Threshold-Style Processing of Chinese Characters for Adult Second Language Learners

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Abstract

To assess the learning of word form and meaning in an unfamiliar writing system, we carried out primed naming experiments with learners of Chinese at the end of their first and second terms of Chinese class at an American university. The subjects were required to name a target Chinese character after a prime character was presented for 500 ms. There were three priming conditions defined by the relation between prime and target: orthographically similar, homophonic and semantically related. At the end of the first term, there was a significant facilitation on naming speed in the orthographic condition, but not in the homophonic or semantic conditions. However, at the end of the second term, orthographical facilitation disappeared. Instead, naming speed was facilitated by semantically related primes. A threshold style framework was proposed to illustrate the processing of Chinese orthography, phonology and semantics for second language learners.

Keywords: Chinese; naming; second language; priming; model

Introduction

Learning to read a second language in a new writing system presents complex challenges. An English speaker learning to read Chinese must acquire knowledge of the visual forms of characters, knowledge of the mappings of these forms to meaning and pronunciation, and knowledge of the language itself. Research with college learners suggests that the first of these—learning the visual form of characters—is a fairly rapid acquisition. Students can discriminate novel legal from illegal characters within at least the first four months of classroom learning (Wang, Perfetti, & Liu, 2003). Beyond this learning of form, the question becomes the acquisition of character representations that include orthographic, phonological and semantic constituents that can be activated by the character form. This is the question we address here.

The question must be considered in the context of how Chinese differs from English, and other alphabetic orthographies. Chinese, is considered a logographic or morphosyllabic system (see DeFrancis, 1989; Mattingly, 1992) in which the units of the orthography (characters) correspond to both syllables and morphemes. The typical Chinese character is a square shaped symbol that, with some exceptions, represents one pronunciation and one morpheme. The characters are composed of *radicals*. Some radicals are characters by themselves and some are not. Characters containing only one radical are called simple characters and those containing more than one radical are called compound characters, which can contain 2 to 8 radicals.

An example of simple character is , which is pronounced /ri/4 (PINYIN system: the Chinese national standard alphabetic system which is mainly used to teach children the pronunciation of Chinese characters. The last digit represents one of the four tones in Chinese), and means SUN. An example of compound character is (/qing/1, GREEN), which is composed of one top and one bottom radical. When putting to the left of , we have the character which is pronounced as /qing/2 and means SUNSHINE. In above examples, the meanings of and are highly related and the pronunciations of and have the same onset and rhyme. However, the relationships are not always consistent and can be misleading (Feldman & Siok, 1999a, 1999b).

The radicals can be further decomposed into strokes. There are five classes of strokes (, , , , and). A spatial combination of strokes in specified ways makes a radical, and a specific combination of radicals makes a character. There are two standard character printing form sets used in contemporary Chinese: simplified and traditional. In the two sets, some character forms are identical, but the other forms in the traditional set have more radicals and strokes than the same character in the simplified set. Simplified set was used in the present study. The number of strokes in all simplified Chinese characters ranges from 1 to 30.

Although the visual complexity of Chinese writing, compared with linear alphabetic writing, is a striking feature, a deeper difference is that it allows form mappings that go directly from orthographic form to meaning. Although some evidence suggests that reading Chinese works by a direct route to meaning (Hoosain, 1991), the research now clearly supports the involvement of phonology in reading for meaning (see a review by Tan & Perfetti, 1998). Phonological effects in simple orthographic tasks that do not require meaning (Shen & Forster, 1999; Zhou & Marslen-Wilson, 1996) are not as often found as in semantic relation judgment and meaning categorization tasks (Chua, 1999; Perfetti & Zhang, 1995; Xu, Pollatsek, & Potter, 1999).

Although the access of phonology may be universal, the details of its use must depend on the writing system. A major difference between Chinese and English on orthographic processing was reported by Perfetti and Tan (1998), who used a primed naming paradigm with Chinese materials. They found a graphical facilitation effect at 43 ms prime-target asynchrony (SOA), but facilitation turned into inhibition when the SOA was longer (57 ms). More interestingly, the onset of graphical inhibition was accompanied by a phonological facilitation, with a semantic facilitation at 85 ms. No semantic or phonological facilitation was observed at the short SOA (43 ms). In English, by contrast, orthographic and phonological priming develop together. Using a primed perceptual identification paradigm, Perfetti & Bell (1991) found that orthographic facilitation slightly preceded phonological facilitation at 35 ms and the two increased together through 65 ms. Using lexical decision with French stimuli, Ferrand & Grainger (1994) also found orthographic priming to be slightly earlier than phonological priming (14 vs. 29 ms), and both effects kept rising until 67 ms when orthographic priming reached its ceiling relative to unrelated prime. This contrast between the coupling of orthography and phonology in English and their de-coupling in Chinese suggests a difference in how phonology is activated in the two systems. In an alphabetic system, the word level units do not wait for a complete specification of all letter units prior to activating word level phonology—hence, *cascade* processing style (Berent & Perfetti, 1995; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seidenberg & McClelland, 1989). But in Chinese, the word-level phonology is not activated prior to a full orthographic specification of the character—hence, *threshold* processing style (Perfetti, Liu, & Tan, 2002, 2005).

