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Implicit reading in Chinese pure alexia

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ABSTRACT

A number of recent studies have shown that some patients with pure alexia display evidence of implicit access to lexical and semantic information about words that they cannot read explicitly. This phenomenon has not been investigated systematically in Chinese patients. We report here a case study of a Chinese patient who met the criteria for pure alexia and had lesions in the left occipitotemporal region and the splenium of the corpus callosum. His explicit and implicit reading was evaluated with various stimuli in a number of tasks. We found that despite his severe impairment in overt reading and the definition of any characters, his performance was well above chance in various implicit tasks. His accuracy with respect to lexical decisions was so high that his performance was almost normal. These findings provide unequivocal evidence for the existence of implicit reading in Chinese patients with pure alexia and further support the involvement of the right hemisphere.

1. Introduction

Pure alexia is an acquired reading disorder, characterized by selective reading impairment in premorbidly literate individuals, with few or no writing problems (Dejerine, 1892; Warrington & Shallice, 1980). The classical account of pure alexia attributes this syndrome to a disconnection of the visual input to the left angular gyrus by damage to the visual cortex of the left occipital lobe and the splenium of the corpus callosum (Dejerine, 1892; Geschwind, 1965). However, in recent years, it has been found that a lesion limited to the left ventral occipitotemporal cortex can also result in pure alexia, indicating a key role for this region in this reading disorder (Beversdorf, Ratcliffe, Rhodes, & Reeves, 1997; Binder & Mohr, 1992; Cohen et al., 2003; Damasio & Damasio, 1983; Gaillard et al., 2006; Ino et al., 2008; Leff, Spitsyna, Plant, & Wise, 2006). This finding parallels recent functional magnetic resonance imaging (fMRI) studies of healthy subjects (e.g., Binder, Medler, Westbury, Liebenthal, & Buchanan, 2006; Cohen et al., 2002, 2003; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002; Jobard, Crivello, & Tzourio-Mazoyer, 2003), in which the left ventral occipitotemporal cortex was consistently shown to be selectively responsive to visual word stimuli in a variety of tasks.

Another recent insight is the recognition that patients with pure alexia can retain some implicit reading abilities, despite profound impairment of explicit reading processes such as reading aloud and word identification (Behrmann, Plaut, & Nelson, 1998; Bub & Arguin, 1995; Coslett & Monsul, 1994; Coslett & Saffran, 1989a, 1989b; Coslett, Saffran, Greenbaum, & Schwartz, 1993; Feinberg, Dyckes-Berke, Miner, & Roane, 1995). Indeed, a number of studies have demonstrated that alexic patients often show above-chance performances on some implicit tasks, such as lexical decision and semantic categorization tasks (Behrmann et al., 1998; Saffran & Coslett, 1998). This finding is consistent with the observation of the word superiority effect (Bowers, Bub, & Arguin, 1996) and the Stroop effect of words (McKeeff & Behrmann, 2004) in alexic subjects.

Not surprisingly, some researchers suggest that implicit reading in pure alexia is mediated by the right hemisphere (RH) because the primary lesion in these patients is on the left hemisphere (LH) (Coslett & Saffran, 1989a, 1989b; Feinberg et al., 1995; Larsen, Baynes, & Swick, 2004; Mayda et al., 2004; Saffran & Coslett, 1998). Consistent with this hypothesis, patients with pure alexia often perform better on concrete or highly imaginable words than on abstract words and functors (function words) and better on nouns than on verbs, which are thought to be typical characteristics of the orthographic processing in the RH (Larsen et al., 2004; Mayda et al., 2004; Saffran & Coslett, 1998). Furthermore, several fMRI studies of pure alexics have shown a strong activation to words

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in the right occipitotemporal area early after the onset of alexia (Cohen et al., 2004; Henry et al., 2005; Ma et al., 2004), providing further support for this hypothesis.

However, not all agree with the RH account of implicit reading in pure alexia (e.g., Baynes, 1990; Rapp & Caramazza, 1997). In many reported cases of implicit reading, the left ventral occipitotemporal cortex is not completely destroyed and the splenium of the corpus callosum is often intact. Therefore, it seems reasonable to assume that implicit reading can be subserved by the residual function of the LH. We report here a case study of pure alexia in a native Chinese speaker with extensive lesions in the left occipitotemporal cortex together with damage to the splenium of the corpus callosum. This allowed us to test the RH hypothesis without confounding the analysis with any residual reading function of the LH.

Equally importantly, because written Chinese is markedly different from alphabetic writing systems in several respects, this case also allowed us to examine whether alexia in native Chinese speakers manifests in different reading patterns, in both explicit and implicit reading tasks, compared with the alexia of alphabetic readers. Written Chinese, often called a "logographic" writing system, uses characters as the basic units. Visually, each character is composed of different strokes, which may or may not cross each other. The number of strokes in a character can vary considerably, ranging from one to more than 20. The strokes are combined to form simple characters or radicals, which in turn are further combined to form compound characters. There are two types of radicals: semantic and phonetic. Within a compound character, the semantic radical often occupies the left or top position, whereas the phonetic radical is on the right or at the bottom. The position of the radical is an important part of the orthographic rules of Chinese characters. If the positions of the radicals in a "character" are in the "correct" positions (thus orthographically legal), this "character" is regarded as a pseudocharacter, although it has no meaning or phonology. If any of the radicals is placed in a wrong position (and is therefore orthographically illegal), the "character" becomes a noncharacter (Ho, Ng, & Ng, 2003; Yin & Butterworth, 1998). Many radicals are also themselves simple characters, with their own meanings and pronunciations, whereas others are bound forms, which always act as components and must be combined with other radicals to form characters. There are about 1000 radicals, which form about 4500 characters in the modern Chinese writing system (Yin & John, 1994). These features make Chinese characters visually much more complex than alphabetic script.

