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The interaction between semantic and the nonsemantic systems in reading: Evidence from Chinese

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Abstract

We report a Chinese-speaking patient WJX with left temporal lobe ischemic damage resulting in dementia. Similar to English speaking patients with this pathology, WJX showed impaired semantic system functioning together with a well preserved ability to read aloud Chinese characters including characters with unpredictable mappings between orthography and phonology—so called irregular characters. The summation hypothesis [Hillis, A. E., & Caramazza, A. (1991). Mechanisms for accessing lexical representations for output—evidence from a category-specific semantic deficit. *Brain and Language*, *40*, 106–144; Hillis, A. E., & Caramazza, A. (1995). Converging evidence for the interaction of semantic and sublexical phonological information in accessing lexical representations for spoken output. *Cognitive Neuropsychology*, *12*, 187–227] proposes that the good reading performance can be explained by the integration of a semantic route of reading and a nonsemantic route. Most Chinese characters contain components that can give a clue to the pronunciation (phonetic radical) and the meaning (semantic radical) of the character. We compared his comprehension and oral reading performance by varying the consistency of phonetic radicals and the transparency of semantic radicals. We observed an interaction between WJX's character comprehension and the consistency of the phonetic radical on reading performance; however, the transparency of semantic radicals had no effect on performance. We argue that this case report provides converging evidence for the principles of the summation hypothesis for reading.

Keywords: Chinese dyslexia; Nonlexical processing; Summation hypothesis

1. Introduction

Reading aloud, the process of generating sounds upon seeing a visual word, has been studied intensively by cognitive psychologists and neuropsychologists over the past 30 years. It is generally agreed that at least two cognitive processes are involved (Coltheart, 1978; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; see Fig. 1). One cognitive process involves reading via the semantic representation of the word, and is called the "semantic route". The other process uses a nonlexical (sublexical) route that operates according to grapheme-phoneme-conversion (GPC) procedures. In the semantic route, following analysis by the visual system, a letter string activates its corresponding representation in the orthographic lexicon, and then its semantic representation, followed by retrieval of a phonological lexical representation and the production of the corresponding phonemes. In the nonlexical route, the letter string activates its corresponding phonemes through GPC procedures without contact to lexical representations.

There is a variety of empirical support for these two routes for reading. The fact that normal readers can read pronounceable nonwords that have no meaning, e.g., "wug", suggests the existence of a nonlexical route. This is buoyed by findings in the neuropsychological literature of a double dissociation between surface and deep dyslexic readers. Surface dyslexic patients can read regular words and nonwords far better than irregular words, and they produce regularization errors with irregular words (e.g., reading "pint" as /pint/), suggesting reliance on the nonlexical reading route. By contrast, deep dyslexic patients produce semantic substitutions and their reading performance is influenced by semantic factors such as word concreteness.

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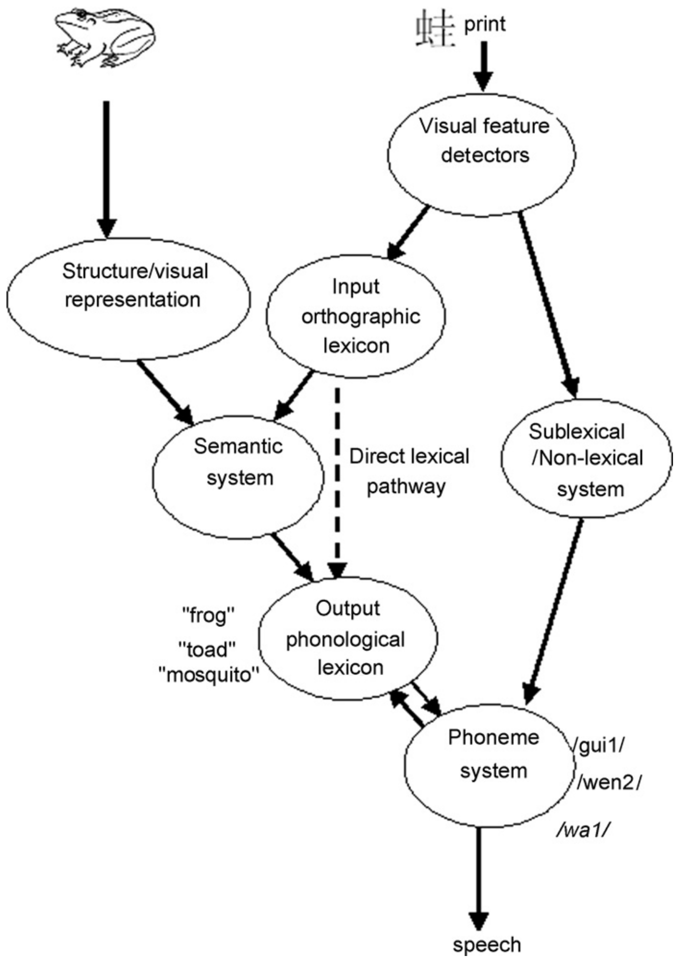

Fig. 1. A schematic model of reading. The dashed line indicates a possible but not necessary direct route proposed by some researchers.

This suggests the involvement of a semantic route for reading (Coltheart, 1980; Kremin, 1982).

A third reading route has also been proposed which involves direct mapping from an orthographic lexical representation onto a phonological lexical representation without going through the semantic system (Bub, Cancelliere, & Kertesz, 1985; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart et al., 2001; Funnell, 1983; McCarthy & Warrington, 1986; Shallice, 1988; see the dashed line in Fig. 1). This third route is often referred to as a direct lexical route. Note that this should not be confused with the use of the term "direct" referring to the direct activation of semantic properties by orthographic input (as opposed to via phonology). The proposal of this third route of reading was motivated by reports of oral reading in patients with dementia (Schwartz, Marin, & Saffran, 1979; see also Blazely, Coltheart, & Casey, 2005; Cipolotti & Warrington, 1995; Lambon-Ralph, Ellis, & Franklin, 1995; Noble, Glosser, & Grossman, 2000; Raymer & Berndt, 1996). Of most interest was the observation that some patients, despite severe deficits in the semantic system and to the nonlexical reading procedure, can nevertheless read words correctly that they do not understand, including irregular words. For instance, patient WB (Funnell, 1983) could not read nonwords including pseudohomophones, e.g., brane, suggesting a deficit in reading via the nonlexical procedure. WB also showed deficits in semantic judgments on spoken and written words, indicating that the semantic route for reading was also impaired. However, his reading ability for words from a wide range of frequencies was relatively preserved. It is assumed therefore that successful oral reading was achieved through a third route, the direct lexical route. Another important piece of evidence for a third route was presented in Coltheart, Masterson, Byng, Prior, and Riddoch (1983). In this case study, their patient could read irregular words correctly without comprehending the meaning of those words. For instance, he could read "steak" correctly but defined it as a "fencing post". As the semantic route was not functioning properly in this case, and the nonlexical route could not generate an accurate response because the word steak is irregular, Coltheart et al. assumed that a direct lexical route is necessary to account for this pattern (also see Coltheart & Funnell, 1987; Ellis & Young, 1988; Lambon-Ralph et al., 1995; Schwartz et al., 1979).

However, an alternative explanation for these patterns of reading has been proposed within the dual route framework, arguing that a third route is not logically necessary (Hillis & Caramazza, 1991, 1995). This "summation hypothesis" assumes that partial information from an impoverished semantic system and partial information from a nonsemantic nonlexical procedure could be enough to "summate" to the correct response for some patients. According to this hypothesis, those patients with deficits to the semantic system causing failures on measures including picture naming or comprehension tasks which require them to distinguish between the target and semantically related items, may retain access to *some* semantic information, including the semantic category of the item. In word reading, the ambiguous activations through the semantic system are resolved by phonemic information activated through the nonlexical system, even though this nonlexical activation may be imperfect or underspecified, either because the nonlexical procedure is also impaired to some degree, or because the target is not fully regular. Take the irregularly spelled word "pear" as an example. A patient with a semantic deficit may only retain the semantic information that a pear is a fruit and phonological lexical nodes of "pear", "apple" and "lemon" are activated to similar degree. As a result, he or she may name the picture of a pear as "apple" or "lemon", or in comprehension tasks (such as picture-word matching) erroneously choose the semantic foil "apple" as the target. However, when presented with the visual word, phonemic information that is activated by the letter "p" or the rime "ear" will converge onto the phonological representation of the word "pear" and not "apple" or "lemon". This activation would be sufficient to allow correct oral reading of an irregular word despite imperfect knowledge of the word meaning.