This threshold assumption of Chinese orthography is very important in the computational lexical constituency model (Perfetti et al., 2005). In the model, a successful lexical access needs the activation of three constituents: orthography, phonology and semantics. Each constituent has a corresponding level consisted of many processing units. Each orthographic unit represents one character in the mental lexicon. A phonological unit represents an onset, a rhyme or a tone. A semantic unit represents the meaning of one character. The process begins by the activation of one or multiple orthographic units (characters) that corresponds to the input from radical level units. Only when an orthographic unit reaches its activation threshold level does activation feed forward to phonological and semantic units.

Because the Lexical Constituency model concerns only skilled reading, it is silent on how the learning of constituents proceeds. Certainly, a learner comes to acquire knowledge about the orthographic form of characters in connection with their meanings and pronunciations. However, the completeness of constituent learning and the accessibility of the constituents can vary over learning. It is possible that priming experiments can provide some window on the degree of orthographic, phonological and semantic learning. In fact, a primed naming study has been done with children (native speakers of Chinese) who were learning to read Chinese. Wu, Zhou and Shu (1999) found differential effects: Phonological effects in primed naming for third and sixth grade children, but semantic effects for sixth grade children only.

With adults learning Chinese as a foreign language, there is little reason to expect the pattern of phonological facilitation before semantic facilitation, as was observed in the studies of both adult and children native speakers. Native speakers learn the orthographic form of Chinese characters after they have already known most of the phonological expressions and their meanings. Second language learners do not have this language foundation, but rather acquire the language along with the writing system. The unfamiliarity of Chinese characters and their visual-spatial differences from left-to-right linear alphabets may place a premium on learning orthographic form. Thus, the threshold assumption of Chinese character reading would apply to learners as well to skilled readers. The character orthographic form must be acquired as a functional unit and connections to pronunciation and meaning would develop as the character form is acquired. It is likely also that the demands of meaning translation in second language learning puts a premium on the semantic connections of the character over the pronunciation connections. If these observations are correct, we expect that adult learners, like Chinese skilled readers, will read learned characters in threshold style, showing orthographic facilitation effect when the processing time of prime is less than what needed to reach its threshold. We would also expect semantic primes, which pre-activate characters with similar meaning, to be effective earlier in learning than phonological primes.

To examine these issues, we turned to primed naming task which has successfully examined the character processing speed of native Chinese speakers (Perfetti & Tan, 1998). By studying priming effect as a function of prime type over two time points in learning, we can observe changes in the accessibility of orthographic, phonological and semantic constituents of characters over learning. For example, the rapid acquisition of the orthographic form of characters observed in our previous study suggested an implicit perceptual learning that might pay off in acquisition of specific characters (Wang et al., 2003). If so, we would expect that relatively early in learning, preceding a target character with an orthographically similar prime should produce facilitation. Because the orthographic processing follows the threshold style processing, phonological and meaning processes are delayed until the moment of orthographic recognition (at threshold). Thus, priming from characters related in meaning and pronunciation, may have less effect early in learning relative to orthographic primes. With additional learning, a brief exposure of a character can become sufficient for its recognition, as the character comes to reach its orthographic threshold more quickly. Thus, any advantage of a preceding orthographic prime is eliminated due to the competition between the prime and target. For native speakers, long enough SOA and orthographic prime would even produce inhibition, as found by Perfetti & Tan (1998). Learning would also lead to stronger connections from orthography to meaning and pronunciation, allowing both semantic and phonological primes to become facilitative.