Linguistically, the orthography of Chinese characters is much more opaque than that of alphabetic words. The visual form of a character only provides very limited information about the sound form of this character. Simple characters with similar shapes have very different sounds. For instance, 田/tian 2/, 由/you 2/, 甲/jia 3/, and 申/shen 1/ have similar appearances but have completely different pronunciations. Although about 80% of modern Chinese characters are phonetic compound characters, only about one-third are "regular", in that the phonetic radical has the same pronunciation as that of the whole character, so exceptions are more frequent than regular forms. Furthermore, unlike alphabetic words, in which the letters or letter combinations systematically map to phonemes, thus displaying grapheme-to-phoneme conversion (GPC), Chinese characters map onto the syllable level. A phonetic radical may (for a regular character) or may not (for an irregular character) have the same pronunciation as the whole character that contains the radical, but the pronunciation of a radical can never be a segment of the whole character's sound. This means that the pronunciation of a character is never made up of the combination of its radicals. For example, 里/Li 3/ is pronounced the same as 理/Li 3/ but is completely different from 埋/mai 2/, and 里 does not map to any segment of the pronunciations of 理 or 埋. It should also be noted that the homophone density of Chinese characters is much higher than that of alphabetic scripts. There are about 400 syllables (regardless of their tones), whereas there are more than 4500 characters (Language and Teaching Institute of Beijing Linguistic College, 1986). This means that, on average, more than 10 characters share one sound (syllable).

As a result of these visual and linguistic features, reading and learning to read Chinese characters place very high demands on visuospatial processing and rely on memorizing the obligatory relationships between the lexical entries and their pronunciations/meanings (Frith, 1985; Lyman, Kwan, & Chao, 1938; Peng, Shu, & Chen, 1997; Tan, Spinks, Eden, Perfetti, & Siok, 2005; Tzeng, Hung, Cotton, & Wang, 1979; Zhou & Marslen-Wilson, 1999). These findings have led to the reasonable assumption that processing Chinese characters involves more of the RH than does the processing of alphabetic scripts, and this has been repeatedly demonstrated by psycholinguistic studies (April & Tse, 1977; Chen, Cheung, & Flores d'Arcais, 1995; van Orden, 1987). In addition to the behavioral data, fMRI studies of healthy Chinese subjects have shown the activation of the bilateral ventral occipitotemporal cortices during reading tasks (Liu et al., 2008; Peng et al., 2003), whereas only weak or no activation was observed in the right occipitotemporal cortices during alphabetic word-reading tasks (Binder et al., 2006; Cohen et al., 2000, 2002, 2003; Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002; Fiebach, Friederici, Muller, & von Cramon, 2002; Jobard et al., 2003).

The uniqueness of Chinese characters may also cause Chinese alexic patients to show different reading patterns. For example, a letter-by-letter strategy is commonly and effectively used by alphabetic alexic patients to assist them in the recognition of a single word. However, this strategy can have little benefit for Chinese patients, because the phonetic radical cannot provide reliable phonological information for reading characters. It is also possible that implicit reading is more easily manifested in Chinese alexia. First, as discussed above, Chinese reading places more reliance on the whole character, and Coslett et al. (1993) observed that their subject appeared to use a "whole-word" strategy when he was performing lexical decision and semantic judgment tasks. Second, the greater requirement to memorize the associations between lexical entries and their pronunciations/meanings may make it easier to access phonological and semantic information, although not necessarily at the explicit level.

There are relatively fewer cases of Chinese pure alexia reported in the literature compared with the large number of cases of alphabetic pure alexia (Gao, 2006). The first such case was reported by Lyman et al. (1938). This patient was a Chinese–English bilingual speaker. Of particular relevance is that he could postmorbidly read English much better than Chinese, at least partly because of his successful use of the letter-by-letter reading method. In contrast, although he repeatedly traced the strokes of the presented Chinese character with his finger, this seldom worked. This patient was not a typical case of pure alexia (Yin & Butterworth, 1998) because he showed profound impairment in writing. Wang and Tang (1959) subsequently reported a more typical Chinese alexic patient with no writing deficit. He had a lesion in the left occipitotemporal area and had right homonymous hemianopia and amnesia. Although his spoken language, auditory comprehension, and writing ability were well preserved, his reading ability was severely damaged. He could sometimes read out a few simple and high-frequency characters and some radicals, often by kinesthetic facilitation and context assistance. He also had greater difficulty in reading handwriting than the printed word. Ever since the 1990s, increasing numbers of cases of pure alexia have been reported among Chinese people (e.g., Gao, 2006; Wang, Wang, Feng, & Li, 1998; Yin & Butterworth, 1992, 1998; Zhao, Chen, & Gao, 1998). The association of pure alexia with a lesion in the left occipitotemporal area was common in these Chinese subjects, as among alphabetic patients. However, only a few reports have included a detailed analysis of reading behavior (e.g., Wang & Tang, 1959; Yin & Butterworth, 1998) and no study has reported implicit reading in Chinese pure alexia. Yin and Butterworth (1998) reported two patients with pure alexia and made a detailed assessment of their general language functions. Interestingly, both patients showed some evidence of radical-by-radical reading and the authors argued that this radical-by-radical reading strategy corresponded to the letter-by-letter (LBL) strategy used by alphabetic readers with pure alexia.

In this study, we administered a variety of cognitive and reading tests to a Chinese patient with extensive lesions in the territory of the left posterior cerebral artery, who had completely lost his ability to read Chinese characters aloud. We focused on the characterization of his explicit/implicit reading performance. More specifically, we asked whether this patient had reading patterns similar to both Chinese and alphabetic alexia, as described in the literature, whether implicit reading can be observed in Chinese pure alexia, and whether this phenomenon is more easily manifested in Chinese alexia than in alphabetic alexia.

