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Alphabetic Readers Quickly Acquire Orthographic Structure in Learning to Read Chinese

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This study aimed to explore how alphabetic readers learn to read Chinese. First-year Chinese beginning learners who are skilled English readers were tested for their sensitivity to the visual-orthographic structures of Chinese characters. The study also explored the effect of the frequency of the characters in their curriculum on performance of a lexical decision and naming task. The students' linguistic knowledge about the characters was also tested. Results showed that the beginning learners were sensitive to the structural complexity of characters, they accepted simple characters more quickly and more accurately than compound characters, and they responded faster and more accurately to high-frequency than to low-frequency characters. Sensitivity to the structural composition of the character was also revealed: The learners rejected noncharacters containing illegal radical forms faster and more accurately than those containing legal radical forms in illegal positions, which in turn were rejected faster and more accurately than those containing legal radical forms in legal positions. A significant frequency effect was also found in the naming task, though the effect of structural complexity was not significant. These results suggest that perceptual learning plays an important role in early nonalphabetic learning by alphabetic readers. Both cross-writing system differences and second-language status may have an impact on such learning.

In the last decade, there has been a growing interest in research on reading in nonalphabetic writing systems. Chinese has been the center of interest in this area. This line of research has yielded substantial information on how readers read in a nonalphabetic writing system (e.g., Chen, Flores d' Arcais, & Cheung, 1995;

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Feldman & Siok, 1997; Perfetti & Zhang, 1995; Taft, Zhu, & Peng, 1999; Tan & Perfetti, 1998). The existing research on Chinese reading largely comes from monolingual skilled readers. There has been limited research on the process involved in learning the Chinese writing system. Studying the acquisition of a writing system offers unique information on the development of knowledge in a writing system, thus enhancing our understanding of how a learner acquires basic reading skills. One way to study this learning process is to look at native children's development of reading skills (e.g., Ho & Bryant, 1997a, 1997c; Shu & Anderson, 1997; Shu, Anderson, & Wu, 2000). Another approach, which is what we undertake, is to examine the process of learning a new writing system by skilled readers of another writing system. This emerging line of research will contribute substantially to our knowledge about acquisition of nonalphabetic systems. It will also contribute to forming a new line of second-language reading research, which is currently dominated by studies on learning alphabetic languages such as English or French.

Rozin, Poritsky, and Sotsky (1971) successfully taught eight second-grade inner-city school children with reading disabilities to read English written in Chinese characters. Thirty Chinese characters were selected based on the criteria that they were able to fit together to form various types of English sentences. The students were not required to read these characters in Chinese; instead, they were tutored to read them directly in English translation. Although very little progress was made in reading the English alphabet, these children seemed to be able to identify the 30 Chinese characters in different sentences and in three stories using English translation. This progress was made within a total of about 4 hr of tutoring Chinese characters compared to over half a year of schooling in the English alphabet. Errors occurred rarely in reading the sentences and comprehending the stories. The authors attributed these children's achievement in reading Chinese script to the nature of Chinese orthography in which no phonemic mapping is required. However, what exactly these children learned about the characters and how they learned these characters were not examined in their study.

This study forms a part of a larger ongoing project aimed at exploring how a reader skilled in an alphabetic system acquires rudimentary skill in written Chinese. Our first goal in this project is to capture sensitivity to visual-orthographic structure in the early learning of Chinese characters. We wanted to test whether learners are aware of the internal structural properties of characters in Chinese. We carefully manipulated the two critical orthographic variables in forming a Chinese character: structural complexity and compositional relationship. Acquiring these basic orthographic properties has been shown to be indispensable in skilled Chinese readers (e.g., Peng, Li, & Yang, 1997; Taft & Zhu, 1997) and in learning to read by Chinese children (e.g., Shu & Anderson, 1999). Our question in this study was, would learners acquiring Chinese as a new writing system quickly master the fundamental structural features of the newly learned characters? Related to this, we were interested in exploring the effect of frequency of exposure to characters in the curriculum on such learning. Because these learners learn to read Chinese in an American context where the target language is not being used outside of the classroom, the curriculum instruction is therefore the major source of exposure to the new system. Frequency in this study was defined based on the curriculum exposure for each character. Finally, we were also interested in testing the learners' phonological knowledge of the written characters.

To facilitate understanding further discussion of learning to read Chinese, we first need to describe the Chinese writing and phonological system. We then briefly review the literature on the lexical and visual-orthographic processes involved when skilled and young Chinese readers read Chinese. Finally, we discuss the unique challenge facing beginning readers of Chinese, and we lay out hypotheses related to our particular research interests.

THE CHINESE WRITING SYSTEM

Chinese is often referred to as a logographic writing system, or sometimes more accurately labeled as a morphosyllabic writing system (DeFrancis, 1989; Mattingly, 1992; Perfetti & Zhang, 1995). The basic unit of the Chinese writing system is the character. Each character represents a monosyllabic morpheme and is pronounced as a syllable. Unlike an alphabetic writing system, the graphemes in Chinese do not correspond to individual phonemes. Instead, each grapheme maps onto a syllable, which is also a morpheme.

Each character is composed of basic strokes. Strokes are the smallest building materials for characters. There are 24 basic strokes, for example, —, 丨, 丿, 丶. Certain strokes are combined to form component radicals, for example, 子, 忄. Radicals are the basic components of Chinese characters. According to the Chinese Radical Position Frequency Dictionary (1984), there are 541 radicals. Many radicals are single characters on their own, with their own pronunciations and meanings; for example, 子 has a meaning of *son*, and is pronounced as /zi/3. But there are also many radicals (238) that are not real characters, for example, 忄, 氵. They have no pronunciations. However, they may sometimes provide meaning cues for the whole characters. It is important to note that the combination of strokes, to form radicals, must follow certain stroke positional constraints. Any random combination of strokes could produce illegal radical forms.

