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Consistency, Regularity, and Frequency Effects in Naming Chinese Characters

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Three experiments in naming Chinese characters are presented here to address the relationships between character frequency, consistency, and regularity effects in Chinese character naming. Significant interactions between character consistency and frequency were found across the three experiments, regardless of whether the phonetic radical of the phonogram is a legitimate character in its own right or not. These findings suggest that the phonological information embedded in Chinese characters has an influence upon the naming process of Chinese characters. Furthermore, phonetic radicals exist as computation units mainly because they are structures occurring systematically within Chinese characters, not because they can function as recognized, freestanding characters. On the other hand, the significant interaction between regularity and consistency found in the first experiment suggests that these two factors affect Chinese character naming in different ways. These findings are accounted for within interactive activation frameworks and a connectionist model.

Key words: frequency, consistency, regularity, naming task

1. Introduction

Many efforts towards developing models of pronunciation for alphabetic writing systems have focused on the effects in naming tasks exerted by two properties of words: (1) Frequency (how often a word is encountered), and (2) consistency or regularity (whether the pronunciation has a predictable spelling-to-sound correspondence). Behavioral studies have shown a robust interaction between these two properties. That is, the regularity or consistency of spelling-to-sound correspondences often has little impact on naming high frequency words. However, for low frequency words, regularity or consistency words usually contributes to faster and more accurate naming than for exception words (Seidenberg et al. 1984, Seidenberg 1985, Taraban & McClelland 1987, but see also Jared et al. 1990, 1997). At least two models, the dual-route model and the parallel-distributed processing model (PDP), are proposed to explain this interaction. These models differ from one another in terms of the assumptions they make concerning the mappings between orthography and phonology and concerning the number of mechanisms responsible for the orthography-to-phonology transformation.

1.1 Dual-route and PDP models

The dual-route model uses the notion of "regularity" to define mappings between orthography and phonology. Broadly speaking, a written English word is regular if its pronunciation follows the grapheme-to-phoneme correspondence rules (or GPC rules) of the written language (Venezky 1970); and a word is an exception if its pronunciation deviates from those rules. According to the traditional dual-route model, the "assembled-route" operates by means of GPC rules. This process will produce only "regular" pronunciations and will do so regardless of the frequency or familiarity of the letter string (Coltheart 1978, 1983). In contrast, the addressed-route operates by paired-association. It not only compensates for the mistakes that GPC rules make regarding exception words, but also ensures that the pronunciation system is sensitive to frequency. The interaction of frequency and regularity is explained by the **relative finishing time assumption**. For low-frequency exception words, it is assumed that the assembly route will produce its incorrect pronunciation in about the same interval of time as the addressed route produces its correct one. In such a case, two candidate pronunciations arrive at the response-generation mechanism for programming articulation at approximately the same time, and this creates a conflict. To resolve this conflict delays the onset of pronunciation. It can lead to errors if pronunciation is initiated before the conflict is fully resolved in favor of the correct phonology.

On the other hand, the analogy-based account proposed by Glushko (1979) and the connectionist account proposed by Seidenberg and McClelland (1989) adopted the term "consistency" to describe mappings between orthography and phonology. Spelling-sound consistency was defined with respect to the orthographic body and the phonological rime (Glushko 1979, Taraban & McClelland 1987, Seidenberg & McClelland 1989, Van Orden et al. 1990). A consistent English word (e.g. WADE) is one that has a word-body (-ADE) pronounced in the same way for the entire set of orthographic neighbors. An inconsistent word (e.g., WAVE) has among its neighbors at least one exception word (e.g., HAVE). The definition of consistency is independent of the definition of regularity. Thus a word can be, like WAVE, both regular, because it follows the GPC rules, and inconsistent, because it does not rhyme with all its neighbors. Moreover, a word like WADE that not only follows the GPC rules, but also rhymes with all its neighbors is both regular and consistent.