In considering the effects of prime types, the prime-target SOA is critical (Perfetti & Tan, 1998), and the very short SOAs that produce orthographic effects in skilled native Chinese readers would not necessarily produce interpretable priming effects in learners. Furthermore, because the number of items in the curriculum were very limited, only one SOA can be used in the present experiment. In a naming experiment that used the same group of subjects (Wang et al., 2003), the naming reaction times ranged from 1381 ms for high frequency simple character to 2134 ms for low frequency compound characters. Compared with the 700 to 800 ms naming reaction time of native speakers (Hue, 1992; Perfetti & Zhang, 1991), the learners were nearly one second slower. Because a longer SOA allows more processing time for the prime and possible facilitation effects, we used a 500 ms SOA, much longer than the four SOAs used by Perfetti and Tan (1998).

We present the study below as two experiments, one at the end of the first term and one at the end of the second term. The results for both terms are reported in the result section after Experiment 2.

Experiment 1

Method

Subjects

Twenty-six undergraduate students enrolled in an elementary Chinese class at the University of Pittsburgh participated in the experiment at the end of their first term (12-15 weeks learning, 12 hours a week). The subject ages ranged from 19 to 28. Twenty three subjects had English as their native language and the other three had alphabetic writing system languages (Spanish, Thai and Vietnamese). None of the subjects had been formally exposed to any Chinese environment before taking the class. All subjects had normal or corrected to normal vision. They were paid for their participation.

The above subjects also participated the lexical decision and naming experiments by Wang et al. (2003). The above two experiments were carried out before the current experiment. However, because all 261 items from the curriculum were used in the decision and naming experiments, if there is any repetition effect, it should be equal across the items used in the present experiment.

Materials and Design

The Chinese-corpus based character frequency (Li & Liu, 1988) does not apply to these subjects very well, although they tend to start from more commonly used characters as Chinese native speakers do. Instead, we created a computerized curriculum file based on the text book (Barnes, unpublished manuscript) and tallied the number of appearances for each character by a computer program. Totally there were 261 characters in the first term curriculum occurring from 3 to 287 times. Any character that appeared fewer than three times did not enter further material selection. The teaching method used at University of Pittsburgh discouraged any additional study of Chinese beyond the textbook, which enabled our curriculum-based frequency to serve as a corpus-based frequency and provide a very good estimate of the character familiarity level. Furthermore, the subjective familiarity assessed by the same group of subjects was highly correlated with the curriculum-based frequency (Wang et al., 2003). All the subjects were enrolled in reading and writing sections of the course, which required them to recognize and write individual characters. So the subjects were learning not only multi-character words, but also the pronunciation and meaning of individual characters. Thus, curriculum-based frequency provided a good measure of character familiarity, and that was what we used to select materials.

There were three groups of Chinese prime-target character pairs: orthographically similar, homophonic, and semantically related. There were 40 pairs of characters in each group with 20 related pairs and 20 unrelated control pairs. The related and control pairs in each group shared the same 20 target characters (see Appendix for all related primes, control primes and their common targets). In an orthographically similar pair, the prime either shared a radical with the target (such as (/hai/2, STILL) and (/zhe/4, THIS), total 15 pairs), or had similar strokes and structures (such as (/ren/2, PERSON) and (/ba/1, EIGHT), total 5 pairs), with no phonological or semantic relation. Homophone primes had the same onset and rhyme as the target but had no orthographical similarity or semantic relation (such as (/gong/1, WORK) and (/gong/1, PUBLIC)). Due to the limited vocabulary of the subjects, two types of orthographical similarity (share radical or similar stroke) were used in orthographic condition, and tones were not always the same (7 same and 13 different pairs) in the homophonic condition. Semantically related primes were either in the same category of the target (such as (/xiong/1, ELDER BROTHER) and (/di/4, YOUNGER BROTHER), 10 pairs), or were often appeared together as a compound word in the curriculum (such as (/guo/2, COUNTRY) and (/jia/1, HOME), 10 pairs). There was no orthographical or phonological relation in the semantic pairs.

Unrelated character primes were used as the control baseline for priming effects. Because of the limited vocabulary, it was not possible to use both unrelated character control and noncharacter controls. However, Perfetti and Tan (1998) found no significant difference between these two control conditions. Restricted to a single control baseline, we chose the unrelated character, because it has all three lexical constituents and matches the character prime better. For example, if a neutral noncharacter control with no pronunciation and meaning was used for the orthographic priming condition, any inhibition effect from the prime can be due either to the orthographic similarity or to the lack of competition at phonological and/or semantic level in the neutral condition. Even for a facilitation effect, it is still possible that the facilitation is a “general” effect that can be obtained from any character that has sound and meaning.