2. Materials and methods

2.1. Case description

JXD, a right-handed 73-year-old man, was admitted to the First Affiliated Hospital, Zhejiang University School of Medicine in October 2007, complaining of dizziness for 2 days. He was a retired public official, had received 15 years of formal education, but had no knowledge of English. A clinical examination showed that he was suffering from right homonymous hemianopia with foveal sparing (about 1.5°) but with no other neurological symptoms. Computed tomography and MRI images showed a left posterior cerebral artery infarct, involving the left ventral occipitotemporal cortex, hippocampus, splenium of the corpus callosum, and the dorsal white matter (Fig. 1). The patient was suffering from pure alexia, a slight writing impediment, some visual picture/object-naming problems, and memory impairment. Although he had no difficulty in recognizing faces and no deficit in the production or comprehension of words during conversation, his reading ability was severely damaged. He could not even read aloud or define the Chinese characters that he had just written himself. Although he often traced the characters presented to him with his finger, he could read only a few characters aloud on rare occasions. Occasionally, context assistance was slightly effective. For example, when seeing the character "龙" (/long 2/, dragon), which he did not recognize, he knew it was one of the characters forming the name of a province. Then, thinking hard, he murmured the name /Hei-long-jiang/ (黑龙江), and finally succeeded in reading "龙"/long 2/ aloud correctly.

The neuropsychological tests reported in this paper (except lexical decision 2) were performed in October 2007, 2 weeks after the onset of the patient's alexia. He scored 115 for verbal IQ, 90 for performance IQ, and 106 for total IQ on the Chinese version of the Wechsler Adult Intelligence Scale (WAIS-RC) (Gong, 1992). However, he only achieved a memory quotient of 80 on the Chinese version of the Wechsler Memory Scale (WMS-RC) (Gong, 1999).

2.2. Language and reading tests

2.2.1. General language functions

The Aphasia Battery of Chinese (ABC) (Gao et al., 1992), developed at Peking University First Hospital, was used to evaluate JXD's general language functions. ABC was especially designed to assess the language functions of Chinese patients, and is the most commonly used battery of tests used in clinical linguistics in mainland China. The battery evaluates four aspects of language function, i.e., speech, oral comprehension, reading, and writing.

We then administered a series of assessments to JXD that quantitatively evaluated his explicit and implicit reading abilities. All the real Chinese characters were chosen from the Basic Vocabulary Table of Modern Chinese Characters (Chinese State Language Work Committee, 1988), except lexical decision 2.

2.2.2. Oral reading and comprehension

One hundred fifty monosyllabic (single character) words were taken from the Chinese dyslexia battery of Beijing Normal University (Bi, Han, Weekes, & Shu, 2007). The stimuli were presented individually in the center of a piece of A4 paper. The patient was

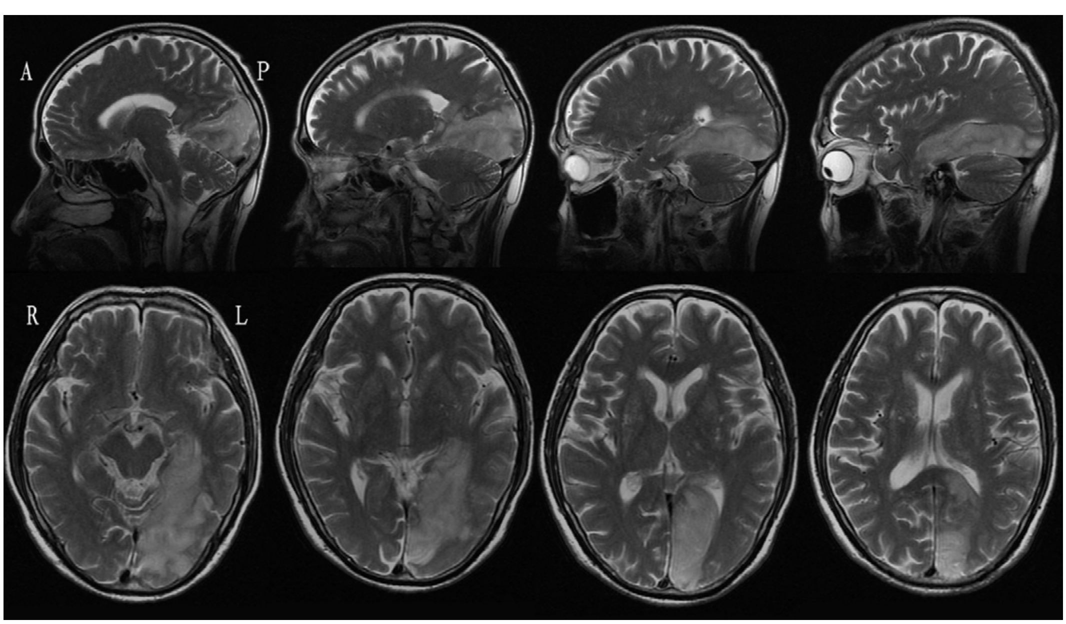

Fig. 1. T2 MRIs taken 4 days after the onset of stroke.

first asked to read each character aloud and then to explain and define it.

In the next five tasks, we determined whether JXD had implicit access to lexical (phonological or semantic) representations of the characters, in case he could not finish the explicit reading tasks.

2.2.3. Homophone matching

The patient was asked to decide whether the two characters presented, ordered from top to bottom in the center of a computer screen, had the same pronunciation. There were 40 pairs of characters in total: 20 homophones and 20 nonhomophones. We selected characters with different phonetic radicals to avoid phonological interference between the stimuli. For instance, "情" (/qing 2/, affection) and "晴" (/qing 2/, sunny), which have the same phonetic radical (青, /qing 1/, green), were not selected.

2.2.4. Word–picture matching

This task consisted of 50 trials (Han, Shu, Zhang, & Zhou, 2005). At the start of each trial, a character printed in the center of a piece of A4 paper was presented to JXD (e.g., 书, /shu 1/, book) for about 2 s. Then two pictures, from top to bottom, were presented in the center of another piece of paper. The two pictures either had a similar shape (e.g., light bulb and pear), were in the same category (e.g., fox and rabbit), or had similar pronunciations of their names (e.g., pictures of a mouse and a book, both read /shu/ but with different tones: mouse /shu 3/ and book /shu 1/). One picture matched the word completely, and the other served as the distractor in shape, semantics, or phonology. The patient was asked to choose one of the pictures to match the word presented to him. Twenty-five nouns and 25 verbs were tested.