Characters can be classified into two categories based on their structural complexity: simple characters and compound characters (see Figure 1). Simple characters are those that cannot be further divided into distinct radical components. In other words, they have one single radical, for example, 工 (meaning *work*, pronounced as */gong/*1). Compound characters are those that contain two or more distinct radical components, for example, 江 (meaning *river*, pronounced as */jiang/*1). The majority of Chinese characters are compound characters (more than 80%) ac-

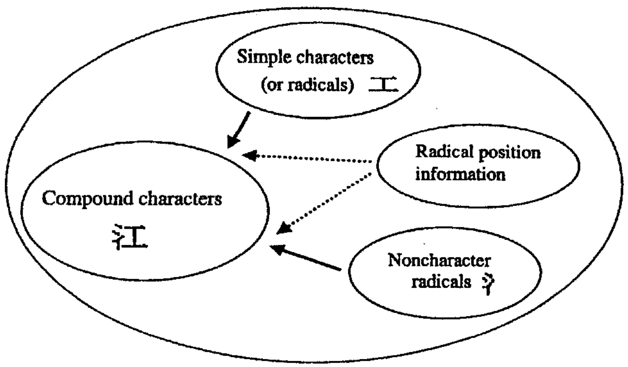

FIGURE 1 Chinese orthographic system.

cording to Zhu (1988). We expect that the structural complexity of the character will affect beginning learners of Chinese. It is apparent that simple characters have a simpler visual-orthographic structure than compound characters; therefore they will pose less of a challenge for the beginning learners in character identification compared to the compound characters.

Radicals in compound characters are configured into certain positions within the character. For example, a two-radical character is normally configured into one of two structures, a left–right or horizontal structure, or a top–bottom or vertical structure. For compound characters, the key feature is that each component of the characters normally has its own fixed position, or legal position—left, right, top, or bottom. For example, 氵 always occurs at the left position of the character, such as 江, 湖, 海, and 溪 (meaning *river, lake, sea,* and *stream*, and pronounced as */jiang/*1, */hu/*2, */hai/*3, and */xi/*1, respectively). If this radical is written in the right position of a character, it will violate its positional constraint and will be considered an illegal character. One point that should be clear is that the compositional relationship of radicals to form characters in the Chinese writing system is different in principle from the compositional relationship of letters to form words in alphabetic writing systems (Perfetti, Liu, & Tan, 2000). Unlike alphabetic letters, the radicals are orthographic units that may carry values as morphemes. Some of the radicals themselves can be characters, providing both meaning and pronunciation information for the whole character. However, the correspondence between component radicals to the sound or the meaning of the whole character is not entirely transparent or completely reliable (e.g., Shu & Anderson, 1997; Shu et al., 2000).

THE CHINESE PHONOLOGICAL SYSTEM

Compared to the complex Chinese orthographic system, Chinese phonological structure is relatively simple. The syllable is the basic speech unit of Chinese. Each syllable is traditionally divided into two parts: the onset and the rime. It is worth noting that there are different dialects among the Chinese population who use the same writing systems, for example, Mandarin, Cantonese, Xiang, Min, and so on. Mandarin is the Chinese language learned by the students in this study. There are 22 onsets and 38 rimes in Mandarin (Ho & Bryant, 1997a). The onset of a Mandarin Chinese syllable is always a single consonant. The rime segment consists of mainly vowels in most of the syllables. For example, /m/ is the onset and /a/ is the rime for the Chinese syllable /ma/. There are only two consonants that appear at the end of a rime in Mandarin. They are /n/ and /ng/ as in /man/ and /mang/ (Siok & Fletcher, 2001). As a result, Mandarin Chinese, like other dialects, has a much smaller number of syllables than spoken English (Hanley, Tzeng, & Huang, 1999). The small number of syllables results in a small number of morphemes that can be uniquely represented in spoken Chinese. In other words, the number of homophones in Chinese is large. However, because of the existence of tone in Chinese syllables, the number of homophones is reduced. A change in the tone of a syllable leads to a change in its meaning. The nature of tone in spoken Chinese is suprasegmental; it is attached to the rime. To process tone separately from rime is a difficult task. Ho and Bryant (1997c) found that Cantonese 3-year-old children cannot detect rime and tone separately, but they can succeed when rime and tone are combined. Five-year-olds, on the other hand, can independently process rime and tone. There are four tones in Mandarin (high-level, often labeled as 1; high-rising, 2; falling-rising, 3; and high-falling, 4). Another important feature of tone is that it is not represented in written Chinese and is therefore not useful for distinguishing morphemes in written Chinese. In this study, we tested Chinese second-language learners' phonological knowledge of the characters by comparing their performance in processing the onset, rime, and tone of the written character.

LEXICAL PROCESSING OF CHINESE CHARACTERS

The mental representation of a Chinese character, according to the lexical constituency model proposed by Perfetti and his colleagues, entails three constituents: orthography, phonology, and semantics (Perfetti & Tan, 1998, 1999; Tan & Perfetti, 1998). One important feature of this lexical constituency model is that it emphasizes the importance of a fully specified orthographic representation prior to the activation of phonological and meaning information in reading Chinese. More specifically, the model postulates that stroke analysis is the first step in visual character identification. The stroke features include stroke types and positional relationships.

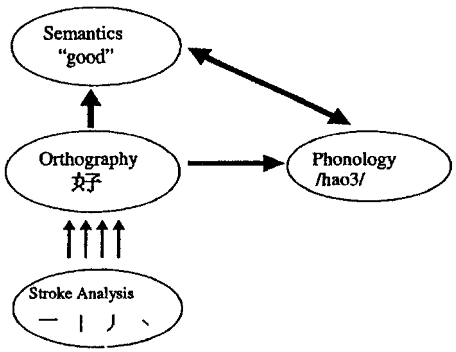

FIGURE 2 Lexical processing model of Chinese characters.

After these features are detected, they send activation to the orthographic units in the character orthographic subsystem. When orthographic units in the character orthographic subsystem reach threshold, they send activation to the phonological units and the meaning system (see Figure 2).

