood of errors; now we turn to the characteristics of the errors themselves. First, when an error is made, is the whole character being mistakenly produced, is a stroke miswritten, or are the logographemes/radicals substituted, deleted, added, or transposed? The answer to this question will provide information regarding the nature of the functional units in the impaired representation. To investigate this issue we compiled all the errors (557 characters) from all subsets in the experiment (876 characters in total). We first classified the erroneous characters into two types according to whether or not the response was a real character. The character responses were scored as whether they had semantic or phonological/orthographic relationship with the targets. The noncharacter responses were further divided into four categories according to type of the erroneous orthographic units: logographeme errors, stroke errors, combination errors, and unrecognizable errors (see Law & Leung, 2000). Errors were scored as logographeme errors when a target logographeme was substituted, deleted, added, or transposed. Stroke errors were those cases where only a stroke was miswritten. Combination errors were those errors when the responses contained both logographeme errors and strokes errors. The possibility that some errors should be categorized as radical errors is discussed later. An unrecognizable error indicated that it was difficult to identify the response. Table 2 displays the examples and distributions of various error types. We can see that the most common errors were logographeme errors.

We further classified the logographeme errors into logographeme substitution, deletion, insertion, and transposition errors (see Law & Leung, 2000). A total of 55% of the 499 characters with logographeme errors contained only a single logographeme error, 32% contained two logographeme errors, 13% contained three, and 1% contained four. When the errors involved multiple logographemes, only in about 8% of the cases were the erroneous logographemes apart (e.g., being the 2nd and the 4th in a four-logographeme character)—that is, the majority were adjacent to each other. This pattern might be associated with the fact that W.L.Z. tended to make more errors towards the end positions of the character (see the Section below) and therefore is not explored further. In total, we collected 796 individual logographeme errors. Table 3 presents the distribution and examples of each error subtype. Logographeme substitution errors were found to be the most prevalent type, indicating that the logographemes are the functional units for the impaired cognitive components.

One caveat that we need to consider is whether the logographeme errors are instead radical errors or stroke errors. The relationship between radicals and logographemes are not systematic. While radicals are linguistic units that bear various kinds of lexical and/or semantic information, logographemes are visual-spatial/motoric units. Some radicals (most semantic radicals) correspond to

Table 2. *The percentage and examples of various error types*

		Examples	
Error type	*% (N)*	*Target*	*Response*
Character	4 (27)	斧(axe, /*fu3*/)	爸(father, /*ba4*/)
Noncharacter			
Logographeme[a]	91 (499)		
Stroke	2 (13)	逃(escape, /*tao2*/)	
Logographeme & stroke	0.3 (2)	请(invite, /*qing3*/)	
Unrecognizable	2 (16)		
Total	100 (557)		

[a] See Table 3 for further information about logographeme errors.

one logographeme, and others correspond to two or more logographemes (most phonetic radicals). If the errors involve single-logographeme radicals, it is impossible to tease apart these two kinds of erroneous units. If an error occurs on two or more logographemes of a target character, we could examine whether these multiple logographemes belong to one radical and for the substitution cases whether the erroneous response also corresponds to a radical. We found that in the whole set of 557 erroneously written characters, the majority (398) of the errors occurred on logographemes that did not correspond to any radical, 147 involved errors (target and/or response) that could be classified both as one logographeme and as one radical, and in only 12 cases were multiple logographemes involved that corresponded to radicals. Therefore, real logographeme errors, as opposed to radical errors, were the most common type of error. By the same token, it is highly unlikely that these errors are stroke errors that happened to constitute logographemes. In all erroneously written logographemes, 95% of the errors were multiple-stroke logographemes. Furthermore, in the rare cases where errors occurred on a single-stroke logographeme, it was always substituted by a multiple-stroke logographeme.

3. Logographeme errors: A regression analysis

We have observed that the copying performance did not seem to be affected by the lexical factors of the target characters, and that the errors were almost exclusively logographeme errors. In this section, we carried out a logistic regression analysis to explore more potential variables that might predict the copying performance of a particular logographeme. We analysed the whole set of 2,931 logographemes that appeared in all the tested characters, out of which W.L.Z. correctly

Table 3. *The percentage and examples of various types of logographeme errors*

		Examples	
Error type	*% (N)*	*Target*	*Response*
Substitution	80 (639)	嘶(hoarse, /*si1*/)	
Deletion	19 (151)	萎(wither, /*wei3*/)	
Insertion	1 (6)	笋 (escape, /*tao2*/)	
Transposition	0 (0)		
Total	100 (796)		

copied 68%. The dependent variable was the score of W.L.Z.'s copying result for a particular logographeme (1 for correct and 0 for incorrect). The predictors covered a range of various properties of the logographemes and of the corresponding characters, including number of logographemes in the corresponding test character, log frequency of the corresponding test character (Sun, 1998), stroke number of the logographeme, log frequency of the logographeme (Standards Press of China, 1994), and the temporal position of the logographeme in the corresponding test character.