2.2.5. Semantic categorization

This test consisted of 60 single–character words: 30 living (15 animals and 15 plants) and 30 nonliving entities (man-made objects), which were individually presented in the center of a computer screen. JXD was instructed to decide whether the presented character referred to a living thing or not.

2.2.6. Word–word matching

This set of stimuli consisted of 80 items (nouns, adjectives, verbs, and functors – 20 of each type) randomly presented in the center of a computer screen. Each item consisted of one character on the left and two characters on the right (upper and lower). JXD was instructed to indicate which of the two characters on the right was more semantically related to the character on the left.

2.2.7. Lexical decision

Test 1: Three kinds of stimuli were used in this task: 60 real characters (e.g., 炉), 30 legal pseudo-characters (e.g., 忚, both radicals at legal positions), and 60 false characters (e.g., 层 and 知, formed by adding or omitting one stroke within each real character). JXD was randomly presented with the set of 150 stimuli in the center of a sheet of paper, and asked to decide one by one whether the characters were real Chinese characters or not.

Test 2: Five kinds of characters (420 in total) were used in the test, including 90 high-frequency characters, 90 low-frequency characters, 60 false characters, 90 pseudo-characters, and 90 non-characters (one or two radicals at illegal positions). All the characters had a left–right construction and were matched for strokes. The characters were selected from the Modern Chinese Frequency Dictionary (Language and Teaching Institute of Beijing Linguistic College, 1986). JXD was asked to decide the validity of the characters. This test was conducted twice, being repeated about 10 months after the onset of his stroke (the patient had by then completely recovered from his transient writing impairment, but remained alexic). The stimuli and task were the same in both tests, but the duration of presentation differed. The stimulus was presented for 250 ms in the first test but for an unlimited period in the second test. In the second test, the patient was asked to write down the correct character if he could correctly reject a false character formed by adding or omitting one stroke within each real character.

3. Results

3.1. General language functions

The ABC assessments showed that JXD had severe reading impairment and a slight writing deficit, but his oral speech and comprehension were relatively well preserved (Table 1). JXD's speech was fluent and did not include empty speech, circumlocution, or paraphasia. His performance in the responsive naming task was also normal (12/12; Table 1). For example, when asked "What can be used to cut vegetables?", his response was "A knife". He could also correctly name and identify colors (oral color naming, 12/12; color recognition, 12/12; writing color names, 4/4). However, he failed to name about 60% of objects or pictures familiar to him, although he was able to describe their features and uses (e.g., comb, "a device used in hair care").

His spoken language comprehension score was slightly influenced by his low score for auditory word/picture matching (52/90, listening to the names of pictures and then picking up the corresponding one from five visually presented pictures). His principal impairment was in his inability to read Chinese characters aloud, although he could correctly point to all the characters that he heard (10/10, auditory character/print matching: listening to names of characters and then picking a corresponding one from five visually presented characters), and could occasionally name one or two radicals in the presented characters. In the oral reading and word–picture matching test, he could read none of the words

Table 1
Assessment of the patient's general language abilities (ABC).

Items	Scores
Spoken speech	
Spontaneous speech	
Information content	5/5
Fluency	30/30
Repetition	97/100
Naming total	44.5/82
Objects/pictures naming	12.5/40
Serial naming[a]	10/20
Color naming	12/12
Responsive naming	10/10
Comprehension total	192/230
Yes/No	60/60
Auditory word/picture matching	52/90
Following directions	80/80
Reading total	15/120
Oral reading	0/10
Auditory word/print matching	10/10
Oral reading and word–picture matching	5/40
Reading and following written directions	0/30
Reading and filling in the blanks	0/30
Writing total	66/104
Spontaneously writing	21/40
Writing name and address	10/10
Written naming of pictures	9/20
Writing state of illness	2/10
Writing to dictation	24/34
Copying	1/10

[a] In this test, the patient was asked to say as many vegetable names and multisyllabic words that begin with the first character (syllable) "大" (/da 4/, means 'big') as possible within a minute.

or characters (0/20), but correctly matched five pairs of 20 words and pictures (all these five pairs were colors and their corresponding names; Table 1).

His writing ability was relatively well preserved. Although he showed severe impairment in copying from print, his spontaneous writing and writing to dictation were well preserved (copying vs spontaneous writing, $\chi^2_{(\alpha=0.05)} = 4.266$, $p = 0.039$; copying vs writing from dictation $\chi^2_{(\alpha=0.05)} = 9.224$, $p = 0.002$). Moreover, he correctly wrote the names of nine of the 20 pictures tested, similar to his performance in oral picture naming. JXD displayed no visuospatial functional impairment and no apraxia, neither did he have difficulty in recognizing numerals or any defect in calculation. Therefore, according to the ABC assessment, his language deficit was rated as pure alexia, with minimal agraphia and anomia.

3.2. Oral reading and comprehension

In the oral reading test, JXD could not read aloud any of the 150 characters presented to him; nor could he explain any character, although he often claimed that he was familiar with these characters.

3.3. Homophone matching

In the homophone-matching task, JXD correctly matched 26 of 40 pairs, statistically greater than chance (one-tailed binomial test, $Z = 1.739$, $p < 0.05$; Table 2).