The activation threshold of orthographic units is determined by the frequency of occurrence of characters and component radicals in everyday use. Frequency has been an important factor in reading research (e.g., Forster, 1976; Hino & Lupker, 1998; Liu, Wu, & Chou, 1996; McClelland & Rumelhart, 1981; Paap, McDonald, Schvaneveldt, & Noel, 1987; Seidenberg & McClelland, 1989). A Frequency × Regularity interaction has been a robust finding for both alphabetic writing systems such as English (e.g., Seidenberg, 1985; Seidenberg, Waters, & Barnes, 1984; Waters & Seidenberg, 1985) and nonalphabetic writing systems such as Chinese (e.g., Fang, Horng, & Tzeng, 1986; Hue, 1992; Peng, Yang, & Chen, 1994). For instance, Chinese reading research has consistently shown that regularity[1] has less effect on the naming latency of high-frequency characters than low-frequency characters. In the case of low-frequency characters, regular characters were named faster than irregular characters. In other words, the effect of frequency decreases with increasing regularity. Whether and in what way frequency plays an important role in beginning Chinese learners is an issue to be addressed in this study.

[1]In Chinese reading literature, regularity is defined on the basis of the correspondence between the phonetic component radical and the whole character (e.g., Chen, 1993; Tzeng, 1981; Tzeng & Hung, 1988). A regular compound character can be pronounced directly based on its phonetic radical. Therefore, we should be aware that the "regularity" embedded in the Chinese system functions in a different way from that in English.

VISUAL-ORTHOGRAPHIC PROCESSING IN SKILLED AND YOUNG CHINESE READERS

There have been a series of recent studies examining orthographic processing as the basic processing component in reading Chinese. These studies strongly suggest that component radicals and their positional information are explicitly represented in a Chinese reader's lexicon. Shu and Anderson (1999) found that even first- and second-grade students could detect the ill-formed structure of a noncharacter. For example, they can determine that if a real radical is in a wrong or illegal position, the structure is a noncharacter. In other words, they are sensitive to the positional legality of the radicals in the character. The false alarm rate (incorrectly accepting a noncharacter as a real character) was very low for characters containing a legal radical in an illegal position (below 10%). For characters containing ill-formed component radicals, that is, the illegal radical forms, there was a dramatic drop in terms of the false alarm rate from Grade 2 on (from about 50% to 15%), but it was still higher than for those having legal radicals in illegal positions. No clear explanations were given by the authors as to why sensitivity to radical positions develops earlier than sensitivity to radical forms. In this study, we were interested in seeing whether a similar pattern to Chinese children's performance will be shown among a group of adult Chinese learners skilled in another writing system.

Peng et al. (1997) reported a significant orthographic legality effect for Grade 3, Grade 6, and college students. They used noncharacters containing the following conditions: (a) both radicals in legal positions, (b) both radicals in illegal positions, (c) left radical in a legal position but right one not, or (d) right radical in a legal position but the left one not. The results showed that it took the longest time and resulted in most errors for participants to reject the noncharacters with both radicals in legal positions. It was easier for them to reject the noncharacter with one radical in an illegal position, and it was the easiest for them to reject the noncharacter with both radicals in illegal positions. The pattern of results was similar for the three age groups, except that Grade 3 students responded significantly slower than the other two groups. However, there was no significant difference in decision latencies between the Grade 6 students and the university students. In Taft et al. (1999), the two radicals in one character were transposed to create another character. Both radicals were in legal positions in two characters. No difference was found between experimental and control items in terms of response latencies and accuracies. Both lexical decision and naming experiments yielded the same results. These results indicate that there is no interference caused by switching the positions of radical components in the character; thus radical positional information is important in visually recognizing Chinese characters. Taken together, the studies described previously provide reliable evidence supporting the notion that Chinese skilled readers as well as young readers are sensitive to the positional information of component radicals in the character. These readers rapidly identify the stimuli as noncharacters when at least one of the radical components is in an illegal position. They demonstrate great difficulty in identifying a noncharacter when both radicals are in legal positions. Recent studies even showed that 6-year-old children were able to further make use of semantic radical information to infer meaning of the characters (Chan & Nunes, 1998). Ho and Bryant (1997b) demonstrated that even Grade 1 Chinese children showed better performance in reading regular compound characters in which the phonetic components provided sound cues for the whole characters than in reading irregular characters.

Reading literature has shown that young learners of an alphabetic script such as English make use of visual cues in identifying words in the early development of reading (e.g., Ehri & Wilce, 1985; Gough & Hillinger, 1980; Gough, Juel, & Griffith, 1992). We want to emphasize that learning of the visual structure of Chinese characters is fundamentally distinct from early visual associative learning in the alphabetic English system. The nonlinear and rich visual-orthographic information embedded in the characters is crucial in character identification not only for young children but also for adult skilled learners.

LEARNING TO READ CHINESE AS A NEW WRITING SYSTEM

Two important features pertain to learning to read Chinese as a new system by alphabetic readers. First, as we discussed earlier, Chinese presents the highest contrast to alphabetic systems such as English (e.g., Perfetti, 1999). In particular, its graphic forms and spatial configuration contrast sharply with the linear structure of most alphabetic writing systems in the world. Each Chinese character is a salient perceptual unit. It consists of interweaving strokes, which in turn form the component radical(s). Characters differ from each other in terms of the number of strokes, the number of radicals, and the spatial configuration. Therefore, some researchers have argued that visual-orthographic skills may be more crucial in learning Chinese characters than words written in an alphabetic system (e.g., Huang & Hanley, 1994; Leck, Weekes, & Chen, 1995; Tzeng & Wang, 1983). Likewise, Chinese second-language learners will naturally attend to these visual-orthographic details to correctly identify a character. Second, but also important to note, is that, unlike the way in which native Chinese learn to read, these beginning learners are forced to learn to speak and read simultaneously. Consequently, they have very weak linguistic knowledge to support reading characters. Learning to read is essentially a process of learning to associate the spoken form, visual form, and meaning of the printed word (e.g., Adams, 1990; Perfetti, 1992; Treiman, 1993). When the linkage between the spoken form and the other two lexical constituents is weak, it may force second-language learners to rely on the visual form of the words to access the lexicon.