The correlation matrix among the predictors (see Table 4) shows some predicted correlations. For instance, position of logographeme in character and number of logographemes per character were positively correlated. The character frequency and the number of logographemes per character were negatively correlated, indicating that the higher the frequency was, the visually and/or motorically simpler a character tended to be. Similarly, logographeme frequency and stroke number in a logographeme were also negatively correlated. Some correlations were not necessarily predicted but seemed reasonable and interesting—for example, the stroke number within a logographeme and its position in the corresponding character were negative correlated. It might indicate that "simpler" logographemes tend to occur at the end of characters. Some correlations—for example, the negative correlation between the logographeme frequency and the number of logographeme in the target character—are hard to interpret and may be due to unexplored factors or chance.

Table 4. *R-values among the predictors for the regression analysis.*

	NLC	*FC*	*SNL*	*FL*	*PLC*
NLC	1				
FC	−0.084**	1			
SNL	−0.377**	−0.049*	1		
FL	−0.277**	0.006	−0.357**	1	
PLC	0.414**	−0.035	−0.164**	0.018	1

Note: Labels: NLC = number of logographemes per corresponding test character. FC = log frequency of the corresponding test character. SNL = stroke number of the logographeme. FL = log frequency of the logographeme. PLC = temporal position of the logographeme in the corresponding test character.

We conducted a logistic regression using a forward (LR) stepwise method, where the variables are automatically selected and entered into the model in sequence of their weight of contribution on the dependent variable. The results are displayed in Table 5. We found that of the variables, position in the test character was the most significant predictor to the probability of the logographeme copying score, $\chi^2(1) = 546.2, p < .000$, followed by the number of logographemes per test character, $\chi^2(1) = 82.7, p < .000$, the log frequency of the logographeme, $\chi^2(1) = 17.7, p < .000$, and the log frequency of the test character, $\chi^2(1) = 13.0, p < .000$. Stroke number within the logographeme did not make an independent contribution and was not included in the model.

The regression analysis results partly replicated the previous findings that W.L.Z.'s accuracy in writing logographemes was a function of how many logographemes the corresponding test character contained, and the number of strokes in the character or the logographeme did not seem to matter, indicating that character complexity or length was better measured by logographeme than by stroke. The target frequency reached significance in predicting the scoring of a logographeme in this analysis, contradicting the absence of the target frequency effect in the previous section (see Table 1). To confirm that it indeed had an independent contribution, we entered all the other variables into the equation first and then entered the target frequency variable, and we found that it significantly increased the predictive power ($p < .001$). This part of the results suggests either that lexical knowledge influenced W.L.Z.'s copying performance (e.g., see Sage & Ellis, 2004) or that his lexical deficit might indeed play a role in the copying pattern. We argue that it would not seriously challenge our rationale of using W.L.Z.'s copying difficulties to study the postlexical "graphic pathway" for writing, if we look at the overall pattern of his behaviour. In particular, in all analyses when

Table 5. *Results of a logistic regression analysis of 2,931 items with W.L.Z.'s writing accuracy as the dependent variable*

Step	*Variable*	*Model log likelihood*	*Change in −2 log likelihood*	*df*	*p*-value
1	Position of logo in char	−1,838.2	546.2	1	<.0001
2	Number of logo per char	−1,565.1	82.7	1	<.0001
	Position of logo in char	−1,834.0	620.6	1	<.0001
3	Number of logo per char	−1,542.2	54.7	1	<.0001
	Position of logo in char	−1,812.7	595.8	1	<.0001
	Freq of logo	−1,523.7	17.7	1	<.0001
4	Number of logo per char	−1,537.8	58.9	1	<.0001
	Freq of char	−1,514.8	13.0	1	<.0001
	Position of logo in char	−1,807.6	598.5	1	<.0001
	Freq of logo	−1,516.4	16.1	1	<.0001

Note: Position of logo in char = temporal position of the logographeme in the corresponding test character. Number of logo per char = number of logographemes per corresponding test character. Freq of logo = log frequency of the logographeme.

variables other than frequency were examined frequency was always controlled for.