3.4. Word–picture matching, semantic categorization, and word–word matching

We used word–picture matching, semantic categorization, and word–word matching to characterize the implicit semantic access of JXD. He also achieved an above-chance result (one-tailed binomial test, $Z = 4.24$, $p < 0.001$) on the word–picture matching test, although he could not name any words and recognized only about half the pictures. He performed better for nouns (23/25) than for verbs (17/25) ($\chi^2_{(\alpha=0.05)} = 4.50$, $p < 0.05$) in this task. In semantic categorization, he correctly classified 47 of 60 (78%) single-character words, significantly above chance (one-tailed binomial test, $Z = 4.389$, $p < 0.001$). However, his performance in classifying words denoting plants was poorer than that for words denoting animals or nonliving things (6/15, 13/15, and 28/30 correct, respectively). In the word–word matching task, he had a correct answer rate of 68% (54/80), which was higher than chance (one-tailed binomial test, $Z = 3.13$, $p = 0.001$). In this task, he answered correctly for 16/20 nouns, 14/20 adjectives, 13/20 verbs, and 11/20 functors. He seemed to perform better on nouns than on functors, perhaps because the number of stimuli was smaller. However, the difference was not significant ($\chi^2_{(\alpha=0.05)} = 2.849$, $p = 0.091$).

Table 2
Summary of explicit and implicit reading abilities.

Tests	*N*	Accuracy (%)	Binomial, *p*
Oral reading and comprehension			
Oral reading	150	0	–
Oral defining	150	0	–
Homophone matching	40	65	0.041
Word–picture matching	50	80	<0.001
Nouns	25	92	<0.001
Verbs	25	68	0.023
Semantic categorization	60	78	<0.001
Living	30	63	0.100
Animal	15	87	0.005
Plant	15	40	0.302
Non-living	30	93	<0.001
Word–word matching	80	68	0.001
Nouns	20	80	0.007
Adjectives	20	70	0.058
Verbs	20	65	0.131
Functors	20	55	0.413
Lexical decision 1	150	97	<0.001

Note: compared to chance level, *one-tailed binomial test*.

3.5. Lexical decision

Test 1: Our results show that JXD made 145/150 correct decisions: 57/60 on real characters, 29/30 on legal pseudo-characters, and 59/60 on false characters. Overall, his accuracy was so high that his performance was almost normal (145/150 in contrast to the full score, $\chi^2_{(\alpha=0.05)} = 3.25$, $p > 0.05$).

Test 2: The trials in which his reaction time was more than three standard deviations from the mean were excluded from further analyses (Table 3). Consequently, 20 of 420 (0.048%) trials under tachistoscopic conditions and 10 (0.024%) under unlimited conditions were not included in the statistical analysis. The results and differences for each type are shown in Table 3. JXD performed worst in the identification of low-frequency characters under both tachistoscopic and unlimited presentation conditions. There was no difference in his result rate between the high-frequency characters and false characters, and the patient corrected all the false characters that he had identified (e.g., 论 制→论 制), indicating that he was aware of subtle orthographic changes. He not only made more errors in recognizing low-frequency characters than in pseudo-characters under both conditions, but also took more time to recognize low-frequency characters under tachistoscopic conditions. Similarly, the identification of pseudo-characters took him longer than the identification of non-characters.

4. Discussion

In this study, we characterized the reading performance of a Chinese patient, JXD, who suffered combined lesions in the left occipitotemporal region and the splenium of the corpus callosum. Because he exhibited a profound reading disability in all explicit reading tasks tested, with no significant deficits in oral production or auditory comprehension, and with relatively few in writing (except copying), his behavioral performance fitted the criteria for pure alexia well. This reading pattern is similar to that of previously reported cases involving Chinese speakers (e.g., Gao, 2006; Wang & Tang, 1959; Wang et al., 1998; Yin & Butterworth, 1998; Zhao et al., 1998). Interestingly, most of those patients were also assessed with the ABC (Gao, 2006; Wang et al., 1998; Zhao et al., 1998).

The hallmark of alphabetic patients with pure alexia is that most can identify, albeit slowly and with effort, some visual words using an LBL reading strategy (Kinsbourne & Warrington, 1962). We found no evidence that JXD used a comparable strategy. Interestingly, Yin and Butterworth (1998) described a radical-by-radical reading strategy in two Chinese patients with pure alexia. However, this strategy did not appear to be very helpful to the patients in reading aloud whole characters that contained the radicals they could recognize. As mentioned in the Introduction, radicals map to the syllable level but not to any parts of the speech sound of a whole character. It is therefore unlikely that the correct pronunciation of a Chinese character can be assembled by sequentially reading the radicals that are contained within the character. In contrast, in alphabetic scripts, the phoneme to which a grapheme (a letter or a letter combination) maps is part of the speech sound of the word. However, it must be noted that the LBL strategy is also applied to irregular words by most patients with pure alexia. In rare cases, patients cannot read irregular words, possibly because

Table 3
Lexicon decision 2 performance of JXD.

Type	Example	250 ms presentation		Unlimited presentation	
		ER (% error)	RT mean (SD)	ER (% error)	RT mean (SD)
High frequency	体 把	4/83(5%)[a]	944(422)[a]	0/87(0)[a]	1339(358)[a]
Low frequency	圾 阱	33/78(42%)[b]	1357(541)[b]	17/88(19%)[b]	2075(1005)
False characters	论 制	7/57(12%)	1106(457)	0/58(0)	1295(356)
Pseudo-characters	斫 扌彡	2/84(2%)	973(373)[c]	4/89(4%)	1913(1169)[c]
Non-characters	禾乚 忄衤	1/88(1%)	786(318)	0/88(0)	1052(218)

Note: ER = error rate, RT = reaction time (milliseconds, ms), SD = standard deviation.
[a] High frequency vs. low frequency, $p < 0.01$.
[b] Low frequency vs. pseudo-characters, $p < 0.01$.
[c] Pseudo-characters vs. non-characters, $p < 0.01$.

they have an additional deficit in lexical spelling or in the recognition system corresponding to whole-word or whole-morpheme specifications in the visual word-form system, even when they can identify the component letters (Patterson & Kay, 1982). This lexical spelling knowledge about word specifications may be acquired during the development of literacy. In learning to read, a word (regular or irregular) is naturally spelled out with the letters in the sequence in which they appear in the word. In contrast, learning to read Chinese characters relies predominantly on a whole-character strategy, because there are hundreds of radicals and numerous patterns in which a character is formed, and because the names of radicals, if they have them, cannot provide consistent clues to the pronunciation of the character they form, not to mention the fact that a large proportion of radicals do not have their own names. Therefore, we believe that radical-by-radical reading might be fundamentally different from the LBL strategy, although reading radicals is sometimes observed in pure alexic Chinese patients, including JXD, the patients of Yin and Butterworth (1998), and others (Gao, 2006; Wang & Tang, 1959). This postulate is further supported by Lyman et al. (1938), who reported a pure alexic patient who was bilingual in Chinese and English premorbidly. He could successfully read some English words with the LBL strategy, whereas there was no improvement in his reading of Chinese characters. Therefore, we have no evidence for the existence of a reading strategy in Chinese alexia comparable to LBL.