Given the previous two unique features in learning to read Chinese as a new writing system, and more important, the unique nature of the Chinese writing system, one important theoretical generalization is that such a unique learning situation will encourage learners to attend to the graphic forms and spatial configuration of the character. We hypothesized that beginning Chinese learners will be sensitive to a character's orthographic structure. Specifically, first, they will be sensitive to the visual complexity of the characters: Simple characters will be easier for learners to identify (e.g., in a lexical decision task) than compound characters, which will be reflected in both reaction time (RT) and accuracy data. Second, these learners will be sensitive to the compositional relationship of the internal character structure. Similar to what was found in Shu and Anderson (1999) and Peng et al. (1997), we expected to find that the Chinese learners in our study would demonstrate sensitivity in a lexical decision task to characters with legal radicals in illegal positions. They would also be sensitive to characters with illegal radical forms. With regard to whether the learners would be more sensitive to the radical positions than radical forms, or vice visa, we had no particular prediction. The learners may be more able to detect the illegality of radical forms than radical positions because, according to Perfetti and his colleagues' lexical constituency model, the character's stroke features will be detected first, including the stroke forms and stroke positions. The activation of orthographic structure, particularly the radical positional feature, would occur after the activation of the radical forms. Given the robust findings in the literature regarding the effect of word frequency in visual recognition, we hypothesized that there would be a strong effect of frequency of exposure to individual characters within the curriculum for learning to read Chinese as a new writing system. The more frequently the characters appear in the curriculum, the more quickly and more accurately responses would be in a character identification task such as lexical decision or naming. In a sound-matching task, in which students were asked to decide whether two printed characters shared the same target sound, we predicted that the learners may demonstrate poorer phonological-processing skills of the written characters at the tone level compared to those at the onset and rime level. We suggest that this is due to the challenge of learning Chinese as a second language and learning tone as a new linguistic property that is absent from their native language, English.

METHOD

Participants

A total of 15 individuals participated in the study; nine of them were attending the first-year Chinese language program at the University of Pittsburgh (Pitt), and the remaining 6 were attending the 1st-year Chinese language program at Carnegie

Mellon University (CMU). The age of the participants ranged from 20 to 22. Eighty percent of the participants had English as their first language; the rest had other alphabetic first languages—for example, Spanish. Eighty percent had some knowledge of another language—for example, Spanish, French, or German. None of them had formal Chinese learning experience. All of the participants had motivation to learn Chinese from strong personal interest—for example, they were studying foreign policy or international business. Some of the participants also indicated that they felt that learning Chinese was a challenging task, and they were curious about the Chinese writing system.

It is important to note that the curricula of the Chinese programs at Pitt and CMU were different from each other in terms of the length of instruction time and the emphasis on listening, reading, and writing. The Chinese language program at Pitt consisted of a spoken language course and a reading and writing course. There were ten 50-min sessions per week for a student who was registered for both the oral and the reading and writing courses, with 7 sessions devoted to oral language practice and 3 to reading and writing. The curriculum content was designed to provide students with cumulative speaking, reading, and writing experience. Both simplified and traditional versions of the characters were taught. The number of characters introduced in the first term was 263, and Pinyin (a Roman alphabetic system) was taught to assist in reading Chinese. The CMU Chinese program had an integrated listening, speaking, reading, and writing curriculum. The characters were taught both individually and in the text context. As with the Pitt program, both simplified and traditional versions of the characters were taught. There were five 50-min sessions per week. Unlike the Pitt program, speaking and reading practice were not separated into different classes. Pinyin was also taught. The number of characters introduced in the first term was 230. The overlapping characters in the two curricula were 130. In both curricula, the instructors did not explicitly teach the decomposition of characters into radicals. The positional constraints of radicals were also not taught. Sound and meaning cueing functions of the different types of radicals were not mentioned in the classes. The instructors were concerned that because of the unreliability of these semantic or pronunciation cueing radicals, instruction of this type of knowledge would cause overgeneralization among the beginning Chinese learners. Likewise, the students were not tested on this knowledge. Only Pinyin was used in the spoken language textbook to help students practice oral language skills. In reading and writing classes, Pinyin was used to assist in learning the individual new characters and was presented alongside them. However, there was no Pinyin attached to the characters in the text composed of short conversations.

All participants took a nonverbal ability test (Raven's Matrices Test; Raven, 1962) and various English skills tests including vocabulary, phonological manipulation, and spelling. The means of these scores indicated that the participants were in the range of normal nonverbal and English reading levels according to Hart and Perfetti (2001) and Perfetti and Hart (2001).

Curriculum-Based Character Frequency and Familiarity Analyses

A computerized curriculum file was created; the text frequency of each character in the curriculum was tallied and defined by the number of appearances of the character in the textbook. We argue that this curriculum frequency information is crucial for assessing the extent of exposure to the characters for the learners. These Chinese beginning learners were not living in the target language country; therefore they had a very restricted learning environment that was exclusively in the classroom. Each character's stroke number and radical number were tallied.

Although both simplified and traditional versions of the character were taught in the class, we only used the simplified version in this study.[2] Actual character familiarity was assessed on an individual participant basis. This familiarity test was done in a separate session before the experimental sessions. Character familiarity was assessed according to three dimensions: (a) visual familiarity—measures how often the participant has seen the character, (b) sound familiarity—measures how well the participant knows the pronunciation of the character indicated by written Pinyin, and (c) meaning familiarity—measures whether the participant understands the meaning of the character as indicated by English translation. Each participant rated all the dimensions of the characters. The order of the three dimensions was fixed and was the same for all the participants. Visual familiarity was first, followed by sound familiarity, then meaning familiarity.

Visual familiarity scores ranged from 1 to 3, with 1 given to characters the participant never sees, 2 to characters the participant sees several times (which was operationally defined as the number of times seen less than 10), and 3 to characters the participant sees many times (the number of times seen more than 10). Sound familiarity was scored from 0 to 2, with 2 given to written Pinyin correct for combined onset, rime, and tone; 1 given to written Pinyin with either one or two of the three linguistic units correct; and 0 when none of the three units was correct. Meaning familiarity was scored from 0 (*incorrect*) to 1 (*correct*).

The correlations between the text frequency and familiarity indices were all significant for both groups of participants (see Table 1). This result suggests that the more the learners were exposed to the characters in the text, the more familiar they were with the character in terms of its visual form, pronunciation, and meaning.

[2]Chen and Yuen (1991) suggested that learning the simplified version of the character might draw more on visual information in reading compared to learning the traditional version.