Glushko (1979) argued that, relative to regularity, consistency provides a better account for word naming latency data because he found that regular but inconsistent words, like WAVE, take longer to pronounce than regular and consistent words like WADE. If regularity is an undifferentiated category, both consistent and inconsistent groups of regular words should be named with the same latency. In addition, pseudowords like TAVE, which resemble exception words, take longer to read aloud than pseudowords like TAZE, which resemble regular words (Glushko 1979). The dual-route model can predict neither of these findings. Therefore, the analogy account claimed that a candidate set of word or subword representations will be activated by perceptual input and the subsequent synthesis process is responsible for the pronunciation. The interaction of frequency and consistency is explained by the relative size and the compatibility of phonological realization of the candidate set. The low frequency exception words activate many neighbors and these neighbors include different and mutually incompatible phonological realizations. The resulting conflict takes time to resolve.

As for the PDP model, the pronunciations are determined within a subsymbolic connectionist network, which connects input orthography to output phonology (Van Orden et al. 1990). The network learns from exposure to particular words. The factor having the largest impact on the model's performance with a given word is the number of exposures to the word itself during training (i.e., word frequency). The high frequency words have been encountered many times in the past. The connection of a high frequency word's orthography and phonology will be quite strong. The settling time of a high frequency word will be relatively fast. The other factor having impact is input to the model in terms of other similarly or non-similarly spelled words; that is, consistency. For the pronunciation of a consistent word, there will be no conflict among the phonological features that become activated. The settling time will also be relatively fast. Both frequency and consistency influence the settling time. On the other hand, the low frequency exception words have not been learned well enough to settle rapidly, by virtue of the sheer strength of their connections. Further, they activate too many incompatible phonological features to settle rapidly by virtue of their consistency. Therefore, the interaction of frequency and consistency is explained as a product of the network's learning history. In general, as the number of exposures to a given word decrease, the naming performance of that word depends more on the properties of similarly spelled word neighbors.

1.2 The characteristics of Chinese orthography

Chinese is characterized as being a logographic writing system with deep orthography. The correspondence between orthography and phonology in Chinese is more arbitrary than in the writing systems with shallow orthographies, like Serbo-Croatian or English. Some researchers believe that the mapping between orthography and phonology in Chinese is quite opaque. Therefore, the pronunciation of each Chinese character must be learned individually, making the assembled route from orthography to phonology unavailable (Paap & Noel 1991). However, if we carefully observe the evolution of writing systems, we find that the relation between script and meaning has become increasingly abstract, while the relation between script and speech has become increasingly clear. DeFrancis (1989) made detailed analyses of various kinds of writing systems from the perspective of their historical development and claimed that any fully developed writing system is speech-based, even though the way speech is represented in the script varies from one language to another (DeFrancis 1989). Furthermore, he emphasized that Chinese orthography is also a speech-based script since more than 85% of Chinese characters are phonograms, in which a part of the character carries clues to its pronunciation.

Chinese writing was possibly pictographic in origin (Hung & Tzeng 1981). However, owing to difficulties in forming characters to represent abstract concepts, phonograms were invented. Phonograms usually are complex characters, typically composed of a semantic radical and a phonetic radical. The semantic radical usually gives a hint to the character’s meaning, whereas the phonetic radical provides clues to the pronunciation of the character. For example: the character 媽 *ma* (mother) is written with a semantic radical 女 to indicate the meaning of “female”, and a phonetic radical 馬 *ma* to represent the sound of the whole character. Due to the historical sound changes and the influence of dialects, many phonetic radicals of the compound character lost the function of providing clues to pronunciation. Among modern Chinese characters, less than 48% of the complex characters have exactly the same pronunciations as their phonetic radicals (Zhou 1978). However, the relationship between orthography and phonology is far from null in Chinese. It is still worth asking whether readers can use their knowledge of the relationship between orthography and phonology in naming.

1.3 Definition of regularity and consistency in Chinese characters

Since there are no GPC rules in Chinese, it is impossible to classify Chinese characters as regular or irregular according to whether they follow the GPC rules.

Previous studies have tried to describe the mappings between Chinese orthography and phonology in two different ways. The first one is to define the "regularity" as whether the sound of a character is identical with that of its phonetic radical, ignoring tonal difference (Lien 1985, Fang et al. 1986, Hue 1992). For example, 油 *you* is regular because it sounds the same as its phonetic radical 由 *you*. An irregular or exceptional character would be the character whose pronunciation deviates from that of its phonetic radical. For example, 抽 *chou* is irregular because it sounds different from its phonetic radical 由 *you*.