In a related observation, tracing the character did not improve JXD's oral reading performance, which is very different from similar observations in alphabetic alexic patients (Charcot, 1877; Ffytche, Lappin, & Philpot, 2004; Lambon Ralph, Hesketh, & Sage, 2004; Zenner, 1904). Quite a few Chinese alexic patients have also failed to read by tracing the characters (Chang, Zhou, & Shi, 1999; Lyman et al., 1938; Yin & Butterworth, 1998), although the tracing strategy was helpful in improving the reading of some patients (Gao, 2006; Wang & Tang, 1959; Yin & Butterworth, 1998). The higher visual complexity and larger number of visual units in Chinese characters may account for the lower efficacy of the tracing strategy. It is interesting that the effectiveness of this strategy appears to be associated with the patients' writing ability, particularly their copying ability. Thus, in the patients reported by Gao (2006) and Wang and Tang (1959), the tracing strategy was sometimes helpful in reading single characters and the patients' writing/copying ability was well preserved, whereas JXD and the patients reported by Chang et al. (1999) and Lyman et al. (1938) showed impaired writing and copying, and a failure to improve their reading with the tracing strategy. The relationship between tracing-aided reading and the patient's writing/copying ability clearly warrants further investigation.

JXD's reading deficit was more severe than those of most Chinese patients with pure alexia reported previously (Gao, 2006; Wang et al., 1998; Yin & Butterworth, 1992, 1998; Zhao et al., 1998), probably because his lesion in the occipitotemporal region was more extensive. The association between a lesion in the occipitotemporal region and a reading disorder is well established in alphabetic readers (Beversdorf et al., 1997; Binder & Mohr, 1992; Cohen et al., 2003; Damasio & Damasio, 1983; Gaillard et al., 2006; Ino et al., 2008; Leff et al., 2006). The case of Chinese alexia reported here and those reported by others (Gao, 2006; Wang & Tang, 1959; Wang et al., 1998; Yin & Butterworth, 1992, 1998; Zhao et al., 1998) suggest that the left occipitotemporal region is also the critical locus in Chinese pure alexia.

It should be noted that JXD also had a lesion in the left splenium of the corpus callosum. Coltheart (1983) speculated that the function of the splenium is to transfer letter representations from the RH to the LH, and Suzuki et al. (1998) have a similar view. Although the nature of the information transferred by this white matter in reading Chinese characters may not be identical to that transferred in reading alphabetic words, the splenium has at least equal importance in reading Chinese characters, as suggested by the study of a patient who had a staged callosal section (Zhang et al., 1991). It has often been suggested that the identification of Chinese characters involves more intensive visuospatial processing, and may therefore demand more frequent communication between the hemispheres. Similarly, although we do not have sufficient data to make conclusive suggestions, we believe that this lesion did contribute to the observed reading pattern of JXD. Conversely, because the splenium of the corpus callosum is not always involved in pure alexics (Yin & Butterworth, 1992, 1998; Zhou, Cao, Meng, & Zhou, 2002), it seems unlikely that a lesion in the splenium is necessary for the onset of pure alexia in Chinese patients.

JXD showed impairment in the oral naming of objects/pictures. He failed to pick the right names corresponding to 70% of the objects/pictures, but could recognize all of them. However, he could provide proper descriptions for the stimuli that he failed to name, such as their uses, features, and colors. JXD's written naming of pictures was also impaired, but similarly, he could correctly describe the pictures that he failed to name in writing. These results suggest that the observed naming impairment was not attributable to visual agnosia, but instead possibly resulted from the disconnection of his visual recognition and the output of object names.

JXD's naming problem was also restricted to the visual modality. In contrast to his visual confrontation naming, his auditory responsive naming was normal. This dissociation between confrontation naming and responsive naming probably arose because his lesion did not involve the anterior temporal lobe, which is thought to be critical for auditory naming rather than for visual naming (Hamberger, Goodman, Perrine, & Tamny, 2001).

In contrast to his recognition of common objects, he had virtually lost his ability to read any Chinese characters, nor could he relate any information about them. Therefore, his reading problem was primarily visual agnosia regarding Chinese characters, possibly combined with naming impairment, although previous studies have suggested that pure alexia does not necessarily coexist with anomia (Wang & Tang, 1959; Wang et al., 1998; Yin & Butterworth, 1992, 1998; Zhao et al., 1998; Zhou et al., 2002). Thus far, we have shown that JXD had differential impairment for recognition of common objects and Chinese characters, with the latter being more severe. Although our results are consistent with a large number of previous studies suggesting that the recognition of visual objects and words involves different neural substrates (e.g., Gaillard et al., 2006; Patterson & Kay, 1982; Salvan et al., 2004; Warrington & Shallice, 1980), other interpretations cannot be excluded. For example, Friedman and Alexander (1984) noted that even for a pure alexic patient without picture-naming impairment, the time required to identify the pictures was prolonged. They suggested that a deficit in the speed of visual identification is not specific to orthographic material. Similarly, Behrmann et al. (1998) suggested that the deficit in pure alexia is not restricted to the orthographic system, but involves a general-purpose visual processing mechanism. Further studies are required to address this fundamental issue regarding the neural underpinning of the repeatedly observed dissociation in the visual processing of words and objects.