The unrelated control characters in each group were matched with the prime characters on average curriculum frequencies, radical numbers, and stroke numbers. Average frequencies in the three groups were as follows: orthographic group (related prime=36, control prime=36, target=21), homophonic group (related prime=49, control prime=50, and target=23), semantic group (related prime=40, control prime=38, target=33). The visual similarity of orthographic pairs and semantic relatedness of semantic pairs were evaluated by 10 native

Chinese speakers on a 5 point scale. The mean standardized similarity for orthographically similar pairs was 2.94 (z=.70), and for control pairs was 1.17 (z=-.70). The mean standardized relatedness score for semantic related pairs was 4.16 (z=.88), and for control pairs was 1.26 (z=-.89).

Because the total number of characters needed in the study was 180 and there were only 261 characters in the stimulus pool of the first term learners, it was unavoidable that some target characters were repeatedly used in the experiment, but the repetition was reduced as best as we can. The repetition in graphical targets was 11 characters at 2.1 times each, 13 in homophonic targets at 2.2 times each, and 11 semantic targets at 2.4 times each.

Procedure

Subjects were required to sit 80 cm in front of a 17-inch computer monitor working at 60 Hz in a controlled illuminated room. The stimuli were shown in the center of the screen in black color on white background and the size was 1.5 cm wide and 1.5 cm high. A trial began with a 500ms fixation followed by a 500ms presentation of the first character (prime). The prime was replaced by the second character (target) with no interval between them, the latter stayed on the screen until the subject pronounced it aloud. Font size was the same for prime and target. However, because the written position and style of strokes and radicals vary from character to character, there was very little physical overlapping between prime and target even in the orthographically similar condition. The naming response was detected by a voice key and the time from the onset of the target to naming response was recorded. Accuracy of naming was recorded by a native Chinese speaker right away. A practice with 10 trials was given before the experiment. Because the targets were presented to each subject twice, once in the related condition and once in the control condition, the 120 trials of experiment were pseudo-randomized for each subject to balance the order of stimuli. As a result, half of the targets was first seen in priming condition, and the other half was first seen in the control condition. The experiment lasted about ten minutes with no break.

Experiment 2

We retested the students at the end of their second term (total 27-30 weeks of Chinese learning, 12 hours per week) with the same materials and procedure as Experiment 1. By this second test point, the average curriculum frequency of the characters used in the present study increased from 36 to 68. The average frequency of the related prime and control prime were still matched after this increase (orthographic group: related prime=65, control prime=73, target=42; homophonic group:(related prime=90, control prime=89, and target=43; semantic group: related prime=75, control prime=71, target=66).

Subjects

Eighteen students from the second term Chinese class at University of Pittsburgh participated in the experiment. These students were a subset of the students in Experiment 1 who continued their Chinese learning in the second term.

The materials, design, and procedure were the same as for Experiment 1, with the materials re-randomized.

Experiment 1 and 2 Results

The subject accuracy was calculated by dividing the number of correctly named trials by the total number of trials in each condition for each subject (excluding less than 5% microphone failures). The item accuracy of each item was calculated by dividing the number of subjects who named this item correctly by the total number of subjects. Only the naming reaction times of correct responses were included in the analysis. For each subject, reaction times shorter than 300 ms or more than two standard deviations longer than the subject mean were omitted from further analysis (3.8% in first term and 4.6% in second term).

Mean reaction times and accuracies across all subjects are shown in Table 1, which contains the results from the 26 first term subjects, and the 18 subjects who participated in both terms. The priming effects on reaction time (Figure 1) were calculated by subtracting the related condition from control condition, but priming effects on accuracy (Figure 2) were calculated by subtracting the control from related condition. So, positive reaction time difference represents shortened reaction time and positive accuracy difference represents increased accuracy.

Overall, the accuracies and naming times of the second term (18 subjects) were much higher and faster than those of the first term (26 subjects). In the first term, the priming effects on accuracy were negligible for all three conditions (0.2%, 0.4%, and -1.0%). There was a large orthographic facilitation (61 ms) on naming times, which represented faster naming when the prime and target characters were orthographically similar. However, the homophonic and semantic effects on reaction time were both negative and small (-5 and -11 ms).

In the second term, the priming effects on accuracies were also quite small (-0.7%, -0.7%) except in the homophonic condition (2.5%). For reaction times, the orthographic facilitation disappeared (-7 ms). Instead, there were homophonic (26 ms) and semantic facilitations (66 ms).

To decide whether the observed effects were significant, subject and item ANOVAs were performed on the reaction times and accuracies of both terms.