The second way to describe the mappings of Chinese orthography and phonology is the concept of consistency. Fang et al. (1986) considered a character to be consistent if all the characters in its set of orthographic neighbors, which share the same phonetic radical, have the same pronunciation; otherwise, it was inconsistent. In addition to this dichotomous distinction of consistency, Fang et al. (1986) introduced a method to estimate the consistency value of a character, which is similar to the degree of consistency defined by Jared et al. (1990) to capture the magnitude of the consistency effect. The consistency value is defined as the relative size of a phonological group within a given activation group. For example, there are twelve characters that include the phonetic radical 由 *you*. Among these, 迪 and 笛 are pronounced as *di* and have a consistency value of 0.17 (i.e., 2/12). Therefore, each character can be assigned a gradient consistency value in addition to the dichotomous category of consistency.

1.4 The role of regularity and consistency in Chinese character naming

Several studies have addressed the role of regularity and consistency in naming Chinese characters. Seidenberg (1985) found that regular characters were named faster than frequency-matched non-phonograms (simple characters without a phonetic radical) when the characters were of low frequency. This result showed that regular, complex characters could be named more efficiently than simple characters with no phonetic radical. However, this is not a typical regularity effect. Fang et al. (1986) asked participants to name regular and irregular characters. The regular characters could be subdivided into two types, consistent and inconsistent. Their results showed an effect due to consistency, but none due to regularity. Specifically, regular-consistent characters were named faster than regular-inconsistent characters, but the regular-inconsistent characters were not named faster than the irregular-inconsistent characters. A similar trend was observed by Lien (1985). However, the stimuli in both these studies were restricted to high frequency characters. Hue (1992) further manipulated the character frequency and found both regularity and consistency effects for low frequency characters.

These results indicate that phonological information contained in Chinese characters is used in character pronunciation. However, some controversy remains. First, both Fang et al. (1986) and Lien (1985) reported a consistency effect for high frequency characters, whereas Hue (1992) did not. On the other hand, Hue (1992) reported the regularity effect, but neither Fang et al. (1986) nor Lien (1985) did so. Therefore, an issue that needs further clarification is whether the consistency and regularity effect can be found in naming high frequency characters. Second, although consistency may be calculated as a continuous value, most previous studies define it as a dichotomous variable in order to contrast the effects of complete consistency with any degree of inconsistency. Fang et al. (1985) found that the pronunciation latencies of simple characters, which serve as phonetic radicals in compound characters, were also affected by their inconsistency values. However, whether the degree of consistency affects naming of Chinese complex characters, or phonograms, and whether this interacts with frequency and regularity remain to be seen.

2. Experiment 1

The first purpose of Experiment 1 was to investigate whether consistency and regularity effects can be found in naming high frequency characters. Four types of characters were included in this experiment. They were (1) consistent and regular, (2) inconsistent and regular, (3) inconsistent and irregular, and (4) the non-phonograms. The second purpose of this experiment was to examine the relationship between regularity and consistency. We manipulated the relative consistency value within inconsistent/regular and inconsistent/irregular conditions to address this specific question.

2.1 Method

2.1.1 Participants

The participants were eighteen undergraduate students recruited from a pool of participants at Yang-Ming University. All were native speakers of Chinese. Their participation partially fulfilled their course requirements.

2.1.2 Apparatus

All stimuli were presented and all responses were collected using a Pentium 166 MMX personal computer with a voice-key relay attached through the computer’s printer port. A microphone was placed on a stand and attached to a voice-key delay. A separate microphone was attached to a tape recorder and was used to record the participants' naming responses.

2.1.3 Materials and design

One hundred and sixty Chinese characters were selected for this experiment. (These are listed in Appendix 1.) Half were high frequency characters (more than 150 occurrences per 10 million) and half were low frequency characters (less than 80 occurrences per 10 million). According to the definition of consistency and regularity in this study, each of the two frequency groups was divided into four subsets by character type: (1) consistent/regular, (2) inconsistent/regular, (3) inconsistent/irregular, and (4) non-phonograms. Subsets of characters within a frequency group were matched for frequency according to the *Mandarin Chinese Character Frequency List* (Chinese Knowledge Information Processing Group 1995). Each subset contained twenty characters. All of the characters in the set of non-phonograms were single characters or compound characters without phonetic radicals. Although some non-phonograms do function as phonetic radicals in phonograms, no such non-phonograms were selected for use in this study. The criteria for each condition and illustrative examples are shown in Table 1.