Color anomia is frequently reported in pure alexics (Damasio & Damasio, 1983), although JXD had intact color-naming ability. Color anomia correlates robustly with damage to the middle occipitotemporal cortex, in addition to the paraventricular region, occasionally accompanied by damage to the splenium of the corpus callosum (Damasio & Damasio, 1983). There have also been many reports of pure alexia without color anomia in both Chinese and alphabetic patients (e.g., Ajax, Schenkenberg, & Kosteljanetz, 1977; Damasio & Damasio, 1983; Vincent, Sadowsky, Saunders, & Reeves, 1977; Wang & Tang, 1959; Yin & Butterworth, 1998). In contrast to pure alexics with color anomia, the pure alexic patients with intact color naming often spare the dorsal outflow from the left calcarine cortex, suggesting that color naming is dependent on the integrity of occipital association systems that are more dorsal (Ajax et al., 1977; Vincent et al., 1977). JXD's normal color naming may be attributable to his partially preserved dorsal calcarine cortex in the LH.

The main finding of this study is the manifestation of implicit reading in a patient with pure alexia, which has not previously been systematically investigated in Chinese patients with pure alexia. JXD was able to perform fairly well in several implicit reading tasks. He could correctly point to the right pictures corresponding to characters, identify whether a character referred to a living thing or not, and match synonyms to a level well above chance. He even seemed to have some ability to access phonological information implicitly. These results clearly show that JXD retained the implicit processing of visual words although his explicit processing was severely impaired, bearing a striking resemblance to the processing of pure alexics in alphabetic languages (Albert, Yamadori, Gardner, & Howes, 1973; Behrmann et al., 1998; Binder & Mohr, 1992; Bub & Arguin, 1995; Caplan & Hedley-Whyte, 1974; Coslett & Monsul, 1994; Coslett & Saffran, 1989a; Coslett et al., 1993; Feinberg et al., 1995; Landis, Regard, & Serrat, 1980; Larsen et al., 2004; Shallice & Saffran, 1986). Even more remarkably, JXD's lexical decision accuracy was almost normal, much better than that reported previously in patients with alphabetic pure alexia. In those alphabetic patients with pure alexia, the performance of similar tasks was just above the chance level (e.g., Coslett & Saffran, 1989a; Larsen et al., 2004).

A lexical decision can be made in different ways, depending on the stimulus type (Forster & Bednall, 1976; Ratcliff, Gomez, & McKoon, 2004). When asked to judge between real characters and non-characters, one can use orthographic rules (e.g., whether the radicals are in legal positions). JXD had no problem with this task. He correctly rejected all the false and non-characters tested, and the reaction time for the rejection of non-characters was even shorter than that for the acceptance of real characters. However, if asked to make a judgment between pseudo-characters and real characters, one needs to resort to extra information about phonology and semantics, other than simple orthographic rules. In regular scripts like Finnish and semiregular scripts like English, lexical access can be obtained through a phonologically mediated route based on the GPC rule (for a comprehensive account of the dual routes used in reading, see Coltheart, Rastle, Perry, & Ziegler, 2001). In contrast, such a mediated route will not be efficient and reliable in Chinese because Chinese lacks systematic print-to-sound mapping and the pervasiveness of homophones in this writing system is extremely high. Therefore, JXD took longer to reject pseudo-characters than to accept high-frequency real characters or to reject non-characters, a similar reading pattern to that observed in normal Chinese readers (Peng et al., 1997). One can also make judgments between pseudo-characters and real characters by directly addressing their meanings. Because of the reduced efficacy of the mediated route, the direct route is known to play a dominant role in normal readers of Chinese (Zhou & Marslen-Wilson, 1996). The direct connection between orthography and semantics might be established gradually as reading develops. A developmental study of Chinese participants found that elementary school students rely more on phonology in reading, whereas college students rely more on orthography (Song, Zhang, & Shu, 1995). The connection between orthography and semantics, together with the fact that some semantic radicals suggest the meaning of the characters, may explain why JXD's performance in lexical decision tasks was better than that of alphabetic alexics. Finally, it is also possible to make lexical decisions based merely on familiarity with the characters (without the activation of phonological or semantic systems), through a mechanism similar to the perceptual representation system assumed by Schacter (1990). This effect is apparent in the contrast between the accuracy of JXD's responses to pseudo-characters and low-frequency characters, although he took about the same time for both tasks. Similar accounts may also apply to his perfect performance in the rejection of the false characters formed by the addition or omission of one stroke in the real characters.

Different behavioral patterns in Chinese and English speakers are also reported in normal readers. Whereas the reaction time to target stimuli in lexical decisions was longer in English readers than the reaction time in naming tasks using the same words (Forster & Chambers, 1973; Katz & Feldman, 1983), the opposite pattern was true for Chinese readers (Peng et al., 1997; Wu, Chou, & Liu, 1994). These observations are explained by the different roles of direct and phonologically mediated routes in the different writing systems (e.g., Peng et al., 1997). Therefore, in English readers, naming is faster because the mediated route plays a dominant role, whereas in Chinese readers, lexical decisions are faster because the direct route plays a dominant role.

Interestingly, JXD's performance in the homophone-matching task was also above the chance level, suggesting access to phonology. This is not commonly reported in pure alexia, although Montant and Behrmann (2001) and Larsen et al. (2004) also used homophones to demonstrate access to phonology in their patients. However, we believe that phonology may be more easily accessed when reading Chinese characters, particularly in implicit tasks that mainly depend on whole-word reading. Patients with pure alexia were premorbidly skilled readers. These skilled Chinese readers have established very firm connections between visual forms and sound forms during literacy acquisition and daily reading, and the sight–sound connection is almost exclusively at the whole-character level because the GPC rule does not apply in this writing system. Consequently, phonological representation is automatically and obligatorily activated (Zhou & Marslen-Wilson, 1996, 1999). Furthermore, because homophones are much more prevalent in Chinese than in alphabetic languages, visual forms play a critical role in distinguishing semantics between homophones. In this sense, Chinese characters provide a unique tool with which to investigate how phonology is accessed from visual words.