TABLE 1
Correlations Between Text Frequency and Character Familiarity Indexes Across Characters

	Visual Familiarity	*Pinyin*	*Translation*
Text frequency (Pitt)	.50*	.49*	.41*
Text frequency (CMU)	.33*	.39*	.38*

Note. Pitt = University of Pittsburgh; CMU = Carnegie Mellon University.
*$p < .05$.

Tasks

Lexical Decision

The lexical decision task is a widely used research paradigm in studying various basic processes in word identification (e.g., phonological, orthographic, and semantic processing). We chose to use this method in our study to investigate early sensitivity to visual-orthographic structures in the beginning Chinese learners. In this task, the participant was asked to decide whether the character shown on a computer screen was a real character. Structural complexity as well as radical compositional relationship was manipulated. The frequency effect was also examined. The logic underlying this task is that if the beginning Chinese learners were not sensitive to visual-orthographic information as well as to frequency, there would be no significant response differences among the different stimuli.

Materials and design. There were 160 items in total. Half of them were real characters, and the other half were noncharacters (for examples, see Table 2). Among the real characters, two variables were manipulated: One was the frequency of the character defined as the number of appearances of the character in the textbook (high and low frequency). The mean count for high-frequency characters used in this task was 44.85 for Pitt students, and 15.55 for CMU students; for low-frequency characters, 9.68 for Pitt students, and 4.8 for CMU students. The other variable was the structural complexity of the character defined as whether the character is composed of a single radical or more than one radical (simple and compound characters). The average number of radicals for compound characters was 2 for Pitt students, and 2.28 for CMU students. Manipulation of these two variables resulted in four types of real characters: (a) high-frequency simple characters (HS), (b) high-frequency compound characters (HC), (c) low-frequency simple characters (LS), and (d) low-frequency compound characters (LC). Twenty characters of each type were selected from the curriculum. To control for visual complexity when considering the frequency effect, stroke numbers were matched for HS and LS, and HC and LC characters.

TABLE 2
Examples of Stimuli in Lexical Decision Task

Real Characters		*Noncharacters*	
Types	*Characters*	*Types*	*Characters*
High simple (HS)	小	Legal radical, Legal position (LR–LP)	⿰氵月
High compound (HC)	她	Legal radical, Illegal position (LR–ILP)	⿰月氵
Low simple (LS)	生	Illegal radical (ILR)	[illegible]
Low compound (LC)	机	Symbol	&

The noncharacters were varied according to the legality of the radical forms and the legality of the radical positions. There were four conditions.

1. Legal radicals in legal positions (LR–LP): All of the radicals were selected from the curriculum. Among 20 items, 17 had a horizontal structure and 3 had a vertical structure.
2. Legal radicals in illegal positions (LR–ILP): Seventeen had a horizontal structure, and 3 had a vertical structure. Twelve items had both radicals in illegal positions, 6 items had the left radical in a legal position and the right radical in an illegal position, and 2 items were vice versa. Frequencies of the legal radicals were matched for (a) and (b) conditions.
3. Illegal radicals (ILR): Illegal radicals were created by adding, deleting, or moving a stroke from one location to another within a legal radical. Ten items were simple noncharacters, and 10 were compound noncharacters in which 7 had a horizontal structure and 3 had a vertical structure.
4. Visual symbols, such as $, *: This was taken as a baseline condition.

The order of all the items was randomized for each participant.

Procedure. A computer program called E-Prime (Psychology Software Inc., Pittsburgh, PA) was used to control the timing of the presentation of the stimuli. The Chinese character was presented in white against a black background and was approximately 2 cm in height and 2 cm in width. The participant was seated approximately 70 cm from the computer screen. The participant saw a fixation sign (+) first for 500 ms, followed by a target character until a response was given. The participant's task was to judge whether the target was a real character. The participant was instructed to press the left mouse button to indicate *Yes* and the right one to indicate *No* as quickly and accurately as possible. The temporal resolution of mouse button presses was 10 ± .5 ms. Feedback was given for each trial, with "Correct" shown on the screen for a correct response and "Incorrect" for a wrong response. The time interval between the feedback and the following fixation sign was 500 ms. RTs were recorded by measuring the interval between the presentation of the target stimuli and the onset of the decision. Ten practice trials were given before the experimental trials.

Naming Task

This task was used to see if the effect of frequency and character structural complexity depends on the nature of the reading task. We would expect that the effect of frequency and structural features should apply to both lexical decision and naming tasks.

Materials. The 80 real characters used in the lexical decision task were used in a naming task. The naming task was administered before the lexical decision task; the interval between the two tasks was about 1 week. In the naming task, we also included some filler characters. As in the lexical decision task, the real characters were divided into four categories: HS, HC, LS, and LC. Again, there were 20 characters in each category.

Procedure. The participant saw a fixation sign (+) first for 500 ms, followed by the target character until a naming response was given over a microphone that was connected to the computer. A computer program was able to detect the signal from the microphone and calibrate the RTs automatically. The temporal resolution of the timing was 1 ms. No feedback was given for each trial. The experimenter recorded the naming accuracies. Ten practice trials were given before the experimental trials.

Onset, rime, and tone matching task. This task was designed to tap into learners' ability to manipulate and differentiate among the linguistic units in Chinese characters. This task is important because we wanted to demonstrate their knowledge of the sounds of the characters. The participant was presented with three characters—one was the target character, and the remaining two were candidate characters. The participant was asked to judge which of the two candidates shared the same onset, rime, or tone with the target character. Onset-rime and tone are the two basic phonological dimensions in the Mandarin–Chinese spoken language. In the onset condition, the target shared its consonant onset only with the correct candidate character. In the rime condition, the target shared its rime only with the correct candidate. Because of the attachment of rime and tone in the Chinese syllable,

TABLE 3
Examples of Items in Onset-, Rime-, and Tone-Matching Task

	Target	*Candidate 1*	*Candidate 2*
Onset	见 /jian/4	有 /you/3	京 /jing/1
Rime	先 /xian/1	家 /jia/1	天 /tian/1
Tone	忙 /mang/2	回 /hui/2	书 /shu/1

tone was controlled for each item in the rime condition. In the tone condition, the target shared its tone only with the correct candidate (for examples, see Table 3). There were 84 items in total, 24 items for each condition. None of the candidates involved shared any visual similarity with the targets, and curriculum frequencies of the items across trial conditions were matched.