One interesting observation that emerged from the regression analysis is that the performance on a particular logographeme was highly affected by its serial order position in character ($p < .0001$). To further clarify this "position effect", we split all the characters with two to five logographemes in delayed copy according to the numbers of logographemes in each character into 242 two-, 389 three-, 300 four-, and 52 five-logographeme characters. We then scored each logographeme in each character. The scoring procedure approximately abided by the principle of analysis on incorrect response used in the case of patient L.B. (Caramazza & Miceli, 1990, p. 250).

Figure 4 shows that W.L.Z.'s error percentage for each position within the characters varied according to the logographemes' numbers. Collapsing all the characters regardless of the character length, the first, second, third, fourth, and fifth logographemes in the characters were incorrectly written 7% (71/983), 31% (304/983), 51% (381/741), 63% (223/352), and 63% (33/52), respectively. W.L.Z.'s writing exhibited a significant gradual increase in error percentages from the initial logographeme to the final one in character, $\chi^2(4) = 583.5, p < .0001$. Moreover, a similar pattern presented in every stimuli group broken up by length: two-logographeme, $\chi^2(1) = 95.8$, $p < .0001$; three-logographeme, $\chi^2(2) = 215.7$, $p < .0001$; four-logographeme, $\chi^2(3) = 287.4$, $p < .0001$; and five-logographeme, $\chi^2(4) = 63.3$, $p < .0001$, characters. For example, he wrote 箭 as , where the last logographeme 刂 was substituted with 攵. He wrote 煮 as , where the first logographeme 耂 was accurately written, the middle one | | was replaced by 贝, and the last one 灬 was deleted. In other words, a linear serial position effect presented in W.L.Z.'s writing.

There are several possible explanations for this effect. First of all, it is possible that the logographemes at the end position tend to be more difficult (e.g., visually more complex or less frequent). Second, if the effect is real, it might originate

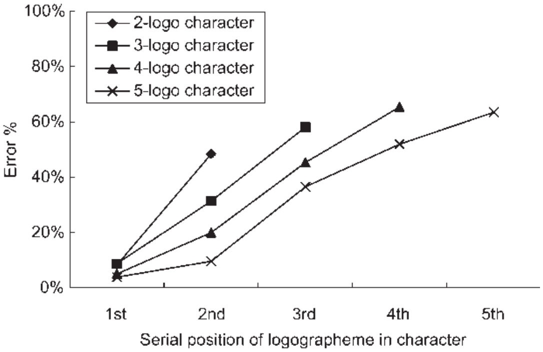

Figure 4. *Serial position effect of the logographemes in copying characters.*

either from the input process (when visually encoding the stimuli) or from the output process (when reproducing the stimuli). Although there has been evidence that the visual input in word recognition happens in a parallel fashion (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), one can imagine that the input process in a copying task scans the target character in a left-to-right/top-to-bottom fashion and therefore favours the left/top logographemes over those on the right/bottom. Indeed, in an study (Zhang & Sheng, 1999) where participants were asked to name logographemes embedded in different position of visually presented Chinese characters, it was observed that the naming performance for the same logographeme was better in the top position than in the bottom position and was better in the left position than in the right position. The authors attributed such results to the viewing habit of Chinese readers. By contrast, if the positional effect originates from an output process, a "temporal" effect is predicted such that earlier output logographemes are better copied than later output logographemes. Many Chinese characters present an interesting discrepancy between the "(input) spatial order" and the "(output) temporal order". For example, the character 退 has two logographemes: 艮 and 辶. In a temporal perspective, 辶 is its last written logographeme, whereas from the spatial left-to-right sequence, it is the first one. Given that an input deficit would produce either no positional effect (as in parallel processing) or an effect favouring the left/top over the right/bottom logographemes (in that scanning order), if the later output elements in such characters are found to be more prone to impairment, it should be due to a buffering process for output. In other words, if a "temporal" positional effect was observed, it would be strong evidence for the hypothesis that W.L.Z.'s copying errors result from the impairment of a buffering component in the output process that serves a similar functional role as the "graphemic output buffer" in writing alphabetic languages. The following analyses and experiment were done to test these three hypotheses regarding the position effect.