Hillis and Caramazza (1991, 1995) reported empirical evidence that is compatible with the summation hypothesis. For instance, one of their patients, JJ, had deficits in visual word comprehension (except for animals) suggesting impairment in the semantic reading pathway. However, he was very good when reading irregular words. When his comprehension and reading performance were compared in an item analysis, there was an interaction between his knowledge about the semantic dimensions of the word and the regularity of the item. When he showed partial comprehension of a word, he read that word correctly, including irregular words. However, when he could not understand word meanings, there was a strong regularity effect. He could read all regular words correctly but no irregular words correctly.

The summation hypothesis can explain the patterns of reading displayed by JJ and several other patients (e.g., GLT, Hillis & Caramazza, 1995) within the dual route framework without the requirement of a direct lexical route. The main advantage of the summation hypothesis over the triple route model (e.g., Coltheart et al., 2001) is that summation is a more parsimonious explanation since it requires one less cognitive procedure for normal oral reading and it can explain data from patients assuming a single deficit locus, which is to the semantic system only. However, if a direct lexical route for reading aloud is also assumed, then JJ must be assumed to have an additional deficit in that route.

In this paper, we report converging evidence for the summation hypothesis from a Chinese-speaking patient with dementia. Our patient WJX produces semantic errors in both comprehension and production tasks. However, his oral reading performance is significantly better than his comprehension and production of the same lexical items. Following the logic of Hillis and Caramazza (1995), we investigated if the discrepancy between WJX's word-reading and picture-naming performance could be explained through the summation of partial information from a semantic and a nonsemantic route. In addition, we asked whether reading in Chinese via the nonsemantic route uses nonlexical procedures that may be comparable to GPC rules in English or is equivalent to the direct lexical route that is assumed by Coltheart and colleagues to be available for oral reading in alphabetic languages.

Data from Chinese speakers is particularly informative for studying reading because of the unique features of the script. Written Chinese is often viewed as the most typical example of an opaque script because it has no grapheme-phoneme correspondences. The basic written units are logographic characters that correspond to syllables in sound. There are about 3500 commonly used characters. Some are freestanding morphemes that can stand alone as a word and others are so-called bound morphemes in that they usually occur together with another character in a compound word. There is no visual component within a character that corresponds to any *segmental* information of the printed form. That is to say there is no visual-sound-correspondence at the *segmental* level that resembles the GPC system assumed used in alphabetic scripts. This is why some writers posit that in Chinese "the distinction between a lexical and nonlexical route for reading aloud cannot even rise", and "there are no reasons to expect universals of written language" (Coltheart et al., 2001, p. 236). Indeed, while the existence of a third direct lexical route in alphabetic scripts is in dispute, researchers have often assumed that a direct lexical route that maps lexical orthography onto lexical phonology without contacting semantic representations is available for reading in Chinese (e.g., Law & Leung, 2000; Law & Or, 2001; Law, Wong, & Chiu, 2005; Law, Yeung, Wong, & Chiu, 2005; Taft, Liu, Zhu, 1999; Taft & Zhu, 1995, 1997; Taft, Zhu, Peng, 1999; Weekes & Chen, 1999; Weekes, Chen, & Yin, 1997; Zhou & Marslen-Wilson, 1997). Theoretical discussions have mostly focused on whether there are linguistic and empirical reasons to posit nonlexical correspondences between orthography and phonology in Chinese. In order to understand this debate, we will briefly summarize the characteristics of the Chinese script.

The Chinese written script began with a small set (about 200) of pictographic symbols depicting the meaning of objects and actions, e.g., 口, /kou3[1]/, "mouth". The visual-sound correspondences in these symbols were completely arbitrary. However, a productive way of forming new characters emerged, most notably for characters with abstract meanings, which used existing symbols to represent the sound of a new character and another component to indicate its meaning. The result is that over 80% of modern characters are composites of a semantic radical and a phonetic radical, which are typically aligned in a left-to-right fashion. The phonetic radical corresponds to a syllable and is usually another lexical item (word) when it stands alone. The whole composite character can sometimes be a homophone with its phonetic radical or rhyme with it, but can also be completely different in sound. For example, the character "栏" (/lan2/, fence) has a phonetic radical "兰" (/lan2/, lily), which gives the character's pronunciation, and a semantic radical "木" (/mu4/, wood), which provides meaning. The character "烂" (/lan4/, rotten) with the same phonetic radical, however, differs from the radical "兰" (/lan2/) in tone.

In order to characterize phonetic regularity, i.e., how reliably the pronunciation of a composite character can be predicted by the sound of its phonetic radical, two variables be measured. These are called regularity and consistency. Regularity refers to whether a character has the same sound as its composite radical. A *regular* Chinese character refers to a composite character that has the same sound as its phonetic radical (e.g., Weekes & Chen, 1999). However, for a character to be *consistent*, not only must it be a homophone with its phonetic radical, all characters with the same phonetic radical must also be homophonic with that character. In other words, a phonetic radical for a consistent character will always give an unambiguous phonetic cue to the sound of the whole character. Estimates suggest that about 25% of the composite characters taught in elementary schools are regular, and 11% are consistent (Xing, 2002). Chronometric studies show that the information in a phonetic radical is automatically activated in reading composite characters, and the regularity and the consistency of radicals within a composite character also influence reading performance. For example, in experiments where the task is to read aloud the target character after a brief presentation of a prime character, Zhou and Marslen-Wilson (1999) found that the reading of a target character, e.g., 轻 (light, /qing1/), was facilitated by the presentation of a character (猜, guess, /cai1/) which had a phonetic radical (青

[1] The *pinyin* system is used for the phonetic transcript of the Chinese characters. The number represents the tone of the syllable preceding it. There are four tones in Mandarin Chinese, flat (1), rise (2), fall-rise (3) and fall (4). Number 0 represents an unstressed syllable.

, turquoise, /qing1/) that was homophonic with the target but is unrelated semantically or phonologically/orthographically. Also, low frequency regular characters are named faster than irregular characters (Hue, 1992; Seidenberg, 1985; but see Shu & Zhang, 1987) and consistent characters faster than inconsistent characters (Hue, 1992; Peng, Yang, & Chen, 1994). Some studies have shown that the phonological information in a radical of an independent phonogram, e.g., the right side of the character 噗 (sound of escaping laughter, /pu1/), has an impact on reading characters, suggesting that pronunciation of a composite might not be retrieved holistically from the lexicon but rather the pronunciation can be influenced by pronunciation of other composite characters that contain the same phonetic radical (e.g., Lee, Tsai, Su, Tzeng, & Hung, 2005). Furthermore, patients with surface dyslexia in Chinese read aloud regular characters better than irregular characters, and sometimes produce the sound of the phonetic radical when reading irregular characters, e.g., read 猜 (guess, /cai1/) as /qing1/, which is the pronunciation of its phonetic radical (青, turquoise, /qing1/). These are referred to as "Legitimate Alternative Responses to Components" or LARC errors by Weekes and Chen (1999) (also see Yin & Butterworth, 1992).

Taken together, the above findings suggest that the phonetic radical contributes to both normal and impaired oral reading in Chinese. However, it is an open question whether the involvement of the phonetic radical is a lexical or nonlexical event. One view (e.g., Wu, Zhou, & Shu, 1999) is that phonetic radical processing might be based on statistical rules, such that the orthographic form of a phonetic radical corresponds to a certain syllable(s) according to probabilities, this being comparable to GPC rules in English. On the other hand, phonetic radical effects might simply be the byproduct of *lexical* processing of the characters containing the radical. A point to note here is that in the triple route model shown in Fig. 1, the direct lexical route for reading operates according to a one-to-one mapping between an orthographic lexical representation (node) and a phonological lexical node. Therefore, any phonetic radical effect on reading in Chinese is not readily explained by simply assuming reading via a direct lexical route without additional specification of how phonetic composite characters are processed. As we mentioned earlier, extant theories start with the assumption that direct lexical links between orthographic lexical representation and phonological lexical representations are sufficient to explain oral reading in Chinese. The most relevant empirical motivation for this view comes from patients like YQS (Weekes et al., 1997) and YKM (Law, Wong, et al., 2005), who can read aloud lexical items much better than they can name the same lexical items presented as pictures. However, as in the studies of English speaking patients reviewed above, such evidence does not necessarily imply the existence of a direct lexical route. Data from Chinese speakers could also be explained by the summation hypothesis if a nonlexical is assumed. Note that the summation hypothesis by itself does not require the proposal of a nonlexical route, as summation could be achieved via the semantic route and a direct lexical route. Our point is merely that before we assume that Chinese reading involves a direct lexical route as almost all current models of Chinese reading do, it is still an open question which of the two nonsemantic routes (direct or nonlexical) in Fig. 1 functions in reading Chinese given that either of them can account for the aphasic cases and the phonetic radical effects cited above. Here, we would address the influence of the phonetic radicals on the composite character reading as the "nonlexical processing" in Chinese following the convention adopted in other studies (e.g., Zhou & Marslen-Wilson, 1997, 1999) and defer the discussion about the precise underlying mechanism (lexical or not) to Section 5.