The 26 first term subjects were analyzed with two within subject factors: condition (graphical, homophonic, vs. semantic) and priming (related vs. control). Greenhouse-Geisser adjustment for violation of variance equality was performed when needed. The ANOVA on accuracies showed a significant condition effect ($F(2,50)=7.605$, $MSE=0.012$, $p=.001$), but neither priming effect ($F(1,25)=.033$, $MSE=0.002$, $p=.857$) nor condition x priming interaction ($F(2,50)=0.639$, $MSE=0.001$, $p=.498$). The ANOVA on reaction times showed a marginally significant condition x priming interaction effect (F(2,50)=2.656, MSE=7654.857, p=.080).

Since we are mainly interested in the priming effects, three planned paired t-tests were carried out between three related conditions and their corresponding controls. It was found that only the 61 ms reaction time facilitation of the orthographic priming was statistically reliable (t(25)=-2.901, p=.008). Item analysis was consistent with the subject analysis with a marginal graphical priming effect on reaction time (t(19)=-1.897, p=.073).

To look for changes across terms, we combined the 18 subjects who were in both the first and second terms and did within subject ANOVAs with three factors: term (first vs. second), condition (graphical, homophonic, vs. semantic) and priming (related vs. control). The item ANOVAs were also carried out using the same 18 subjects data with two repeated factors (term and priming), because items were the same across terms. Since the three types of prime-target pairs used different target set, condition was used as a between item factor.

The subject ANOVA on accuracy showed a marginally significant term effect (F(1,17)=3.377, MSE=0.07, p=.084), a significant condition effect (F(2,34)=7.129, MSE=0.02, epsilon=.612, p=.011), and a marginally significant condition x priming interaction (F(2,34)=2.917, MSE=0.001, epsilon=.628, p=.095). The item ANOVA on accuracy only showed a significant term effect (F(1,17)=35.187, MSE=0.003, p=.000).

Planned pairwise t-tests were performed on accuracy between each related condition and its control condition. The only significant one was a item wise homophonic priming in the second term (t(19)=2.155, p=.044).

The subject ANOVA on reaction time showed a marginally significant term effect (F(1,17)=4.253, MSE=442302.570, p=.055), a marginally significant condition effect (F(2,34)=2.618, MSE=14126.808, p=.088), and a significant term x condition x priming three way interaction (F(2,34)=3.914, MSE=7149.924, p=.030). The item ANOVA on reaction time showed a significant term effect (F(2,1)=43.673, MSE=6604.962, p=.000) and a significant term x priming x type interaction (F(57,2)=3.209, MSE=9879.772, p=.048).

Planned paired t-tests between each related condition and its control showed that in the first term, the 18 subjects who also participated in the second term had a similar pattern as all 26 subjects: a reliable 61 ms graphical facilitation (t(17)=-2.146, p=.047). In the second term, the only significant difference was a 66 ms semantic facilitation effect (t(17)=-2.880, p=.01). The 26 ms phonological facilitation did not reach significant level (t(17)=.701, p=.493). For item reaction times, the first term result was consistent with the subject analysis. It showed a marginally significant orthographic priming effect on reaction time (t(19)=-1.897, p=.073). However, no t-test was significant in the second term, even the semantic priming (t(19)=-1.654, p=.115).

A posthoc ANOVA was performed to compare the priming effects on reaction time in the first term between the two types of orthographically similar pairs: no shared radical vs. shared radical. The mean priming effect of similar stroke and structure pairs which did not share radicals (5 pairs, mean z score of relatedness: 0.78) was 155 ms. The mean priming effect of the shared radical orthographic pairs (15 items, mean z score of relatedness: 0.70) was 33 ms. There was a significant radical x priming interaction ($F(1,25)=5.113$, $MSE=18870.74$, $p=.033$).

A second post-hoc ANOVA for the tone-same and tone different homophonic pairs on accuracies was performed to look for potential tone effect in the second term. Tone was used as a between-item factor and priming was a within-item factor. The mean accuracy priming effect of the tone same pairs (7 pairs) was 1.5% and that of the tone different pairs (13 pairs) was 3.1%. The interaction of tone and priming was not significant ($F(1,18)=.404$, $MSE=0.001$, $p=.533$).