Table 1: Examples and characteristics of the characters in different frequency groups and character types for Experiment 1

	Character type			
	Consistent /regular	Inconsistent /regular	Inconsistent /irregular	Non-phonogram
High frequency				
Example	距	誠	媒	傘
Pronunciation	ju4	cheng2	mei2	san3
Meaning	distance	honest	medium	umbrella
Frequency	985	1096	1224	1030
Consistency value	1.00	0.46	0.42	*
Low frequency				
Character	胰	膛	儕	吝
Pronunciation	yi2	tang2	chai2	lin4
Meaning	pancreas	chest	a class	stingy
Frequency	39	33	28	42
Consistency value	1.00	0.53	0.39	*

Note Frequencies were calculated using the technical report of the *Mandarin Chinese Character Frequency List* (1995). Character frequencies greater than 1500 were truncated to 1500. Asterisk (*) indicates no consistency value.

For investigating whether consistency level affects naming performance, we subdivided the inconsistent/regular character and inconsistent/irregular character sets into relatively high and relatively low consistency subsets. Each subset included ten characters. The consistency values of the relatively high group ranged from 0.50 to 0.89. Those in the relatively low group ranged from 0.10 to 0.47. The criteria for each condition and illustrative examples are shown in Table 2.

Table 2: Examples and characteristics of the characters differing in regularity, consistency, and frequency for Experiment 1

Regularity	Regular		Irregular	
Consistency	High	Low	High	Low
High frequency				
Example	誠	週	媒	抽
Pronunciation	cheng2	zhou	mei2	chou
Meaning	honest	week	medium	to pump
Frequency	1188	1003	1308	1139
Consistency value	0.64	0.28	0.65	0.20
Low frequency				
Example	胰	桅	儕	犢
Pronunciation	yi2	wei2	chai2	du2
Meaning	pancreas	mast	a class	calf
Frequency	32	34	27	28
Consistency value	0.73	0.33	0.58	0.21

Note Frequencies were calculated using the technical report of the *Mandarin Chinese Character Frequency List* (1995). Character frequencies greater than 1500 were truncated to 1500.

2.1.4 Procedure

Participants were individually tested in a small room. They sat in front of the PC at a distance of approximately 60 cm. Before exposure to the experimental stimulus items, they underwent ten practice runs, so as to familiarize them with the procedure and so that the experimenter could adjust the sensitivity of the voice-key delay.

During the experimental period, one hundred and sixty characters were presented to each participant in random order. Each trial began with a visual presentation of a fixation point for 1000 ms, accompanied by a 500 Hz beep signal for 300 ms. Then a target character was presented in the center of the screen for the participant to name. All participants were instructed to name each character as quickly and as accurately as possible. The target character remained on the screen until the participant responded or until an interval of 3000 ms had expired. Articulation onset latencies were recorded by means of the voice-key delay. Naming latencies were discarded from trials on which there were pronunciation errors or voice-key triggering errors due to environmental noise. The pronunciation errors were recorded by the experimenter. Uncertainties regarding naming responses were resolved by listening to the audiotape. Naming latencies longer than 1500 ms were considered null responses by the program, and those 200 ms or shorter were regarded by the program as voice-key triggering errors. After the response or the expiration of the 3000 ms interval, a blank screen was displayed until the experimenter recorded the correctness of the response. The participants could take a break after each set of 40 experimental trials or after any trial if necessary.