Another unique feature of Chinese characters is the existence of semantic radicals, which are somewhat comparable to inflectional morphemes (e.g., -ment) except that the semantic radicals are associated with conceptual information of character and not grammatical properties. Like phonetic radicals, semantic radicals are not necessarily reliable. Approximately, 88% of composite characters have *transparent* or *semi-transparent* semantic radicals, e.g., 河 (river), 溪 (stream), 湖 (lake), 海 (sea), 湿 (wet), 汗 (sweat), 洗 (wash), all have the semantic radical "氵" which, loosely defined, means water-related. About 12% of composite characters have *opaque* semantic radicals where the typical meaning of the composite character is unrelated to the semantic radicals within the character, e.g., 消, disappear, /xiao1/ (Shu, Chen, Anderson, Wu, & Xuan, 2003). It is still unclear to what degree semantic radicals contribute to the recognition of Chinese characters and so this question will be an additional focus in the current study. The possible effects of semantic radicals on reading in Chinese will also be considered in the context of the integration of output from the semantic system with nonlexical processing.

In the following sections, we describe the details of WJX's neuropsychological profile including his performance on language tasks. In Experiment 1, we compared his performance on oral reading tasks to other tasks involving different processing components such as meaning judgment, with the aim of establishing the locus of his cognitive deficits. In Experiment 2, we focus on whether putative nonlexical correspondences have an impact on oral reading performance and its relationship with the semantic dimension by manipulating the phonological and semantic transparency of characters.

2. Case background

WJX is a 75-year-old right-handed man who received high-primary school education, and formerly worked as an amanuensis in a police bureau of Beijing City. His family reported 4 years of deteriorating memory at first testing. WJX scored 16 on the Chinese version of the MMSE indicating probable dementia. CT scan revealed a small low-density focus in the posterior limb of the left internal capsule (Fig. 2). A SPECT conducted in December 2001 showed that both hemispheres were thinned, with evidence of ischemic brain damage in the left temporal lobe. The tests for the present study were conducted between October 1999 and May 2004.

In the preliminary screening test conducted in October 1999, WJX showed no problem on a bucco-facial apraxia task, where he was required to execute or imitate 15 actions such as biting the upper lips (15/15). He was near perfect in the word and

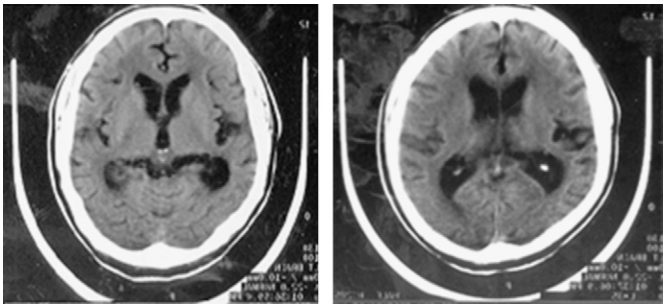

Fig. 2. CT images of WJX.

nonword repetition task (39/40), and was flawless at copying pictures (2/2) and copying words (10/10). His spontaneous speech was fluent and grammatically well formed, but contained frequent semantic paraphrases. For example, his description of the cookie theft picture, included the following statements

"这个人拿着一个小孩，上面是果品一类的东西，这个手里拿着一个圈子，这的东西都砸了，一筐一筐的，有饭碗，这有一鸟，蹬着圆凳够东西，小孩跟小孩玩，往嘴里吃呢。这是一男孩，一女孩."

(This man holds a child, with fruit stuff on it. This hand holds a ring, and things inside are all broken, one basket and one basket. There is bowl, and a bird here, stepping on the stool reaching for stuff. Children playing with children here, put stuff into the mouth to eat. This is a boy, and a girl.)

WJX was impaired on tests of word comprehension. He scored 8/15 correct in an auditory word-picture matching task where he needed to match one spoken word to one of four pictures (a target, a semantic foil, a visual foil and a unrelated foil); 10/20 correct in an auditory sentence-picture matching task where he matched one spoken sentence to one of two pictures (the foils are either semantic or with reversed role); 9/15 in the visual version of the word-picture matching task; 11/20 in an additional visual sentence-picture matching task. He was also impaired in oral picture naming (56/130) and written picture naming (2/11). Semantic errors were prevalent in responses such as producing 鹿 (deer, /lu4/) when given the picture of a 羊 (sheep, /yang2/). The fact that he made semantic errors in all comprehension and naming tasks shows a deficit in the semantic system. This was confirmed by his greatly reduced category fluency (animals = 4). By contrast his oral reading ability, was well preserved (53/57, words and nonwords[2] combined) and not characterized by semantic errors. All oral reading errors were exclusively form related errors e.g., 龟 /gui1/→(电) /dian4/, 妆 /zhuang2/→(汝) /ru3/, 坡 /po1/→/pei1/, 横 /heng2/→/geng3/.

The profile that emerged from screening was that WJX showed a typical pattern of impairment to language processing that is similar to many English speaking patients with dementia, i.e., he suffered from impairment to tasks requiring access to the semantic system, but had a preserved reading ability, even for relatively opaque characters. Such a pattern resembles cases such as WB (Funnell, 1983) and YQS (Weekes et al., 1997), who were cited as evidence of a direct lexical route (addressed as "nonsemantic route" in Weekes et al., 1997) in reading. In Experiment 1, we tested this impression by giving WJX comprehension tasks that were presented in the visual and auditory modalities using a relatively large item set, as well as oral word reading and picture naming tasks using the same lexical items. In Experiment 2, we constructed a different set of materials to examine the possible effects of phonetic and semantic radicals on his reading, and then compared his comprehension and reading abilities with these characters directly.

3. Experiment 1: Comparison across lexical tasks

3.1. Method

Items were 226 words taken from the Chinese adaptation of the Snodgrass and Vanderwart (1980) set (Shu, Cheng, & Zhang, 1989). Four tasks were administered: oral picture naming, oral word reading, spoken word/picture verification and written word/picture verification. In the verification tasks, a picture was presented along with a word, either spoken or written, and WJX was required to say "yes" or "no" to indicate whether the word corresponded to the picture. Each target pictures was paired with three words administered in three separate blocks, including the correct word, a semantic foil and a formal foil related to the target either by visual form or by sound or both. Semantic and formal foils were taken from Shu et al. (1989). A target was scored correct only if it was correctly identified in all three trials—i.e., the patient correctly accepted the target picture and rejected the two foils. In our view, these strict criteria provide a test of comprehension that is more sensitive than word-picture matching because the patient cannot "guess" the correct response by knowing that the foil is not the target. Written production tasks were not administered because the patient complained that writing was too effortful.

The complete set of 226 items in Shu et al. (1989) was presented in the oral picture naming and reading tasks, and a subset of 162 was used in the word/picture verification tasks. The three items for each target in the verification tasks were assigned into three blocks using the Latin-square method. The three blocks were administered over a period of 1 month with a 2-week break between the administrations of each block. The oral naming and oral reading tasks were administered in two counterbalanced sessions administered one month apart. The verification tasks were scored on site by the experimenter and the naming and reading tasks were recorded onto an audiotape, transcribed and scored afterwards. The entire experiment was completed in a total of eight sessions.

3.2. Results

WJX's first complete responses were scored. We categorized the oral picture naming and reading responses into six categories: (1) correct; (2) semantic errors, i.e., responses that are semantically related to the target (e.g., 嘴, mouth /zui3/→耳朵, ear, /er3 duo0/); (3) mixed errors, i.e., responses that were both semantically and formally related to the target (e.g., 摩托车, motorcycle, /mo2 tuo1 che1/→自行车, bicycle, /zi4 xing2 che1/); (4) phonological/visual errors, i.e., responses that were only phonologically related or visually related to the target (e.g., 蛋糕, cake, /dan4 gao1/→帽子, cap, /mao4 zi0/); (5) other, including responses that were nonwords, unrelated words, or circumlocutions; (6) Do not knows. In the verification tasks, the false acceptance of the semantic foil was a semantic error and the formal foil a formal error.

The results for each task were broken down by error type and are presented in Table 1. WJX's performance on spoken word/picture verification was significantly better than his written word/picture verification ($\chi^2_1 = 7.12$, $p < 0.01$) and oral picture naming ($\chi^2_1 = 4.98$, $p < 0.05$). His overall percentage correct was comparable between oral picture naming and written word/picture verification ($\chi^2_1 < 1$). Also, his oral reading performance was significantly better than all of the other three tasks (p's < 0.0001).