3.1. Testing the difficulty difference account. To rule out the possibility that the position effect is due to the difficulty difference in different positions, 30 pairs of characters were selected. The two characters in each pair share one identical logographeme that are in different positions (e.g., 放—访, with the logographeme "方" on the left of "放" and the right of "访"). The two groups of characters were also matched on frequency (410 vs. 535; $t < 1$). W.L.Z. correctly copied fewer critical logographemes when they were on the right position than when they were on the left position (22/30 vs. 13/30); $\chi^2(1) = 5.55$, $p < .05$. For example, he correctly wrote "火" in "灶", but miswrote "火" in "伙" as "贞". This pattern was also replicated by using 30 pairs of noncharacters where the same logographemes were used both in the left and in the right positions on different trials, $\chi^2(1) = 40.85$, $p < .0001$.

3.2. Distinguishing the (input) spatial position vs. the (output) temporal position. To clarify whether the positional effect is an (input) spatial effect or an (output) temporal effect, we inspected all characters ($N = 28$) from the tested set that showed discrepancy between the spatial position and the temporal position—for example, 退 (the last spatial logographeme is 艮, and the last logographeme to be written is 辶). If it is the spatial position that matters we would predict the logographeme on the left (辶) to be copied better than the one on the right (艮), and vice versa if the temporal position matters. The results showed that the (relatively) right logographemes (19/28) were indeed copied more correctly than the (relatively) left logographemes (12/28) in these characters, $\chi^2(1) = 3.54$, $p = .06$. Furthermore, this difference is not attributable to any "difficulty" differences because the 28 right logographemes were "simpler" (stroke number: 2.89 vs. 3.68, $p < .05$) and of higher frequency (112 vs. 38, $p = .07$) than the 28 left logographemes. Thus, although the "temporal" positional trend was only marginally significant for these characters, it was in the reverse direction from all the other cases where temporal position and spatial position were consistent, indicating that the position effect indeed was temporal.

4. Target–response logographeme relationships

When W.L.Z. failed to copy a logographeme correctly, what did he write? We examined the visual/motoric relationship between the target logographeme and the corresponding erroneous response to study whether the errors maintained any particular kind of properties of the target logographeme. Such analyses would inform us whether there is more information retained in the impaired component when the specific identity of the logographeme is lost. To avoid any potential confound, we studied the characters in which W.L.Z. made only one substitution error and collected 209 logographeme substitution errors. We compared each target–response pair on visual/motoric dimensions, using measures on the overall visual configurations (structure, stroke relation) and individual stroke element (first stroke shape). “Structure” and “stroke relation” provide measures for the visual arrangements of the elements (e.g., structure—strokes are aligned in a left/right fashion or in a top/down fashion or otherwise; stroke relation—strokes are aligned in a crossing manner or a connecting manner, etc.). The “stroke shape” variable measures the motoric features and/or visual shapes of an individual stroke by categorizing strokes into five rough categories (e.g., horizontal or vertical). We used classification criteria for each category of these properties derived from the CCCSGCSIP (1998; see the labels in Table 6 for detailed descriptions), calculated the probability of W.L.Z.’s substitution errors to be within a same category for a given property, and compared the observed within-category probability to a chance level.

Take the “stroke relation” property, for example. It can be categorized into six subtypes (single strokes, crossing, separate, connecting, crossed-connecting, and crossed-separate). We want to know whether W.L.Z.’s within-category substitution (i.e., a single-stroke logographeme substituted for another single-stroke one, a separate stroke logographeme substituted for another separate stroke one, etc.) tended to occur more frequently than the chance level. First, we counted W.L.Z.’s observed value of within-subcategory substitution performance and found that 36% (75/209) substitutions occurred within category. Then we calculated the chance level of within-subcategory substitutions using a Monte Carlo simulation procedure, adapting the method used to establish the chance levels of visual/motor similarity in Rapp and Caramazza (1997). Firstly we randomly re-paired the 209 erroneous logographemes with the target logographemes and then computed a within-category probability on the result of this re-pairing. A total of 5,000 such random pairings of the items in the target-error list were carried, generating 5,000 baseline within-category probability values for this “stroke-relation” property. To obtain values reflecting how likely W.L.Z.’s observed within-category probability (36%) for this measure is due to chance level, we calculated the percentage of instances with a value equal to or higher than this observed value in the 5,000 baseline runs. We found that such instances were generated only 43 times, and the percentage (43/5,000) was less than 0.01 (i.e., $p < .01$). The same procedure was also conducted for the properties “structure” and “first stroke shape”. As shown in Table 6, the patient’s observed within-category probability for structure and first stroke shape were never observed in 5,000 random pairings (ps $< .0002$). Thus, W.L.Z.’s logographeme substitution errors tended to occur within the same categories for all three measures, indicating the preservation of visual/motoric properties.