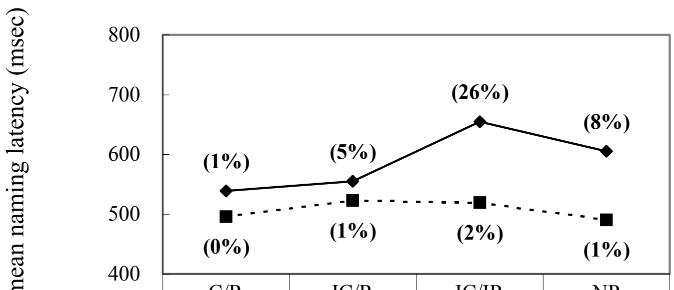
2.2 Results

2.2.1 Analysis of frequency and character type

There were two variables for this analysis: frequency (high vs. low) and character type (consistent/regular, inconsistent/regular, inconsistent/irregular, and non-phonogram). These were treated as within-subject variables in the analysis by subjects (F_1) and between-item variables in the analysis by items (F_2). Analyses of variance (ANOVA) were performed on latency data and accuracy data. The mean reaction time and percent error rate for the each condition are presented in Figure 1.

Figure 1: Mean naming latencies and error rates for conditions with different frequencies and character types for Experiment 1

Fig. 1. Mean naming latencies and error rates for conditions with different frequencies and character types in Exp 1



	C/R	IC/R	IC/IR	NP
Low frequency	539	555	655	605
High frequency	496	523	519	491

C/R:consistent/regular; IC/R:inconsistent/regular, IC/IR/inconsistent/irregular; NP:nonphonograms

Participants named high-frequency characters significantly faster than low-frequency characters, $F_{1(1,17)}$=255.52, p<.001, MSe=238418, and $F_{2(1,152)}$=126.20, p<.001, MSe=357873, and more accurately, $F_{1(1,17)}$=50.29, p<.001, MSe=0.289, and $F_{2(1,152)}$=31.52, p<.001, MSe=0.325. The main effects of character type were significant both in the latency data, $F_{1(3,51)}$=22.79, p<.001, MSe=30177, and $F_{2(3,152)}$=17.22, p<.001, MSe=48830, and in the accuracy data, $F_{1(3,17)}$=32.015, p<.001, MSe=0.115, and $F_{2(3,152)}$=12.489, p<.001, MSe=0.129. The interaction between frequency and consistency was also significant in the latency data, $F_{1(3,51)}$=31.11, p<.001, MSe=24096, and $F_{2(3,152)}$=12.13, p<.001, MSe=34388, and in the accuracy data, $F_{1(3,51)}$=27.36, p<.001, MSe=0.095, and $F_{2(3,152)}$=10.24, p<.001, MSe=0.106.

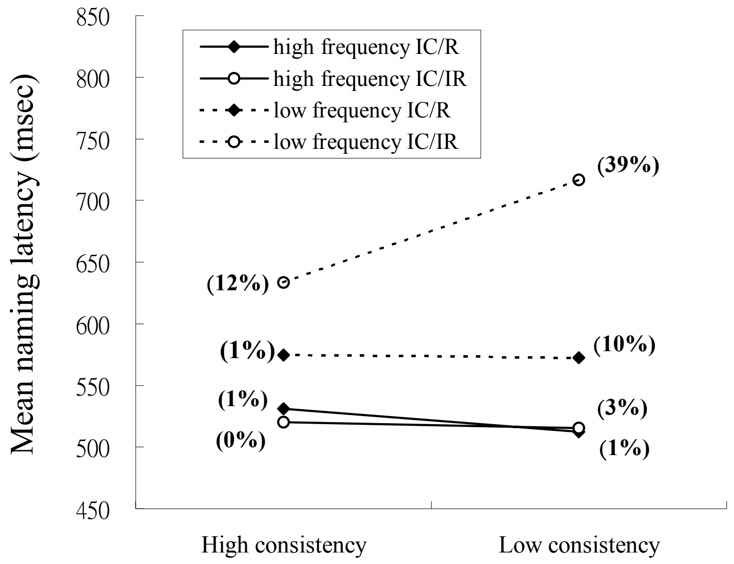
For the high frequency condition, the simple main effect of character type was significant in the latency data in the analysis by participant, $F_{1(3,102)}$=4.317, p<.01, MSe=4529, but not in the analysis by item, F_2<1. None of those effects achieved significance in the accuracy data, Fs<1. Post hoc comparisons of the latency data from the analysis by participant were conducted to see if there were consistency and regularity effects in naming high frequency characters. A significant consistency effect showed that participants named consistent/regular characters faster than the inconsistent/regular ones, $F_{1(1,102)}$=5.69, p<.05. There was no difference in naming latency between the inconsistent/regular and inconsistent/irregular character sets (F_1<1), nor between the non-phonograms and consistent/regular character sets (F_1<1). However, the non-phonograms were named much faster than the inconsistent/regular characters, $F_{1(1,102)}$=8.22, p<.01, and faster than the inconsistent/irregular characters, $F_{1(1,102)}$=6.16, p<.05.