[2] Nonwords were created by combining two character/syllables. These are comparable to pseudo-compounds in English e.g., "tea row" each with an extant syllable.

Table 1
Percentage breakdown of WJX's responses on the four tasks in Experiment 1 (item numbers in parentheses)

	N	Correct	Semantic errors	Mixed errors	Formal errors	Other	Do not know
Spoken word/picture verification	162	56 (91)	22 (35)	–	3 (5)	–	–
Written word/picture verification	162	41 (67)	20 (32)	–	1 (2)	–	–
Oral picture naming	226	45 (101)	26 (59)	3 (7)	0 (0)	18 (40)	8 (19)
Oral reading	226	94 (213)	0	1 (3)	1 (2)	3 (8)	0

Note: In Tables 1 and 2, the data points for semantic errors in the verification tasks are the error percentage and error numbers in the block where the targets were each paired with a semantic foil, i.e., the occurrences that the patient falsely accepted the semantic foil out of the 162 trials. The same works for the "formal error" cells. The items in the parentheses do not add up to the total number in the verification tasks because: (1) false alarms – trials where the patients falsely rejected the target picture names – were not presented here and (2) the trials where a target pictures were correctly identified in one block (e.g., semantic) but erroneous in another (e.g., formal) were not categorized into any of these categories in the table.

If we look at the "miss" trials in the verification tasks, semantic errors were more common than formal errors (auditory verification: 35/162 versus 5/162, $\chi_1^2 = 25.67$, $p < 0.0001$; visual verification: 32/162 versus 2/162, $\chi_1^2 = 29.57$, $p < 0.0001$). Semantic errors were also the most frequent error type in oral picture naming. Examples are: 椅子 (chair, /yi3 zi0/)→床 (bed, /chuang2/), 骆驼 (camel, /luo4tuo0/)→马 (horse, /ma3/), 青蛙 (frog, /qing1 wa1/)→螃蟹 (crab, /pang2 xie4/). The mixed errors included 母鸡 (hen, /mu3 ji1/)→ 公鸡 (rooster, /gong1 ji1/), 铅笔 (pencil, /qian1 bi3/)→ 圆珠笔 (ball pen, /yuan2 zhu1 bi3/). The proportions of semantic errors to all errors combined were comparable among the three tasks (pairwise comparisons, p's = 0.145–0.681). By contrast, he made no pure semantic errors in word reading. In the three instances where the responses were semantically related to the target, there was also a phonological relationship: 蛋糕 (cake, /dan4 gao1/)→ 鸡蛋 (egg, /ji1 dan4/), 扫帚 (broom, /sao4 zhou0/)→ 笤帚 (broom, /tiao2 zhou0/), 蚂蚱 (locust, /ma4 zha4/)→ 蚂蚁 (ant, /ma3yi3/). All other errors were words or pseudowords that were orthographically and/or phonologically related to the target, e.g., 蛇 (snake, /she2/) → tuo2 (驼, camel), or omissions (犀牛, rhinoceros /xi1 niu2/→ 牛, cow, /niu2/).

When comparing the results of the oral reading task to the other tasks, one caveat needs to be considered—the majority of the items are compound words. Compound words, comprising two or more characters account for over 80% of the items in this experiment (reflecting the proportion observed in the language overall). It is reasonable to assume the phonology of constituent characters in a compound may be accessed independently of the whole word (see a similar position in Law & Or, 2001). For example, take the compound 雪人 (snowman, /xue3 ren2/). Although, the semantic and/or the lexical representation in the phonological lexicon is not available to the patient, he may recognize the individual characters, 雪 (snow, /xue3/) and 人 (man, /ren2/) because they are of higher frequency or familiarity than 雪人 (snowman, /xue3 ren2/) as a whole. If WJX indeed reads compounds by assembling the characters, it is not comparable to lexical access in oral picture naming, where the components are not available. There were 35 monosyllabic (mono-character) words in all of the four tasks. We therefore looked at WJX's performance on these 35 items and found that the pattern resembled the pattern across the whole item set including compounds (see Table 2).

3.3. Summary

WJX was impaired on oral picture naming, spoken word comprehension and written word comprehension tasks. Furthermore, the majority of his errors were semantic. A selective impairment to the semantic system can explain this pattern quite simply. His oral reading exhibited a different pattern to production and comprehension performance. Not only was he correct on significantly more trials, that is, he could read many items that he failed in oral picture naming and comprehension, he never made a pure semantic error. Instead, he produced a few erroneous responses that sound similar to the phonetic radical such as naming 青椒 (green pepper, /qing1 jiao1/) as a nonword 青叔 (/qing1 shu1/). These errors suggest that WJX utilized nonlexical processes in reading. However, this could not be true exclusively since he read many irregular characters correctly where the phonetic radical does not provide a reliable cue to pronunciation, e.g., 猜 (guess, /cai1/) whose phonetic radical 青 (turquoise, /qing1/) has a different pronunciation. As we argued earlier, WJX's performance resembles the pattern of cases like WB (Funnell, 1983) in general and more directly *anomia without dyslexia* in Chinese (Weekes & Chen, 1999; Weekes et al., 1997), which *prima facie* supports the proposal of a third route in addition to the semantic and nonlexical route in reading—a direct lexical route connecting orthographic input and phonological output.

In the next experiment, we varied the phonetic radical transparency of characters directly and compared comprehension and reading performance on an item-by-item basis. We also manipulated the transparency of the semantic radical. Again the aim was to see how the semantic system and the nonsemantic system work together in reading Chinese characters.

4. Experiment 2: Oral reading and comprehension

4.1. Method

Items were 150 monosyllabic (single character) words from our in-house "BNU Chinese dyslexia battery" which were constructed by manipulating: (1) the regularity and the consistency of phonetic radicals and (2) the transparency of semantic radicals. Characters with a phonetic radical that has the same pronunciation as the whole character were classified as regular. Characters with a phonetic radical that has the same pronunciation as the whole character were classified as *consistent* if all characters with this phonetic radical are pronounced in the same way. Note that a character can be regular but not consistent (as in English), if the phonetic radical is pronounced the same way but it sometimes occurs in other characters with different pronunciations. Finally, an irregular character had a phonetic radical that is pronounced differently to the whole character. A character was classified as semantically transparent if the semantic radical depicting its meaning, e.g., 江, river, /jiang1/ is consistent with the typical meaning of the semantic radical 氵, water-related, as in 海, sea, /hai3/; 湖 lake, /hu2/; 淹, flood, /yan1/; 渴, thirsty, /ke3/; 湿, wet, /shi1/, etc. A character is classified as semantically opaque if its meaning was unrelated to the typical meaning of the semantic radical, e.g., 消, disappear, /xiao1/. To

Table 2
Percentage breakdown of WJX's responses on the 35 monosyllabic items the four tasks in Experiment 1 (item numbers in parentheses)

	Correct	Semantic errors	Mixed errors	Formal errors	Other	Do not know
Spoken word/picture verification	74 (26)	20 (7)	–	3 (1)	–	–
Written word/picture verification	54 (19)	20 (7)	–	0	–	–
Oral picture naming	63 (22)	17 (6)	0	0	11 (4)	9 (3)
Oral reading	97 (34)	0	3 (1)	0	0	0

Table 3
Stimuli properties in Experiment 2

Types of semantic radicals	Types of phonetic radicals	Example	*N*	Word frequency (/1.8 million)	Number of orthographic subcomponents	Number of strokes
Transparent	Reg-con	柄	30	175	2.77	9.90
	Reg-incon	町	30	208	2.50	9.30
	Irreg-incon	狐	30	204	2.67	9.77
Opaque	Reg-con	俱	20	226	2.90	9.55
	Reg-incon	漠	20	215	2.80	9.40
	Irreg-incon	猜	20	191	2.70	9.65

obtain a more objective view of semantic opacity, the selected characters were paired with their semantic radicals and given to 14 participants (undergraduate students from Beijing Normal University) to rate their semantic relatedness on a 7-point scale, with 1 being unrelated and 7 being most related. The mean rating was 5.73 for the characters with "transparent" semantic radicals and 3.25 for "opaque" semantic radicals, and the difference was highly significant $t(149) = 41.9$, $p < 0.000001$. Table 3 displays the features of the six types of characters used and examples. The character types were matched for surface character frequency, and their visual complexity (the number of strokes and the number of logographemes[3]) according to one-way ANOVAs, *F's* = 0.19–0.94, *p's* = 0.455–0.966.