Discussion

The results showed a clear character processing speed difference between two consecutive terms. At the end of the first term, there was an orthographic facilitation on the reaction time of naming when the prime and target looked similar. However, at the end of the second term of learning, the orthographic facilitation disappeared. Instead, there was a meaning facilitation on the naming speed (shorter naming reaction time for the semantically related pairs) and a phonological facilitation on the naming accuracy (higher accuracy for the homophonic pairs, but significant only in the item analysis). A similar graphical facilitation had been found in Chinese native speakers by Perfetti and Tan (1998), but only at the shortest SOA (43 ms) in their study. Shen and Forster (1999) found graphical facilitation at 50 ms SOA. It is interesting to note that Chinese native speakers did not show graphical facilitation at longer SOAs (57, 86, and 115 ms in Perfetti & Tan, 1998), but actually showed inhibition effects in two of them (57 and 86 ms). According to the interactive constituency model (Perfetti, et al., 2002, 2005), the speed of accessing the orthographic threshold decides the SOA in which graphical facilitation can be observed. For our learners, slower graphical analysis speed on Chinese characters allows facilitative orthographic effects to emerge over a longer time window (500 ms).

Due to the limitation of materials and subjects, we did not manipulate the SOA in the present study. The results showed that the fixed 500ms SOA served as a short SOA for the first term learners because the graphical analysis of the prime character could not be completed within 500 ms, which facilitated the processing of the target character. Instead, in the second term, the exact same SOA functioned as a relatively longer one and the meaning of the prime could be accessed within that time. It is clear that there exists a critical time point, which determines whether the graphical preprocessing of the prime can facilitate the target processing. Furthermore, this time point is different for the first term learners, the second term learners and native Chinese speakers. Even though we did not obtain any orthographic inhibition, the vanishing of the orthographic effect at the end of the second term suggested that the threshold style processing also applied to these learners whose native writing systems were alphabetic. Accompanied with the null effect of orthographic pairs were semantic and phonological effects. This overall pattern can be seen to reflect a threshold-sensitive processing by the learners. In the first term, 500 ms functioned as sub-threshold, showing orthographic priming and only orthographic priming. By the second term, 500 ms functioned as above threshold, showing semantic and (less reliable) homophonic priming without orthographic priming. It is this pattern of disassociation of orthography from other constituent effects that we take as the signature of a threshold-based lexical system.

The reasons that Chinese is a threshold system arise from the essential properties of the character system, specifically the lack of sub-syllabic structure within the character. There is no part of the character that corresponds to a grapheme-phoneme mapping that is the essence of alphabetic writings. (It is a rather different matter that characters have constituent radicals that can function in reading. For further discussion, see Perfetti et al, 2005.) Thus the orthographic character unit functions as an on-off gate to lexical processing, with no incremental buildup of grapheme-phoneme connections. Why learners' developing lexical systems (as well as the developed lexical system of skilled readers) should function in this threshold-style is because learners acquire characters as the unit of processing. They learn quickly that there is nothing in the character corresponding to the letter-sound connections they experience in the alphabetic systems of their native language. Rapid perceptual learning (Wang et al., 2003) gives them a sense of the visual form of characters and practice with specific characters brings characters, more or less one-at a time, into a functional lexicon. The connections between each character and its pronunciation and meaning are learned with the character, but they may not reach the strength necessary to automatically function on character recognition.

Contradictory to Chinese reading, it has been found that in the second language learning of alphabetic writings systems (French or Dutch), phonology has been as fast as orthography, which suggested a pre-lexical activation of phonological codes for the second language words (Brysbaert *et al.*, 1999; Van Wijnendaele & Brysbaert, 2002). So the separation of orthography and phonology by orthographic threshold was only found in non-alphabetic word recognition.

A processing framework for Chinese as Second Language (CSL) learners

To illustrate these proposals about the course of learning, we draw on a model of skilled Chinese reading developed by Perfetti et al (2002, 2005), which simulates character naming using the threshold assumption. A learner adaptation of this model (the Lexical Constituency Model) is similar in structure and processing assumptions to the native reader version. Because we do not set parameters nor report a simulation, we consider this a framework for a learner model. The learner framework differs from the model for skilled reading in two major ways: a much smaller vocabulary and slightly stronger connection weights from orthography to meaning than orthography to phonology. The second assumption reflects the slightly stronger semantic priming effect in the second term in our data; however, with learning directed more at pronunciations than meaning, weight differences would be reversed. Unlike the critical threshold assumption, the connection weights can be considered empirically determined parameters settings.

In the absence of an implementation of a model, we use the framework, as illustrated in Figure 3, as a way to see a coarse-grain activation function for a learner. A visual input begins the process of character recognition, sending stroke and position information to the orthographic level. Each unit in the orthographic level corresponds to one learned character. Each input combination of strokes can send not only a full activation to the corresponding character unit in the orthographic level, but also partial activation to all the character units that are orthographically similar. After the threshold of any orthographic unit has been reached, it sends inhibition to all other orthographic units and activation to phonological and semantic levels. An important feature of the orthographic level is that the number of units increases continuously with the number of characters learned.