RESULTS

Performance on the Lexical Decision Task

Data trimming was carried out according to the following procedure: In each of the experimental conditions, any participant's individual item RT (within conditions) that was 2 *SD*s below or above the cell mean was deleted from the data. These outliers were present in each experimental condition, 4.3%, 5.3%, 4.6%, 6.3%, 2.3%, 3.3%, 4.7%, and 3.7% for HC, HS, LC, LS, LR–LP, LR–ILP, ILR, and symbols, respectively. To increase the normality and homoscedasticity of the RTs for the participants (Judd & McClelland, 1989), a log transformation of the data was carried out. The log RTs were taken as the dependent variable for the subsequent analyses.

Real characters: Yes responses. A 2 × 2 × 2 (frequency × structural complexity × group) repeated measures analysis of variance (ANOVA) was performed. The frequency variable consisted of two levels (high vs. low), and structural complexity had two levels (simple vs. compound characters). To test whether differences in teaching approaches would result in different performance patterns, the group (Pitt vs. CMU students) was treated as a between-participant variable. RT analysis was based on correct responses. There was no significant difference between the two groups of participants, $F(1, 13) = 1.47$, $p > .2$. The interactions between the group and the two main effects (frequency and structural complexity) were also not significant, both Fs < 1.

The data combining the two groups are shown in Figure 3. The main effect of frequency was significant, $F(1, 13) = 27.13$, $MSE = .0013$, $p < .001$. The participants made faster correct *yes* responses on high-frequency characters than on

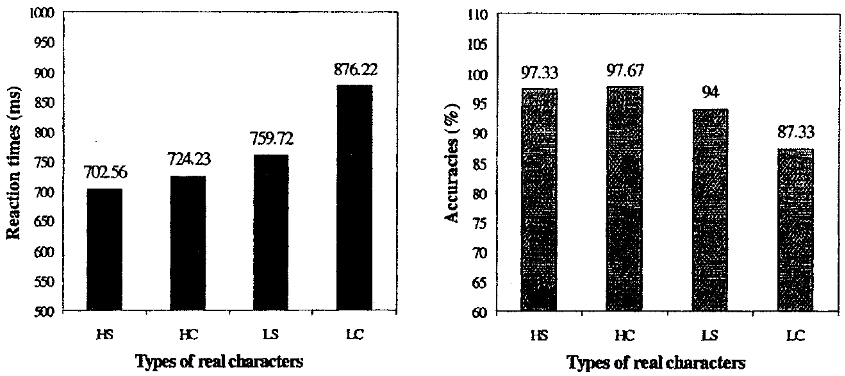

FIGURE 3 Lexical decision latencies and accuracies for real characters (HS = high-frequency simple characters, HC = high-frequency compound characters, LS = low-frequency simple characters, LC = low-frequency compound characters).

low-frequency characters. The main effect of structural complexity of the characters was also significant, $F(1, 13) = 18.39$, $MSE = .00096$, $p < .01$; that is, the participants made faster decisions on simple characters than compound characters. However, these main effects were further qualified by a significant interaction between character frequency and structural complexity, $F(1, 13) = 6.42$, $MSE = .00076$, $p > .05$. The RTs for simple characters and compound characters appeared to differ more for low-frequency characters than for high-frequency characters. Post hoc pairwise comparisons using the Bonferroni adjustment method for multiple comparisons indicated that RTs for HC and HS, HC and LS, and HS and LS were not significantly different from each other, all *ps* > .05. However, RTs for HC were shorter than on LC, HS were shorter than LC, and LS were shorter than LC, all *ps* < .05.

The accuracy data provide complementary evidence for the participants' sensitivity to structural features of Chinese characters. A 2 × 2 × 2 (frequency × structural complexity × group) repeated measures ANOVA was performed on the accuracy data. Again the group effect and the interaction between the group and main effects were not significant. The 2-group pooled data are shown in Figure 3. The main effect of frequency was significant. The participants responded more accurately on high-frequency characters than on low-frequency characters, $F(1, 13) = 17.96$, $MSE = .0038$, $p < .01$. The main effect of structural complexity was also significant. The participants made more accurate decisions on simple characters than compound characters, $F(1, 13) = 8.31$, $MSE = .0018$, $p < .05$. The two main effects were again further qualified by a significant interaction between frequency and structural complexity, $F(1, 13) = 15.21$, $MSE = .0016$, $p < .05$. Post hoc pairwise comparisons using the Bonferroni adjustment method for multiple comparisons indicated that accuracies for HC and HS, accuracies for HC and LS, and

accuracies for HS and LS were not significantly different from each other, all *ps* > .05. However, accuracies for HC were higher than those for LC, HS higher than LC, and LS higher than LC, all *ps* < .05.

Noncharacters: No responses. The group effect again was not significant (see Figure 4). Among the noncharacters, the participants made the fastest rejection on visual symbols. The slowest response came from rejecting the noncharacters containing LR–LP. Pairwise comparisons using the Bonferroni adjustment method for multiple comparisons showed that RTs for LR–LP noncharacters were slower than those on LR–ILP noncharacters, $p < .05$. This result suggested that the learners were sensitive to the position of the radicals in the characters. RTs for LR–ILP noncharacters were slower than those for ILR noncharacters, $p < .05$. This result indicated that the learners could detect illegal forms of the radicals faster than illegal positions of the radicals. Finally, RTs for ILR noncharacters were slower than visual symbols, $p < .05$.

With regard to accuracies, the results were consistent with the RT results. The participants were 100% correct on judging visual symbols; the most error-prone category was the legal radical in legal position. Pairwise comparisons using the Bonferroni adjustment method for multiple comparisons showed that accuracies for LR–LP noncharacters were lower than those for LR–ILP noncharacters, accuracies for LR–ILP noncharacters were lower than those for ILR noncharacters, and accuracies for ILR noncharacters were lower than those for visual symbols, all *ps* < .05. These results again pointed to the ability of beginning Chinese learners to detect the legality of the forms and positions of the radicals in the character.