Stimuli were presented individually, each on the center of a piece of paper, at font SONG, size 48. To test WJX's comprehension and oral reading of characters directly, he was asked to first define the character and then read it aloud. Occasionally, he failed to follow the instructions and read the character before defining it. The characters were presented in a random order, and administration was completed in two sessions about one week apart. The entire testing was recorded on an audiotape and was transcribed and scored later. The whole list was given once in 2003, and a second time in 2004.

4.2. Results

To score WJX's definitions of characters we classified responses into three categories: accurate, partially correct, and wrong. A response was scored as accurate if it had the most crucial features of the target, e.g., defining the character 喊 (/han3/, shout) as "嘴里头嚷嚷的，说什么事，声音大一点，不大，人们听不见" (say something loudly with the mouth, say something, loud, if not loud, people cannot hear). If a response tapped into at least some semantic features of the target, it was scored as partially correct. For example, he defined the character 邮 (/you2/, post) as "写信得用这个字,写书信什么的" ("use this character when to write a letter, write a letter or something"). If the response was semantically unrelated to the target or no response was given then the trial was scored as wrong. The reading responses were scored correct only if all the segmental information and the tone were correct; otherwise it was scored as wrong. Responses were scored by two independent judges and the inter-coder correlation was high ($R^c = 0.80$). Therefore, the scores from one coder only are reported here.

Consistent with the findings from the screening phase and Experiment 1, WJX was significantly better at reading aloud than comprehending character meanings (1st time: $\chi^2_1 = 19.6, p < 0.000$; 2nd time: $\chi^2_1 = 33.4, p < 0.000$). Comparing WJX's performance in earlier and later testing sessions revealed evidence of dementia. His comprehension performance degraded significantly (definition accuracy: 44% versus 31%, $\chi^2_1 = 5.1$, $p < 0.05$). However, his reading performance over the two testing points, however, was relatively stable (69% versus 64%, $\chi^2_1 < 1$).

4.3. Semantic radicals and comprehension

Collapsing the data across both sessions, the percentage of accurate definitions was similar for transparent and opaque characters ($\chi^2_1 < 1$, see Table 4). However, compared to opaque items, transparent items elicited a higher percentage of "partially correct" definitions ($\chi^2_1 = 3.75$, $p = 0.053$) and fewer "wrong" definitions ($\chi^2_1 = 3.76$, $p = 0.052$). This suggests that WJX did use the semantic radical to identify the meaning of some characters. However, while we controlled for the frequency and the visual complexity of the two character groups (opaque semantic radical character versus transparent semantic radical character), there are potential confounding factors that we might have overlooked, i.e., the characters' semantic variables such as imageability or concreteness. To identify whether WJX's comprehension patterns can be attributed to the type of semantic radical or the conceptual properties of the whole character, we presented the 150 characters to 16 students at Beijing Normal University and asked them to rate their imageability on a 7-point scale, with 1 being least imageable and 7 most imageable. Another 16 participants were asked to rate the characters' concreteness (1—most concrete; 7—most abstract). The mean imageability ratings for characters with transparent semantic radicals and opaque radicals were 5.37 and 3.90, respectively, $t(148) = 7.3$, $p < 0.001$, and the mean concreteness ratings 3.85 and 2.66 $t(148) = 7.6$, $p < 0.001$. This suggests that these two variables were indeed confounded with the semantic radical manipulation. To exclude any potential contribution of character imageability and concreteness and to test whether semantic radical opacity had independent effects on character comprehension, we selected a subset of characters in these two groups (33 in each) that were matched for imageability (transparent: 4.7; opaque: 4.7) and concreteness (3.2; 3.4), as well as frequency (228; 218) and visual complexity (stroke number: 9.2; 9.8; logographeme number: 2.5; 2.8). WJX's definition scores on this subset (collapsing twice) showed that the effect of semantic radical opacity on definition performance was eliminated (wrong definition: transparent 46/66, opaque 38/66, $\chi^2_1 = 2.1$, $p = 0.15$; partial definition: transparent 16/66, opaque 13/66, $\chi^2_1 < 1$). We then conducted a logistic regression to verify these findings. The dependent variable was WJX's definition scores (1 for partially correct and 2 for wrong). The predictors were semantic radical opacity ratings, imageability ratings, concreteness ratings, character frequencies, stroke numbers and logographeme numbers. The variables were entered into the logistic regression using the forward stepwise (LR) method. We found that the character frequencies ($p < 0.0001$) and imageability ($p = 0.001$) were the only two significant predictors for the definition types and semantic radical opacity ($p = 0.982$) and concreteness ($p = 0.090$) were not. In other words, in various post hoc analyses, we found that WJX's comprehension ability was a function of the characters' imageability and semantic radical opacity did not make an independent contribution.

4.4. Phonetic radicals and reading

As can be seen in Table 5, WJX read more consistent than inconsistent characters correctly (overall: $\chi^2_1 < 10.9, p < 0.0001$; time 1: $\chi^2_1 < 7.6, p < 0.01$; time 2: $\chi^2_1 < 4.2$, $p < 0.05$), however, there was no difference between performance on regular-inconsistent and irregular-inconsistent characters (χ^2_1s < 1). That is, a significant consistency effect was observed, suggesting that WJX used preserved nonlexical knowledge to generate the phonology of a given character. It is important to stress that this nonlexical knowledge does not simply adapt the pronunciation of the phonetic radical, but instead takes into account the reli-

[3] Logographemes, or sub-components, are visual units that are assumed to be the smallest components in characters other than strokes. They are composed of different strokes in certain spatial relationships. For example, the character "蝗" contains three logographemes: 虫, 白 and 王. See Law and Leung (2000) for detailed analyses for the criteria in defining a logographeme.

Table 4
Percentage distribution of definition performance as a function of semantic radical opacity (item number in parentheses)

Semantic radical opacity	Definition	Regular-consistent	Regular-inconsistent	Irregular-inconsistent	Total
Transparent	Accurate	15 (9/60)	18 (11/60)	28 (17/60)	21 (37/180)
	Partially correct	22 (13/60)	18 (11/60)	27 (16/60)	22 (40/180)
	Wrong	63 (38/60)	63 (38/60)	45 (27/60)	57 (103/180)
	Total	100 (60/60)	100 (60/60)	100 (60/60)	100 (180/180)
Opaque	Accurate	25 (10/40)	15 (6/40)	15 (6/40)	18 (22/120)
	Partially correct	23 (9/40)	13 (5/40)	5 (2/40)	13 (16/120)
	Wrong	53 (21/40)	73 (29/40)	80 (32/40)	68 (82/120)
	Total	100 (40/40)	100 (40/40)	100 (40/40)	100 (120/120)

ability of this phonetic cue. WJX assigned the pronunciation of the phonetic radical to the whole character only when the phonetic radical was reliable, that is, all characters containing the phonetic radical have the same pronunciations, that of the phonetic radical. And when a character has an inconsistent phonetic radical, the patient assigned a "legal" sound – the pronunciation of a possible character containing this radical – to the target. This is why he correctly read a similar percentage of regular/inconsistent and irregular/inconsistent characters, and why he could read correctly several irregular/inconsistent characters.

4.5. Comprehension and reading

In our final and most critical analysis, we addressed the question of whether WJX's impaired semantic system has any effect on his oral reading. Table 5 displays WJX's reading performance as a function of his comprehension of the same lexical items. At time 1, the 35 characters that he defined accurately, he accurately read, including irregular and inconsistent items, i.e., the items with phonetic radicals that give misleading cues. This was also true for the 31 characters where he generated partial definitions. For the 84 characters to which he gave the wrong definition or failed to give any definition, he read 45% of them correctly. Most importantly, there was a significant consistency effect on reading (consistent versus inconsistent: $\chi^2_1 = 5.916$, $p = 0.015$), although no effect of regularity was observed (regular versus irregular: $\chi^2_1 < 1$). The same pattern was observed at the second administration ($T = 2$, see Table 5). An effect of the semantic system on oral reading was confirmed by the observation that transparent characters (with high character imageability) were read correctly more often than opaque characters (low imageability) (71% versus 55%, $\chi^2_1 = 4.090$, $p < 0.05$) at the second administration (when comprehension had degraded) (see Fig. 3).

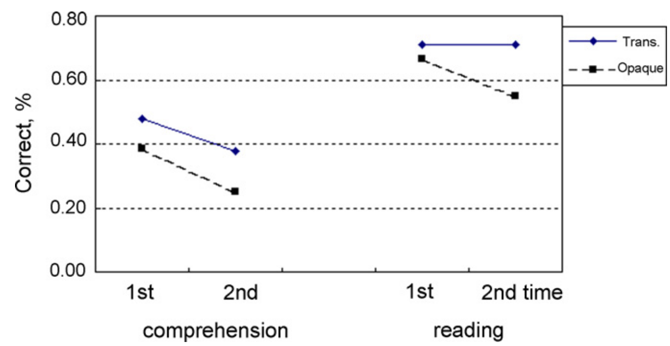

Fig. 3. Correct percentage of comprehension and reading as a function of semantic radical transparency.