The phonological level is a distributed representation level which contains 63 units according to the Chinese national standard PINYIN system: 23 onsets (including a null onset), 34 vowels and 5 tones (including a neutral tone). The combinations of above onsets, vowels and tones are sufficient to represent all syllables of Mandarin Chinese. All learners learned this phonological knowledge in the first two weeks of their curriculum. As a result, all phonological units were fully developed before the end of the first term. Because this level is a distributed representation, there are no within-level linkages, in contrast to the orthography and semantic levels.

Character meaning is a localized representation, each corresponding to a unique meaning of a single character which has been learned (represented by English translation in the present model). The semantic level currently does not contain representation of sub-lexical semantic features. Semantic relations are reflected by between-character connections. There are bi-directional connections between the corresponding phonological and semantic units.

In a naming task, the visual input gradually activates a group of orthographic units including the presented character and other orthographically similar characters. The orthographic unit of the presented character receives most of the activation, if the subject does identify the character correctly. As a result, that unit reaches the threshold before other orthographic units and starts to send inhibition to other units which make the correct character unit a “winner”. Then the “winner” unit activates its corresponding phonological and semantic units. Because the semantic units have internal connections between the semantically related characters, a cohort of semantically related characters are activated and start to activate their phonology. Because the onset, rhyme and tone units for the presenting character receive most of the activation from orthographic and semantic levels, they reach the threshold before other phonological units and the subject does the naming correctly.

When the task is a primed naming task, there is a short exposure of a prime character before the target character. The priming effect (both facilitation and inhibition) is a result of the pre-activation of certain units in the model. For orthographically similar priming, the processing time needed for reaching the orthographic threshold is crucial for observing priming effect. At the end of the first term, the orthographic threshold of the prime could not be reached within the 500 ms SOA. Because the target is orthographically similar to the prime, there is a pre-activation of the orthographic unit for the target character before the target character is presented, which makes the activation speed of the target faster than the unrelated control. As a result, when the processing speed of the prime is slow, the phonological units receive activation earlier and reach their threshold faster in the orthographically similar than in the control condition.

However, at the end of the second term, the processing speed at the orthographic level was much faster (130 ms faster in the reaction time of control conditions) and the orthographic unit of the prime can reach its threshold within 500 ms. At the moment the threshold is reached, it starts to send inhibition to all other units and depresses all the pre-activations on orthographically similar units at the orthographic level. As a result, there is no facilitation effect on the target anymore. Furthermore, at a specific SOA, there could be inhibition effects depending on how strong the competition is between the prime and target orthographic units (Perfetti et al., 2002, 2005), even though it is not clear that whether this competition is strong enough for the inhibition to be observed in learners. It is possible that the strength of competition depends on the proficiency of reading.

After the orthographic threshold has been reached, the orthographic unit of the prime sends activation to its pronunciation and meaning units. In the condition where the prime and target had the same onset and rhyme (and sometimes tone), a pre-activation for the target pronunciation helped the target to be correctly named. A trend of faster naming latency (26 ms) was also observed. In the semantically related condition, the semantic unit of the prime partly activates the target unit, then the latter pre-activates the exact onset, rhyme and tone combination in the phonological level which leads to a faster naming latency.

Consistent with the fast learning of graphical structure (Wang et al., 2003), the learners had acquired graphical form information by the end of the first term, and their orthographic representations were sufficient to produce a facilitation within 500 ms SOA. Even though neither phonological nor semantic connections were functional within 500 ms at the first term, the learners did have access to pronunciations and meanings of the target character when allowed ample processing time, since these same subjects were able to perform the pronunciation spelling (PinYin) and translation tasks very well (Wang et al., 2003).

The present framework does not include a separate radical level because radicals were not taught explicitly in the curriculum of our subjects. However, the radicals not only play an important role in the reading of native Chinese speakers (Ding, Peng, & Taft, 2004; Taft & Zhu, 1997), but also help alphabetic users to learn Chinese (Taft & Chung, 1999; Wang *et al.*, 2004). The posthoc analysis showed the five orthographically similar pairs without sharing radicals had stronger facilitation effect than those with shared radicals. This result was opposite to what was found in native speakers (Ding et al., 2004). It is possible that stroke and spatial analysis dominate the early processing of first term learners. However, this result was based on five items only. There is no doubt that a learner will develop some radical knowledge at a certain learning stage, either explicitly or implicitly. But the length of learning needed is still an unanswered issue.