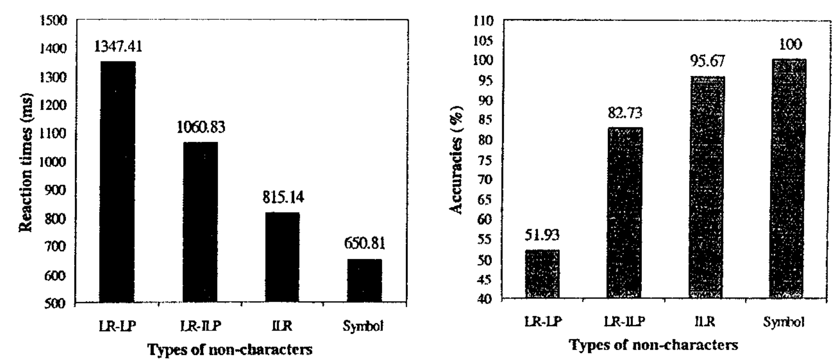

FIGURE 4 Lexical decision latencies and accuracies for noncharacters (LR–LP = legal radicals in legal positions, LR–ILP = legal radicals in illegal positions, ILR = illegal radicals).

Performance on the Naming Task

The RT data underwent a trimming procedure. Any participant's RT that was 2 *SD*s below or above the cell mean was deleted from the data in each condition. The percentages of the outliers were 4.6, 5.1, 5.2, and 5.9 for HC, HS, LC, and LS conditions, respectively. A log transformation was performed. The important result in the naming task was that the effect of frequency was again significant for both RT and accuracy data (see Figure 5). The participants named high-frequency characters significantly faster and more accurately than low-frequency characters, $F(1, 13) = 56.07$, $MSE = .0035$, $p < .001$, and $F(1, 13) = 203.39$, $MSE = .014$, $p < .001$. Pairwise comparisons using the Bonferroni adjustment method for multiple comparisons indicated that, for both RT and accuracy data, HS were named significantly faster and more accurately than LS, and HC faster and more accurately than LC, both $ps < .05$.

However, the effect of structural complexity was not significant either for RT data, $F(1, 13) = 3.78$, $MSE = .0084$, $p = .08$, or accuracy data, $F < 1$. The interaction between frequency and complexity was not significant for either RT or accuracy data, $F(1, 13) = 1.68$, $MSE = .0072$, $p > .2$, and $F(1, 13) = .97$, $MSE = .0042$, $p > .3$. The group effect was not significant again for either RT or accuracy.

Performance on the Onset, Rime, and Tone-Matching Task

This sound-matching task allows us to test the students' skills in isolating and differentiating the linguistic units of the Chinese characters. Means and standard deviations of correct percentages of onset, rime, and tone matching are listed in Table 4. Although some discrepancies in matching performance might be noticeable between the Pitt and CMU group, the participants overall performed more poorly on tone matching than onset and rime matching. For Pitt students, tone-matching scores were significantly poorer than both onset and rime matching, $t(8) = 5.6$, 2.94, respectively, both $ps < .05$. For CMU students, tone-matching scores were significantly poorer than onset but not rime matching scores, $t(5) = 4.18$, for onset, $p < .01$, $t(5) = 1.48$ for rime, $p > .1$. Performance on onset and rime matching did not differ significantly for both groups, $t(8) = 2.19$, $p > .05$ for Pitt, $t(5) = -.99$, $p > .7$ for CMU.

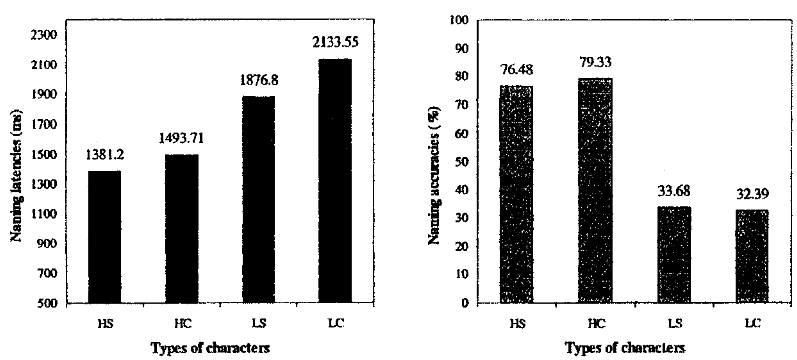

FIGURE 5 Naming latencies and accuracies for real characters (HS = high-frequency simple characters, HC = high-frequency compound characters, LS = low-frequency simple characters, LC = low-frequency compound characters).

TABLE 4
Means and Standard Deviations of the Accuracies of Onset, Rime, and Tone Matching

	Pitt (%)		*CMU (%)*	
	M	*SD*	*M*	*SD*
Onset	85.19	11.24	70.83	6.97
Rime	75.93	13.14	73.91	15.31
Tone	52.31	22.16	61.11	7.76

Note. Pitt = University of Pittsburgh; CMU = Carnegie Mellon University.

DISCUSSION

This study provides clear and strong evidence for early visual-orthographic sensitivity in lexical processing of Chinese characters by beginning Chinese learners who are skilled in an alphabetic system. Despite limited learning experience, and without explicit radical instruction, beginning Chinese learners demonstrated sensitivity to the structural complexity of the character; they accepted simple characters more quickly and more accurately than compound characters. They also showed sensitivity to the compositional relationship of the character; they rejected a noncharacter containing ILRs more quickly and more accurately than one containing LR–ILP. They also rejected a noncharacter containing LR–ILPs more quickly and more accurately than one containing LR–LPs. The fact that the learners rejected noncharacters containing ILR forms faster and more accurately than those containing LR–ILPs suggests that these learners develop an awareness of correct radical forms earlier than that of correct radical positions. This result could be explained by the fact that stroke features including stroke types and stroke positional relationships are the basic information in processing characters. As we described earlier, each component radical of the character is composed of strokes. Perfetti and his colleagues (Perfetti & Tan, 1998, 1999; Tan & Perfetti, 1998) suggested that when the readers visually encounter the character, it is the stroke features that first get activated. After the stroke features are detected, they send activation to the component radicals in the orthographic system. Accordingly, we suggest that in learning Chinese, sensitivity to the form of the radical will be acquired earlier than sensitivity to the positional property of the radical in the character.