4.6. Summary

We found that although the opacity of a semantic radical had psychological reality – WJX understood the meaning of transparent characters better than opaque characters – we failed to detect any *independent* effect of the semantic radicals and the differences were fully accounted for by the imageability of the character. Of greatest interest were the interactions between character comprehension and the effect of phonetic radical transparency on oral reading. If WJX could give partial information about the meaning of a character including characters that are irregular and contain inconsistent phonetic radicals, he was near perfect in the oral reading task. Effects of phonetic radical transparency appeared only for characters that he failed to comprehend completely. This pattern echoes perfectly the reading behavior of patient JJ (Hillis & Caramazza, 1991).

5. General discussion

We have reported WJX, a patient with dementia who could read aloud better than he could comprehend and orally name pictures. This pattern of spared oral reading in dementia is similar to other patients reported in the literature (Blazely et al., 2005; Cipolotti & Warrington, 1995; Lambon-Ralph et al., 1995; Noble et al., 2000; Raymer & Berndt, 1996; Schwartz et al., 1979). Like other dementia patients, the locus of the lesion for WJX was relatively diffuse with temporal lobe damage more

Table 5
Correct percentage of reading as a function of comprehension (item numbers in parentheses)

Time	Definition	Regular-consistent	Regular-inconsistent	Irregular-inconsistent	Total
1st	Accurate	100 (10/10)	100 (10/10)	100 (15/15)	100 (35/35)
	Partially correct	100 (14/14)	100 (10/10)	100 (7/7)	100 (31/31)
	Wrong	69 (18/26)	37 (11/30)	32 (9/28)	45 (38/84)
	Total	84 (42/50)	62 (31/50)	62 (31/50)	69 (104/150)
2nd	Accurate	100 (9/9)	100 (7/7)	100 (8/8)	100 (24/24)
	Partially correct	88 (7/8)	100 (6/6)	100 (11/11)	96 (24/25)
	Wrong	67 (22/33)	43 (16/37)	35 (11/31)	49 (49/101)
	Total	76 (38/50)	58 (29/50)	60 (30/50)	65 (97/150)

extensive in the left than the right hemisphere. Left temporal lobe damage is also consistent with lesion sites reported for other patients who have spared oral reading coincident with impaired comprehension, e.g., JJ (Hillis & Caramazza, 1991). WJX's pattern of performance also replicates other Mandarin speaking patients with left hemisphere damage (Weekes & Chen, 1999; Weekes et al., 1997) and Cantonese-speaking patients with left hemisphere damage (Law & Or, 2001; Law, Wong, et al., 2005; Law, Yeung, et al., 2005).

Our most important empirical findings are the following: In Experiment 1, we compared WJX's performance on oral picture naming, spoken word comprehension and written word comprehension tasks to oral reading. WJX was impaired in both production and comprehension tasks, and semantic errors were the dominant type. In Experiment 2, the following points emerged: (1) the status of the phonetic radical had an effect in WJX's reading, such that consistent characters were read better than inconsistent characters; (2) the semantic radical of characters did not seem to affect character processing. WJX's pattern of character definition performance could instead be attributed to character imageability that co-varied with the semantic radical type; (3) if WJX had only partial semantic knowledge about a character, he could read the character, including inconsistent/irregular items but if he could not access any semantic information at all, he relied only on the consistency of the phonetic radicals to read aloud.

We will now discuss the implications of these results for understanding the cognitive processes involved in reading aloud Chinese characters, including the following issues: (1) the (insignificant) role of semantic radicals in Chinese character recognition; (2) nonlexical processing in reading Chinese characters that is revealed by the consistency effect of phonetic radicals; (3) the interaction between semantic variables and the nonlexical variables accounted for by the "summation" hypothesis; (4) the nature of nonlexical processing in Chinese in comparison with alphabetic languages.

First, the absence of the semantic radical effects in character comprehension after controlling for imageability is intriguing. There are chronometric studies showing that when participants are asked to judge whether a presented character is semantically related to its semantic radical, characters with a large combinability – i.e., having a semantic radical that appears in many characters – are responded to faster (Chen & Weekes, 2004; Hsiao, Shillcock, & Lavidor, in press). In aphasia, Law, Wong, et al. (2005), Law, Yeung, et al. (2005) showed that semantic radicals also play a role in written production. In writing tasks, their dysgraphic patient produced semantic radical substitutions that were more closely related to the target character than would be expected by chance. Our results demonstrate that semantic radical opacity is highly correlated with character imageability. Therefore, in order to examine the *independent* effect of semantic radicals, items must be controlled for these confounding variables.

Second, the effect of phonological consistency on WJX's oral reading, particularly for characters that he could not comprehend at all, adds weight to the claim that the phonetic radical has an impact on character reading. For example, there are patients reported who make regularization errors by pronouncing the sound of a phonetic radical (Weekes & Chen, 1999). Also in chronometric studies, characters with consistent phonetic radicals are named faster (Fang, Horng, & Tzeng, 1986; Hue, 1992; Peng et al., 1994). Our results are important because, instead of simply adapting the pronunciation of any phonetic radical, WJX's reading performance was sensitive to the reliability of the phonetic radical, i.e., whether characters with the same phonetic radical are always pronounced the same. Only when the phonetic radical was "consistent", could he read better. Take a regular but inconsistent character, 清 (clear, /qing1/), for example. It has a phonetic radical 青 (turquoise, /qing1/) that appears in other characters with different pronunciations, e.g., 猜 (guess, /cai1/). And irregular characters, 税 (tax, /shui4/) whose phonetic radical 兑 (exchange, /dui4/) also appears in other characters 说 (talk, /shuo1/). There was no observable difference in WJX's reading performance with these items. WJX also produced more "analogous" errors (e.g., read 税, tax, /shui4/ as 说, say, /shu1/) than LARC errors (e.g., read 税, /shui4/ as 兑 /dui4/). The implications of these observations on the nature of the nonlexical processing in reading Chinese will be further discussed below.

The summation hypothesis (Hillis & Caramazza, 1991, 1995), which assumes the integration of a semantic route and a nonlexical route, can explain WJX's performance perfectly. The hypothesis goes as follows. Input from the semantic system normally contributes to the process of oral reading in Chinese. There is also a nonlexical system that bypasses the semantic system. The two systems contribute to the final product for oral reading in an interactive manner. This is shown by the interaction between the semantic system and the nonlexical process. Take a regular-inconsistent character "蚊" (mosquito, /wen2/), for example, its phonetic radical, "文", means literature and is pronounced as /wen2/. This same phonetic radical also appears in other characters having different sounds including "坟" (tomb, /fen2/). The definition WJX gave for "蚊" (mosquito) is "家庭中有一种，就是，有一种，这种字，这种就是蚊子，有一种天上飞的蚊子" (The home has one kind, one kind, this kind of character, mosquito, one kind of mosquito that flies in the sky). The meaningful semantic properties presented are "home has it" and "fly in the sky". Based on these properties, the lexical representation for "苍蝇" (fly, /cang1 ying0/), "蜜蜂"(bee, /mi4 feng1/), "蜻蜓"(dragonfly, /qing1 ting2/), "蝴蝶"(butterfly, /hu2 die2/), may all be activated. WJX lacked precise semantic information to distinguish among these. However, the phonetic radical "文" in the target leads to the activation of the possible sounds associated with it —/wen2/ and /fen2/. The activation from the partial semantic properties and the phonetic radical converge onto the correct response /wen2/. By the same token, an irregular word can also be read correctly by the combination of partial semantic information and nonlexical activation from the phonetic radicals. For example, one irregular character is "途" (path, /tu2/) with a phonetic radical "余" (residue, /yu2/). This phonetic radical appears in characters "徐" (slowly, /xu2/), "涂" (to smear, /tu2/), "除" (to remove, /chu2/). WJX defined the target "途" (path, /tu2/) as "走道，这儿不好走" (walk, it is hard to walk here). The words qualifying the semantic property that relates to "walk" include 道 (street, /dao4/), 路 (road, /lu4/), 走

(walk, /zou3/), 跑 (run, /pao3/), 行 (proceed, /xing2/). Nonlexical phonological activation from the phonetic radical includes /tu2/, /xu2/ and /chu2/. Again partial semantic information and nonlexical activation converge onto the response /tu2/. A summation account based on a dual route framework assuming semantic and nonlexical systems that interact at the level of phonological output, explains our case adequately.