As illustrated in the semantic level of Figure 3, it is quite feasible that English translations were used to mediate accessing the meaning of these Chinese characters, as in other second languages (Kroll, Michael, & Sankaranarayanan, 1998; Kroll & Sholl, 1992). It also has been found that Chinese speakers who are learning English showed significant priming from the English prime to the homophone of a semantic related Chinese character, which showed that Chinese translation mediate the access of meaning in English reading for English learners (Guo & Peng, 2003).

The current results could not provide clear evidence on whether phonology or semantics is processed faster for these learners. (A posthoc t-test between the priming effects of phonology and semantics in the second term was not significant; however, semantic priming effects were reliable in subject-wise naming speed, whereas phonological effects were reliable only in item-wise naming accuracy.). A reasonable assumption is that, because the learners were exposed to connections from orthography to phonology and from orthography to meaning nearly simultaneously, they developed the two connections at a comparable rate. As their Chinese spoken proficiencies reach a higher level, which rely on robust connections from phonology to meaning, we would expect more phonological involvement in meaning processes in word reading.

Our results were also partly confirmed by an ERP study of learners from the same university population (Liu, Perfetti, & Wang, in press). In a task of delayed naming, this study found a larger N200 (orthographic) component for Chinese materials than English at the occipital electrodes, but only in the first term of learning. By the second term, this orthographic effect was absent; instead, a larger N400 (interpreted as semantic and phonology) was observed.

A general picture emerges, based on three studies of the same population of learners using different methods: the present priming study, the ERP study (Liu et al., in press), and an fMRI study of naming that showed similar activation patterns for Chinese native speakers and Chinese second language (Nelson, Liu, Fiez, & Perfetti, 2003). Although learners cannot approximate the skill level of the native speaker in one year of learning, their character processing within this year begins to show the acquisition of the visual-graphic, semantic, and phonological components that function for the skilled native reader.

Conclusion

After one term of instruction (15 weeks of learning), adult learners of Chinese as second language showed orthographic priming effects and only orthographic effects with 500 ms of prime exposure, suggesting that they had acquired functional orthographic representations of the characters. After another term, these orthographic effects gave their way to semantic and (weaker) phonological effects. This pattern, we suggest, reflects the threshold nature of the character lexicon, in which character recognition is achieved by activation that reaches a character-specific threshold. First term orthographic effects, on this account, reflected pre-threshold activation of orthographic form; second term semantic and phonological effects reflected lowering of the orthographic threshold, which allowed post-threshold activation of semantics and phonology to occur within 500 ms. Like skilled readers, learners of Chinese must acquire character specific representations that are accessed in threshold style. Learning—practice with specific characters—lowers the threshold of characters, allowing semantic and phonological connections to be accessed.

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Appendix

GRAPHICAL SIMILAR		HOMOPHONE		SEMANTIC RELATED	
Prime(Control)	Target	Prime(Control)	Target	Prime(Control)	Target
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
( )		( )		( )	
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( )		( )		( )	
( )		( )		( )	
( )		( )		( )	

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Table 1 Mean reaction time (standard error) in milliseconds and accuracy (standard error) of Experiment 1 and 2

TERM (NUMBER OF SUBJECTS)	CONDITION	PRIME PAIRS	CONTROL PAIRS
	Graphic	1241 (75)	1302 (70)
		87.2% (2.7%)	87.0% (2.9%)
TERM 1 (26	Homophonic	1305 (77)	1300 (79)
subjects)		79.5% (4.0%)	79.1% (3.8%)
	Semantic	1279 (75)	1268 (69)
		85.5% (3.2%)	86.5% (2.7%)
	Graphic	1292 (87)	1353 (80)
		90.2% (2.6%)	90.1% (2.7%)
TERM 1 (18	Homophonic	1358 (96)	1337 (92)
subjects)		84.2% (4.2%)	82.2% (4.5%)
	Semantic	1323 (88)	1307 (76)
		88.4% (3.6%)	88.7% (2.9%)
	Graphic	1137 (65)	1130 (51)
		93.6% (1.7%)	94.3% (2.0%)
TERM 2 (18	Homophonic	1160 (74)	1186 (72)
subjects)		88.5% (3.8%)	86.0% (4.9%)
	Semantic	1085 (51)	1151 (56)
		91.3% (2.5%)	92.0% (2.4%)

Figure Legend