GENERAL DISCUSSION

We presented a Chinese patient on whom we focused on the delayed copying performance to study the postlexical process involved in writing Chinese characters. We found that the semantic characteristics of the test characters did not affect the likelihood of making an error but the character frequency did, suggesting that the lexical deficit of the patient might contribute to the copying performance. After we controlled for the lexical

Table 6. *Comparison of the observed versus the expected percentage of the within-category substitutions between the target logographemes and responses*

	Observed value		*Expected value*			
Logographeme property	*%*	*N*	*%*	*Range*	*Instance*	*p*-value
1. Structure	43	89/209	28 ± 3	19–37	0	<.0002
2. Stroke relation	36	75/209	29 ± 3	19–40	43	<.01
3. First stroke shape	42	87/209	23 ± 3	13–34	0	<.0002

Note: Labels: 1. A total of 10 overall spatial categories, including unique (e.g., · ·), left-right (e.g., 非), top-bottom (e.g., 贝), top-middle-bottom (e.g., 象), surround upper left (e.g., 丿), surround upper right (e.g., 亅), surround below (e.g., 凵), surround three-quarters (e.g., 丿(), surround full (e.g., 囯), and frame (e.g., 木). 2. Six types of stroke relation including single strokes (e.g., · ·), crossing (e.g., 廾), separate (e.g., 彡), connecting (e.g., 冂), crossed-connecting (e.g., 九), and crossed-separate (e.g., 必). 3. The physical configuration of the strokes in the logographeme, including horizontal (e.g., · ·), vertical (e.g., 丨), slanted (e.g., 丿), pointed (e.g., 丶), and crooked (e.g., 乛).

frequency contribution, the following findings regarding his delayed copying performance emerged from our experiment:

1. A particular word length factor—number of logographemes—affected delayed copying performance.
2. The erroneous units almost always corresponded to logographemes as opposed to radicals or strokes, with logographeme substitutions being the most frequent type of error.
3. The logographeme's temporal position in the corresponding character and the logographeme frequency were significant predictors of the copying performance, but its stroke number was not.
4. When a logographeme substitution error was made, it was substituted by those having similar visual/motoric properties.

We first infer the deficit locus of our patient from these findings based on the framework developed with alphabetic writing, and then we discuss in turn the *universality* and language *specificity* of the impaired representation based on the analyses of the patient.

Locus of the deficit

Because W.L.Z. was perfect in direct copying, his difficulty in delayed copying cannot be attributed to any peripheral motor deficit. His errors in delayed copying did not originate from the semantic or phonology–orthography–conversion systems because of the absence of semantic, grammatical, and phonetic regularity effects. Although the significant contribution of the character frequency in the regression analyses suggests that his lexical deficit played a role in the copying task, we controlled for this frequency variable in various analyses and therefore the error patterns we reported should result from impairment in the stages beyond lexical retrieval—that is, from the "the graphic pathway".

Within "the graphic pathway", Finding 1 and the positional effect of Finding 3 suggest that the deficit originated in a buffer-like structure since it had the characteristics of a working-memory component. The performance was sensitive to the *amount* of information (number of logographemes) and the *time* being held in memory. The more information the buffer contained, and the longer it remained in the buffer, the more likely errors were to occur. It is critical to note that we observed a *temporal* and not *spatial* order effect, indicating that effect originated at a buffering process during output instead of input in the delayed copy task. Therefore we propose that W.L.Z. was impaired at the level of a buffering component for output, and such impairment contributed to the delayed copying errors. The brain damage seemed to have caused an abnormally rapid decay of information or failure in the refresh mechanism during the buffering process.

Finding 2 and the logographeme frequency effect (in predicting the error rates) in Finding 3 indicate that logographemes, as opposed to strokes or radicals, are the functional units represented in this impaired component, and its resistance to impairment is sensitive to frequency. For this reason, we named this buffering component in writing Chinese characters "logographeme output buffer" (LOB). We further observed that there was stroke-feature similarity between the target logographeme and the response logographeme, indicating that LOB in writing Chinese characters encodes graphic information (shape and/or stroke features).

Below we discuss the theoretical implications of our findings for two issues: the universality of a buffering component in the writing process and the language-specific parameters of such a component.