The case of LJG (Weekes & Chen, 1999) who showed a similar pattern to WJX, can also be viewed as evidence supporting this framework. LJG had impairment to the semantic system and made semantic errors in all comprehension and production tasks but he could read many items that he failed on confrontation naming. His reading was called surface dyslexic because he produced LARC errors when reading irregular characters. Furthermore, the effect of regularity was only present for characters with abstract meanings. Characters with concrete meanings were read well regardless of the phonetic regularity of the item. If we assume that LJG's semantic deficits impact on abstract concepts more than concrete concepts, which is possible (see Crutch & Warrington, 2005 for a review), then his oral reading is consistent with the summation hypothesis. The fact that LARC errors instead of "analogous" errors were observed could either be because these two categorization criteria were confound in the items tested or because LJG and WJX preserved different types of nonlexical procedures.

We will now consider in greater detail the substance of nonlexical procedures. We have so far used the term "nonlexical" for mechanisms that resulted in phonetic radical consistency effect in reading, assuming that it reflects how knowledge of a character component contributes to reading of the whole character. However, as we have acknowledged in the Introduction, it is unclear whether this nonlexical knowledge in Chinese equates to a rule based system that is assumed in some models of reading in alphabetic languages. First, although there is no GPC on the segmental level ("ea" ->/E/) for Chinese characters, it is theoretically possible to isolate a reading mechanism based on the rules of (nonlexical) subcomponent orthography-phonology-correspondence. The following specific proposal could be entertained. In Chinese, the pre-lexical orthographic properties that are involved in visual character identification include strokes, logographemes (see Han, Zhang, Shu, & Bi, 2007; Law & Leung, 2000) and radicals just like letters shapes and graphemes in alphabetic languages. Among these units, certain subcomponents (radicals), e.g., "青" correspond to the sounds including /qing1/, /qing2/, /qing3/, /cai1/, /jing1/ and /jing4/, and possibly rhyming units /ing1/. Such correspondences might be acquired during character learning (Wu et al., 1999). Upon seeing a composite character such as 请 (please, /qing3/), the radical "青" involved in the character identification process activates all possible sounds corresponding to 青 without contacting any stored lexical representation of 请. Characters containing a "consistent" phonetic radical only generate one sound through this procedure, and ones with "inconsistent" phonetic radicals generate multiple sounds and therefore take longer to read and are more prone to reading errors. Note that these "orthographic subcomponents" radicals and "sounds" are peripheral properties of a character and are not the *lexical* representations in the orthographic lexicon and the phonological lexicon. Lexical representations are abstract entities that link different kinds of information (semantic, orthographic, phonological, grammatical, etc.) that are not specified with any orthographic or phonological contents. Furthermore, there are cases where the phonetic radicals do not correspond to any independent lexical items (e.g., the radical of 译, translate, /yi4/) and therefore they cannot operate through the radicals' lexical representations. It should be emphasized that the nonlexical rules we propose here differ from the GPC rules in English in several aspects. Take the DRC model (Coltheart et al., 1993, 2001) as a specific example. The GPC rules in that model operate on phoneme units and in a one-to-one fashion using the most commonly occurred correspondences. In our theory, in order to account for the consistency effect and the absence of a regularity effect, we have to assume a "rule" system that is rather ambiguous with mostly one-to-many mappings. If one were to assume such a nonlexical route, a third direct lexical route linking the orthographic and phonological *lexical* representations may not be necessary in Chinese, as opposed to what is assumed in all current neuropsychological and computational models of Chinese character reading (e.g., Perfetti, Liu, & Tan, 2005).

Alternatively, the phonetic radical consistency effect might be accounted for fully by lexical processing. It is generally assumed that during reading, a visual word activates all words in the orthographic lexicon that look similar, and activation spreads to their corresponding phonological lexical representations and hence their sound either through the semantic system and/or a direct lexical route (Coltheart et al., 2001; McClelland & Rumelhart, 1981). Sharing the same radical would result in higher orthographic similarity. Only when a character has consistent phonetic radicals, do all the activated orthographic neighbors point to the same phonological output. A consistency effect and a "reading by analogy" phenomenon might therefore arise either because of competition among activated phonology for inconsistent characters, or stronger convergent activation from multiple items for consistent characters, or both. In other words, the phonetic radical effect might actually be an orthographic similarity effect and nonlexical connections may not be necessary at all. Such a proposal requires the premise that the system is cascading. That is, all lexical nodes activated in the orthographic lexicon contact their counterparts in the phonological lexicon, as opposed to what would happen in a discrete network where only a selected lexical node undergoes subsequent processing. This is indeed how Coltheart et al. (2001) explains the (neighborhood) consistency effect observed in English within their dual-route model (also see Taft & Zhu, 1997). With such a proposal about the mechanism underlying the phonetic consistency effect, the summation hypothesis would explain WJX's reading pattern by assuming the integration of activations from the semantic route and the direct lexical route (the dashed line in Fig. 1). This idea seems to be partly shared with a model developed for explaining impaired reading of Chinese characters in Weekes et al. (1997). However, unlike the position we hold here that the lexical representation are orthographically and phonologically underspecified abstract entities, Weekes et al. assumed that there are representations of strokes, radicals and characters at the level of the orthographic input lexicon, and syllables, rimes and tones at the level of the phonological output lexicon (see also Luo & Weekes, 2004). Although, they did not specify the status of the mechanisms that link representations in the nonsemantic route(s), the fact that all these modality-specific properties (e.g., strokes, tones) were assumed to be part of the lexicons, means that any processes linking the orthographic and phonological lexicons would be considered lexical.

We have laid out two accounts that can explain the effect of phonetic radical consistency on reading Chinese characters. One is by assuming a set of radical-sound correspondence rules (nonlexical), and the other by assuming lexical connections with cascading activation starting from orthographic cohorts. It is not obvious which should be preferred based on theoretical grounds. One may argue that assuming nonlexical rules to explain the radical consistency effect would be a more universal account for reading. On the other hand, a language-specific rule system with such ambiguity (mostly one-to-many mappings) seems rather post-hoc. Our results and the empirical findings in the literature on the phonetic-radical consistency effect in Chinese character reading cannot distinguish these two accounts either. This argument parallels to some degree the classical debate between the dual-route model and the connectionist theory and we believe that further computational work would be necessary to yield conclusive results. The critical point here, however, is that only one, and not both, of these two kinds of assumptions would be necessary according to the summation hypothesis to account for our case.

One further point to make about the potential evidence that could distinguish between the rule-based mechanism and the lexical account would be the observation of a Chinese speaking patient who could read existing phonetic composite characters, but was unable to read either the phonetic radicals or pseudo-characters that contain these phonetic radicals. This would suggest that a *nonlexical* mechanism is normally available for reading phonetic radicals and can be selectively impaired with brain damage, similar to the abolition of GPCs observed in phonological dyslexia in alphabetic scripts (Funnell, 1983). Note that a report of this type would be of interest independent of the question of whether there is a rule-based mechanism underlying reading in Chinese (Weekes, Yin, Su, & Chen, 2006).

To conclude, the reading performance of our patient WJX demonstrates that oral reading of Chinese characters involves the semantic system as well as a nonsemantic route, which is constrained by the consistency of phonetic radicals. Of most importance, there is an interaction such that information activated from these two routes can be integrated to produce an oral reading response. This pattern is very similar to the interactions between semantic and nonlexical knowledge reported in the oral reading performance of patients who read alphabetic languages and supports the summation hypothesis.