With regard to the neural substrates of implicit reading, Coslet, Saffran, and colleagues (Coslett & Saffran, 1989a; Coslett et al., 1993; Saffran & Coslett, 1998) suggest that LBL reading and the word length effect are consequences of processing in the impaired LH, whereas covert reading and lexical/semantic effects are mediated by the RH. Therefore, high-imagery words tend to be read better than low-imagery words, and concrete nouns tend to be read better than function words (Coslett & Saffran, 1989a; Coslett et al., 1993). Alternatively, Behrmann and colleagues (Behrmann et al., 1998) argue that the sequential reading pattern and the higher level lexical/semantic effects can be explained in terms of the properties of the normal interactive lexical processing system located in both hemispheres. After damage to the left hemisphere, covert lexical activation is assumed to reflect the residual operation of this interactive lexical processing system (Behrmann et al., 1998; Bub & Arguin, 1995; Montant, Nazir, & Poncet, 1998). Although our data are insufficient to allow us to choose between these models, they do provide strong evidence of the involvement of the right hemisphere in implicit reading.

First, JXD had extensive lesions affecting the left inferior occipitotemporal lobe and the splenium of the corpus callosum, so both the LH reading areas and the input pathways of orthographic representation could have been involved. As a result, the rapid and parallel processing of Chinese characters by the left inferior occipitotemporal reading areas would have been difficult to complete.

Second, the neuropsychological tests used in our study were performed during the early stage of the disease, which allowed no or little reorganization around the left ventral occipitotemporal cortex. Ma et al. (2004) reported no activation in or around the left ventral occipitotemporal cortex of a pure alexic patient, even 45 days after onset, whereas the right ventral occipitotemporal cortex was activated by Chinese characters. Therefore, JXD must resort to the RH, especially the right occipitotemporal cortex, to access lexical information. Consistent with other research (e.g., Landis et al., 1980), our study offers more convincing evidence regarding this issue than have most previous reports, in which implicit reading was often conducted late after the onset of alexia (Behrmann et al., 1998; Bub & Arguin, 1995; Coslett & Monsul, 1994; Coslett & Saffran, 1989a, 1989b; Coslett et al., 1993; Feinberg et al., 1995), when functional and structural reorganization could have compromised the claim of the preexistence of an implicit system in the RH.

Third, unlike alphabetic words, which can be read letter-by-letter, Chinese characters cannot be read from their components (radicals or strokes). JXD could not access the whole character representation by combining these components in a way comparable to LBL reading of alphabetic writing, which is thought to be performed in the residual left occipitotemporal cortex (Coslett & Monsul, 1994; Coslett et al., 1993; Montant & Behrmann, 2001). Accordingly, the hypothesis that implicit reading in pure alexia could benefit from letter recognition (Behrmann et al., 1998) cannot apply to our patient and the other Chinese patients of previous studies. In contrast, as discussed earlier, Chinese readers almost exclusively rely on holistic reading. It is well established that the LH is better at sequential processing and analysis, whereas the RH is better at holistic processing (Patterson & Bradshaw, 1975; Tzeng et al., 1979). Therefore, processing Chinese characters relies more heavily on the RH, particularly the visuospatial system, than does the processing of alphabetic words (April & Tse, 1977; Chen, Cheung, & Flores d'Arcais, 1995; Frith, 1985; van Orden, 1987; Zhou & Marslen-Wilson, 1999). Consistent with this, fMRI studies have shown that, unlike reading alphabetic words, which often only activates the left ventral occipitotemporal cortex, reading Chinese characters also activates the right ventral occipitotemporal cortex (see review by Bolger, Perfetti, & Schneider (2005)). The hypothesis that the RH plays a more important role in reading Chinese characters is also consistent with the observation that JXD's performance in implicit reading was better than that reported in most previous studies of alphabetic pure alexics.

Finally, the presence of phonology access in our patient is an additional piece of evidence for the role of the RH in implicit Chinese reading. Zhang et al. (1991) reported a patient in whom both the anterior and posterior corpus callosa were resected (including the splenium). Remarkably, this patient could read aloud 40% of the Chinese characters presented to his left visual field, which is consistent with our current finding insofar as access to phonology through RH characters is plausible in "reading" Chinese.

It must be noted that implicit effects are typically observed when words are presented tachistoscopically, although there have been some exceptions, e.g., Coslett and Saffran (1989b) and Feinberg et al. (1995). Brief presentation is used to prevent letter-by-letter reading and to highlight the manifestation of implicit whole-word reading, usually with forced-choice tasks of lexical decision and classification (Lambon Ralph et al., 2004; Landis et al., 1980). However, as discussed above, Chinese pure alexics cannot use the radical-by-radical spelling strategy, which is presumably comparable to LBL reading, to help them read. Consistent with this explanation, in the second lexical decision test, we observed significant implicit lexical effects with both brief exposure and unlimited presentation, and the effect sizes were similar (Table 3).

This study had several limitations, which should be considered in interpreting our results. First, JXD had anomia for visual pictures/objects. This may have had some effect on the tests of his language function, such as the score for the oral comprehension test in the ABC. However, he had no color anomia, so he did not have a general naming problem. Second, his lesion extended to the left hippocampus, which may have been partly responsible for his verbal memory impairment. Nevertheless, our main focus was implicit processing, which seems to be independent of this kind of memory. Third, we did not test the effect of character complexity (stroke number) on the lexical decision tasks. Even with these limitations, this study provides clear evidence for the existence of a strong implicit reading process in Chinese pure alexia and adds support to the RH reading hypothesis. Further studies using functional imaging in the patient to measure the brain activation in each hemisphere during implicit reading tasks should allow more direct testing of the RH hypothesis.

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