The universal and language-specific aspects of the output buffer

In alphabetic languages, convincing empirical evidence for the existence of a graphemic output buffer comes from the strong association between oral spelling and written spelling performance in certain classes of patients. Nevertheless, the lack of oral spelling means in Chinese does not mean that a buffering structure is not necessary for writing Chinese characters. If we consider the theoretical motivation for the proposal of a buffering process in writing, the idea of it being universal in all languages becomes natural. In general, when the "unit" of information that is output from one representation is larger than what the subsequent representation can take as input for further processing, it is reasonable to assume the existence of a buffer to hold the to-be-processed units temporarily. Our analysis demonstrates that logographemes are the basic units in writing Chinese characters, in a sense comparable to the status of letters in alphabetic writing systems (see a similar position in Law, 2004), and that there exists a universal output buffering component in writing both in Chinese and in alphabetic languages.

Of course there are fundamental differences between the units being represented in the output buffer for alphabetic languages and Chinese. One critical difference is that the "graphemes" in alphabetic languages represents amodal graphemes without name, shape, or font. Shape and stroke information are implemented at level(s) beyond the graphemic output buffer—that is, the allographic representation and graphic motor pattern. Indeed, Rapp and Caramazza (1997) reported that patients who had selective graphemic buffer deficit showed no target–response similarity in visual-spatial or stroke features in their substitution errors, while they showed similarity with regard to abstract properties (e.g., consonant/vowel status or syllable organization). Target–response similarity in terms of visual-spatial or stroke features was present in the substitution errors made by patients who suffered from "graphic motor pattern" deficit. Furthermore, graphemes have been argued to correspond to phonemes (e.g., see Tainturier & Rapp, 2004, for a discussion), and therefore the buffer contains multidimensional phonological-related features along with the grapheme identities and their order, such as the consonant–vowel status and possibly syllabic organization information. By contrast, logographemes in Chinese characters are purely "orthographic" units and do not serve as the connection between individual sounds and orthography. In fact, only 49% can be pronounced (CCCSGCSIP, 1998), and their pronunciations do not correspond to the pronunciations of the characters they appear in.

Thus, it is interesting why logographemes act as the basic units in writing characters, as opposed to other units, such as strokes. We argue there are computational advantages to having logographemes as the functional units. Consider the character 福 (luck, /*fu2*/), for example. The idea of having strokes as the functional units seems unlikely. First, strokes of a character are generally too many to be kept in the working-memory system. The normal capacity of working memory is from four to nine chunks (Cowan, 2001; Miller, 1956), whereas 福 has 13 strokes (mean number of strokes in Chinese characters is 12.85, Standards Press of China, 1994). Second, the strokes constituting a character are highly ambiguous in shape and position. For example, 福 has four "丨" of various sizes in different positions, easily leading to confusions in writing. By contrast, the logographemes in a character can be easily kept in working memory. 福 is segmented into four logographemes with spatial specification (礻, 一 凵, and 川; mean number of logographemes in a character is 3.64, Standards Press of China, 1994), which is lower than the maximum memory load. Also, the ambiguity among strokes disappears when strokes of a character are embedded in logographemes. Another possible candidate for functional units in the buffer are radicals, a position motivated by the cases that made writing errors on radical levels (e.g., Law, 1994, 2004; Law & Caramazza, 1995; Law et al., 2005). However, it is unclear what can be gained by having radicals as functional units because semantic radicals most correspond to logographemes, and phonetic radicals usually correspond to existing characters. Their patients' writing errors can therefore be explained by either logographeme errors or character errors.

The differences of the intrinsic characteristics of logographemes and alphabetic graphemes should lead to structural differences between LOB for Chinese and the graphemic buffer in alphabetic languages. Present findings from W.L.Z. might indicate that the logographemes in the buffer are represented by some kind of orthographic feature. W.L.Z.'s logographeme substitution errors resulted in significantly higher proportion of logographemes having similar visual/motoric properties (structure, stroke relation, first stroke shape) to the target logographeme than what was expected by chance. This could reasonably be due to the fact that, although the brain damage led W.L.Z.'s buffer system to be unable to efficiently access and/or select identity information of the target logographeme, the stroke shape information of the logographemes was preserved. Thus, the system tried to look for a substitute with similar visual/motoric information to that of the target logographeme.

To conclude, by studying the delayed-copying performance of a Chinese dysgraphic patient, we have evidence that an output buffering component is universal in logographic and alphabetic languages, and that the structure within the buffer is shaped by language-specific parameters. The output buffer structure in Chinese represents the identity and visual/motoric properties of logographemes.

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