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Appendix A. Stimuli used in Experiment 2

Labels: (1) Target character; (2) the phonetic transcript of the target character; (3) the meaning of the character; (4) the phonetic transcript of the phonetic radical; (5) the meaning of the semantic radical

1	2	3	4	5	1	2	3	4	5
Phonetic radical: regular and consistent; semantic radical: transparent									
轮	*/lun2/*	Wheel	*/lun2/*	Vehicle	钩	*/gou1/*	Hook	*/gou1/*	Metal
浓	*/nong2/*	Dense	*/nong2/*	Water	拧	*/ning3/*	Screw	*/ning3/*	Hand
境	*/jing4/*	Area	*/jing4/*	Soil	萝	*/luo2/*	Radish	*/luo2/*	Grass
碗	*/wan3/*	Bowl	*/wan3/*	Rock	掏	*/tao1/*	Draw	*/tao1/*	Hand
钢	*/gang1/*	Steel	*/gang1/*	Metal	烤	*/kao3/*	Bake	*/kao3/*	Fire
蚜	*/ya2/*	Aphid	*/ya2/*	Insect	湖	*/hu2/*	Lake	*/hu2/*	Water
杖	*/zhang4/*	Crutch	*/zhang4/*	Wood	彩	*/cai3/*	Color	*/cai3/*	Many
议	*/yi4/*	Discuss	*/yi4/*	Speech	慌	*/huang1/*	Anxious	*/huang1/*	Heart
疯	*/feng1/*	Crazy	*/feng1/*	Illness	熄	*/xi1/*	Extinguish	*/xi1/*	Fire
喂	*/wei4/*	Feed	*/wei4/*	Mouth	芽	*/ya2/*	Bud	*/ya2/*	Grass
躲	*/xiong1/*	Chest	*/xiong1/*	Flesh	愣	*/leng4/*	Distracted	*/leng4/*	Heart
唤	*/duo3/*	Avoid	*/duo3/*	Body	莲	*/lian2/*	Lotus	*/lian2/*	Grass
唤	*/huan4/*	Call	*/huan4/*	Mouth	柄	*/bing3/*	Handle	*/bing3/*	Wood
栏	*/lan2/*	Fence	*/lan2/*	Wood	刚	*/gang1/*	Exactly	*/gang1/*	Falchion
枫	*/feng1/*	Maple	*/feng1/*	Wood	姨	*/yi2/*	Aunt	*/yi2/*	Woman
Phonetic radical: regular and consistent; semantic radical: opaque									
帮	*/bang1/*	Help	*/bang1/*	Towel	值	*/zhi2/*	Value	*/zhi2/*	Human
纲	*/gang1/*	Outline	*/gang1/*	Thread	俱	*/ju4/*	All	*/ju4/*	Human
试	*/shi4/*	Examination	*/shi4/*	Speech	俯	*/fu3/*	Bow	*/fu3/*	Human

Appendix A (*Continued*)

1	2	3	4	5	1	2	3	4	5
捷	/jie2/	Nimble	/jie2/	Hand	阀	/fa2/	Valve	/fa2/	Gateway
绅	/shen1/	Caballero	/shen1/	Thread	伸	/shen1/	Extend	/shen1/	Human
键	/jian4/	Key	/jian4/	Metal	伦	/lun2/	Logic	/lun2/	Human
距	/ju4/	Distance	/ju4/	Foot	腐	/fu3/	Corrupt	/fu3/	Flesh
密	/mi4/	Close	/mi4/	Hill	滚	/gun3/	Roll	/gun3/	Water
伟	/wei3/	Great	/wei3/	Human	仗	/zhang4/	Battle	/zhang4/	Human
慢	/man4/	Slow	/man4/	Heart	奖	/jiang3/	Award	/jiang3/	Big
Phonetic radical: regular and inconsistent; semantic radical: transparent									
蚊	/wen2/	Mosquito	/wen2/	Insect	泥	/ni2/	Mud	/ni2/	Water
碑	/bei1/	Tombstone	/bei1/	Rock	沾	/zhan1/	Moisten	/zhan1/	Water
材	/cai2/	Material	/cai2/	Wood	葱	/cong1/	Shallot	/cong1/	Grass
拌	/ban4/	Mix	/ban4/	Hand	揍	/zou4/	Beat	/zou4/	Hand
奶	/nai3/	Grandma	/nai3/	Woman	返	/fan3/	Return	/fan3/	Walk
舱	/cang1/	Cabin	/cang1/	Boat	洋	/yang2/	Foreign	/yang2/	Water
盯	/ding1/	Stare	/ding1/	Eye	抬	/tai2/	Carry	/tai2/	Hand
秧	/yang1/	Seedling	/yang1/	Grain	苞	/bao1/	Bud	/bao1/	Grass
护	/hu4/	Protect	/hu4/	Hand	渔	/yu2/	Fishing	/yu2/	Water
惊	/jing1/	Surprise	/jing1/	Heart	躬	/gong1/	Bow	/gong1/	Body
捶	/chui2/	Beat	/chui2/	Hand	枝	/zhi1/	Branch	/zhi1/	Wood
评	/ping2/	Appraise	/ping2/	Speech	绒	/rong2/	Floss	/rong2/	Thread
译	/yi4/	Interpret	/yi4/	Speech	粮	/liang2/	Grain	/liang2/	Rice
瞄	/miao2/	Aim	/miao2/	Eye	叮	/ding1/	Sting	/ding1/	Mouth
爸	/ba4/	Dad	/ba4/	Father	惜	/xi1/	Cherish	/xi1/	Heart
Phonetic radical: regular and inconsistent; semantic radical: opaque									
窃	/qie4/	Steal	/qie4/	Aperture	褐	/he4/	Brown	/he4/	Clothes
逗	/dou4/	Amuse	/dou4/	Walk	供	/gong4/	Provide	/gong4/	Human
邮	/you2/	Mail	/you2/	Hill	犹	/you2/	Alike	/you2/	Animal
陷	/xian4/	Sink	/xian4/	Hill	寞	/mo4/	Lonely	/mo4/	Cover
漠	/mo4/	Desert	/mo4/	Water	型	/xing2/	Mould	/xing2/	Soil
径	/jing4/	Pathway	/jing4/	Human	低	/di3/	Low	/di3/	Human
球	/qiu2/	Ball	/qiu2/	Jade	稀	/xi1/	Rare	/xi1/	grain
依	/yi1/	Dependent	/yi1/	Human	丛	/cong2/	Clump	/cong2/	One
消	/xiao1/	Disappear	/xiao1/	Water	苍	/cang1/	Grey	/cang1/	Grass
郊	/jiao1/	Outskirt	/jiao1/	Hill	颊	/jia2/	Chap	/jia2/	Leaf
Phonetic radical: irregular and inconsistent; semantic radical: transparent									
狐	/hu2/	Fox	/gua1/	Animal	瞎	/xia1/	Blind	/hai4/	Eye
扭	/niu3/	Gnarl	/chou3/	Hand	污	/wu1/	Filth	/kui1/	Water
悦	/yue4/	Happy	/dui4/	Heart	扯	/che3/	Pull	/zhi3/	Hand
播	/bo1/	Broadcast	/fan1/	Hand	语	/yu3/	Language	/wu3/	Speech
怕	/pa4/	Afraid	/bai2/	Heart	捉	/zhuo1/	Capture	/zu2/	Hand
挥	/hui1/	Wave	/jun1/	Hand	蛙	/wa1/	Frog	/gui1/	Insect
盼	/pan4/	Expect	/fen1/	Eye	途	/tu2/	Road	/yu2/	Walk
疼	/teng2/	Pain	/dong1/	Illness	堵	/du3/	Stifled	/zhe3/	Soil
江	/jiang1/	River	/gong1/	Water	硬	/ying4/	Forcedly	/geng1/	Rock
银	/yin2/	Silver	/gen4/	Metal	辉	/hui1/	Brightness	/jun1/	Light
酒	/jiu3/	Alcohol	/you3/	Water	晒	/shai4/	Bask	/xi1/	Sun
池	/chi2/	Pool	/ye3/	Water	棒	/bang4/	Stick	/feng4/	Wood
训	/xun4/	Instruct	/chuan1/	Speech	碎	/shui4/	Broken	/zu2/	Rock
波	/bo1/	Wave	/pi2/	Water	喊	/han3/	Shout	/xian2/	Mouth
棵	/ke4/	Chin	/guo3/	Wood	泼	/po1/	Splash	/fa1/	Water
Phonetic radical: irregular and inconsistent; semantic radical: opaque									
限	/xian4/	Bounds	/gen4/	Hill	租	/jie4/	Borrow	/xi1/	Human
络	/luo4/	Meshwork	/ge4/	Thread	借	/xing4/	Surname	/sheng1/	Woman
移	/yi2/	Change	/duo1/	Grain	姓	/ji4/	Achievement	/ze2/	Thread
猜	/cai1/	Guess	/qing1/	Animal	绩	/tie1/	Adhibit	/zhan4/	Shellfish
秤	/cheng4/	Scale	/ping2/	Grain	贴	/yue4/	Experience	/dui4/	Gateway
始	/shi3/	Begin	/tai2/	Woman	阅	/pang2/	Face	/long2/	Extensive
软	/ruan3/	Soft	/qian4/	Vehicle	庞	/shu3/	Summer	/zhe3/	Sun
脱	/tuo1/	Doff	/dui4/	Flesh	暑	/xie2/	Inclined	/yu2/	Fight
软	/diao4/	Drop	/zhuo2/	Hand	斜	/jian1/	Difficult	/gen4/	Again
掉	/zu1/	Rent	/qie3/	Grain	艰	/can2/	Incomplete	/jian1/	Evil

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