Frequency plays an important role in learning Chinese characters. The beginning learners made faster and more accurate lexical decisions as well as faster and more accurate naming responses for high-frequency characters than for low-frequency characters. These results suggest that the frequency effect in learning a new writing system is reliable across different task demands. This may imply a general principle underlying learning of a writing system. An interesting interaction between frequency and structural complexity was also found in the lexical decision task. Structural complexity, whether the character is simple or compound, only matters for low-frequency characters, not for high-frequency ones. This finding is analogous to the well-known Frequency × Regularity interaction in both English and Chinese reading research. In curriculum familiarity analyses, all three familiarity indices—visual, pronunciation, and meaning familiarity—were significantly correlated with the text frequency counts of the characters. The more times the learners encountered the character in the curriculum, the better knowledge of the character they had. The exposure to the Chinese writing system for these learners came exclusively from classroom instruction. These learners differed from many other second-language learners in terms of the context in which the learning occurs. In many cases second-language learners immerse themselves in a target language environment.

These findings suggest that perceptual learning characterizes early learning of a nonalphabetic system by alphabetic readers. We suggest that this can be attributed to the logographic nature inherent in the Chinese writing system. The system does not allow direct mapping between graphemes and phonemes. Furthermore, the rich orthographic information embedded in the system attracts learners to attend to the crucial details of the structure of each character, including the forms of correct component radicals and the correct positions for these radicals. The strong effect of frequency on lexical processing and retrieving pronunciation information again reflects the nature of the Chinese system, which is highly driven by its visual-orthographic characteristics. The more times the character is encountered, the better the knowledge of the character. Rozin et al.'s (1971) successful account of teaching reading disabled English-speaking children using Chinese characters supported our findings in some ways. The young children in their study apparently were able to differentiate between the perceptual features of the 30 characters they were taught and associate them with different English syllables.

It is worth noting that the effect of structural complexity was different in the lexical decision and the naming tasks. In the lexical decision task, the learners

made significantly faster and more accurate lexical responses for simple characters than compound characters. However, this effect was not significant in the naming task. The reason for this nonsignificant effect might be due to the low accuracy rates. This result reflects their second-language learning status. They demonstrated great difficulty in mapping sound information onto the print form of the written characters. Because of the low accuracy rates, the error term of the ANOVA would be large, which would decrease the power of the statistical test. However, we can still detect a similar trend of faster and better responses in naming simple characters than complex characters in the naming task just as in the lexical decision task. We would expect that with the increase of Chinese proficiency in this group of students the effect of structural complexity would emerge.

The beginning Chinese learners showed poorer performance in tone matching compared to their performance in onset and rime matching. This result can be explained by the fact that onset and rime have been shown to be universal across many languages in the world and are natural consequences of spoken language development (Bertelson, de Gelder, Tfouni, & Morais, 1989; Cheung, 1999; Cheung, Chen, Lai, Wong, & Hills, 2001; de Gelder, Vroomen, & Bertelson, 1993). In contrast, tone is a unique feature of Chinese compared to English and many other languages in the world. Tone is also tightly attached to the rime unit in the Chinese syllable. Processing tone accurately in Chinese requires the learner first to isolate the tone from the rime to which it is attached and then to differentiate between different tones. It is also noteworthy that the matching task used in this study especially poses challenges for beginning learners, as the stimuli were presented in the written Chinese form. No actual sound information was provided. To succeed in this task, high familiarity with the pronunciations of the characters was required, especially in the case where direct grapheme–phoneme mapping is impossible in reading Chinese. Furthermore, tone is not represented in written Chinese.

It is noteworthy that the different curricula involved in the Pitt and CMU programs did not lead to different performance between the two groups of students in the tasks pertaining to visual-orthographic sensitivity. The Pitt program separated speaking and reading practice and emphasized the students' listening and speaking skills. The CMU program integrated listening, speaking, reading, and writing practice. The students from different instructional approaches, however, demonstrated the same awareness of the character's internal structural features. It appears that despite different teaching strategies, there exists commonality in terms of sensitivity to visual-orthographic legality among Chinese beginning learners. It is worth noting that there was a slight difference between the two groups in learning the internal linguistic structure of the character. Pitt students were slightly better than CMU students on onset items, whereas CMU students were better than Pitt students on tone items. These differences were perhaps related to details of the curriculum, and future research is needed to address this issue. In addition, an oral form of the onset-rime-tone matching task should be included to get a purer measure of phonological-processing skills among beginning Chinese learners. In future research, it also would be interesting to see how phonological-processing and visual-orthographic skills correlate with each other by recruiting a larger sample of Chinese learners. Would learners with weak knowledge of Chinese phonology be more sensitive to its visual-orthographic structure? Or would better phonological-processing skills be associated with greater visual-orthographic sensitivity in learning Chinese just as in learning other language and writing systems, for example, English (e.g., Read, 1986; Treiman, 1993)?

The early sensitivity of American students in processing visual-orthographic information in logographic Chinese characters does not imply that these learners are able to abstract relevant radicals for the meaning cues from the semantic radicals or pronunciation cues provided by the phonetic radicals. As the literature points out, radicals of the characters are normally categorized into two types: the semantic radical (it is often labeled as radical) and the phonetic radical (it is often labeled as phonetic). Semantic radicals are those components in the characters that provide meaning information for the whole character. Phonetic radicals are those that provide a sound cue for the whole character. Both phonetic and semantic radicals have been shown to play an important role in reading Chinese characters (e.g., Chen, 1993; Chen & Allport, 1995; Fang et al., 1986; Seidenberg, 1985; Zhu, 1988). An important question for future research is the extent to which beginning Chinese learners can make use of component radical information to infer the meaning or pronunciation of the character.

CONCLUSION

In summary, one major conclusion can be drawn from this study: Chinese beginning learners who are skilled at an alphabetic system demonstrated early visual-orthographic sensitivity in lexical processing of Chinese characters. They showed sensitivity to the structural complexity of the character. They also showed sensitivity to the compositional relationship of the character, including radical form and radical position. Frequency of exposure was a critical factor in such learning. These results suggest that perceptual learning plays an important role in early nonalphabetic learning by alphabetic readers. Both cross-writing system differences and second-language status may have an impact on such learning.

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