For the low frequency condition, the simple main effects of character type were significant both in the latency data, $F_{1(3,102)}$=47.41, p<.001, MSe=49744, and $F_{2(3,152)}$=27.6, p<.001, MSe=78266, and in the accuracy data, $F_{1(3,102)}$=59.23, p<.001, MSe=0.208, and $F_{2(3,152)}$=22.644, p<.001, MSe=0.233. The post hoc comparison between consistent/regular and inconsistent/regular characters was marginally significant in the analysis of latency data, $F_{1(1,102)}$=2.28, p=.13, and $F_{2(1,152)}$=3.31, p=.07, and was significant in the accuracy data, $F_{1(1,102)}$=4.20, p<.05, and $F_{2(1,152)}$=1.74, p=.19. The inconsistent/regular characters were named faster than the inconsistent/irregular characters, $F_{1(1,102)}$=80.38, p<.001, and $F_{2(1,152)}$=45.62, p<.001, and more accurately, $F_{1(1,102)}$=99.43, p<.001 and $F_{2(1,152)}$=45.62, p<.001. On the other hand, the non-phonograms were named more slowly than were the consistent/regular characters, $F_{1(1,102)}$=36.05, p<.001, and $F_{2(1,152)}$=18.94, p<.001, and less accurately, $F_{1(1,102)}$=11.66, p<.01, and $F_{2(1,152)}$=4.82, p<.05. The non-phonograms were also named more slowly than the inconsistent/regular characters, $F_{1(1,102)}$=20.01, p<.001, and $F_{2(1,152)}$=6.42, p<.05, but there was no difference in naming accuracy. However, the non-phonograms were named faster than the inconsistent/irregular characters, $F_{1(1,102)}$=19.99, p<.001, and $F_{2(1,152)}$=17.81, p<.001, and more accurately, $F_{1(1,102)}$=74.06, p<.001, and $F_{2(1,152)}$ =30.63, p<.001.

2.2.2 Analysis of frequency, regularity, and the consistency level

One further analysis investigated the relationships between regularity and consistency. Both the inconsistent/regular and inconsistent/irregular character groups, both their high and low frequency conditions, were split into two groups based on relative consistency. They yielded three variables for this analysis: frequency (high vs. low), regularity (regular vs. irregular), and consistency level (high vs. low). They were treated as within-subject variables in the analysis by participants (F_1) and between-item variables in the analysis by items (F_2). ANOVAs were performed on the latency and accuracy data. The mean reaction time and error rate for each condition are presented in Figure 2.

Figure 2: Mean naming latencies and error rates for conditions with different frequencies and character types for Experiment 1



IC/R:inconsistent/regular, IC/IR:inconsistent/irregular

Of interest here are the relationships between regularity and consistency. For the latency data, a three-way interaction among frequency, regularity, and consistency level was only marginally significant, $F_{1(1,17)}=4.004$, $p=.06$, MSe=15034, and $F_{2(1,72)}=3.147$, $p=.07$, MSe=12040. There was a significant two way interaction between regularity and consistency in the analysis by participants, $F_{1(1,17)}=7.921$, $p<.05$, MSe=14542, but not by item, $F_{2(1,72)}=2.766$, $p=.12$, MSe=10574. The simple main effect showed that the consistency level was significant only when a character was irregular, $F_{1(1,34)}=9.837$, $p<.001$, MSe=17143. An irregular, high consistency character was named faster than an irregular, low consistency one.

For the accuracy data, the three-way interaction was significant in the analysis by participants, $F_{1(1,17)}=14.167$, $p<0.001$, MSe=0.062, but not in the analysis by items, $F_{2(1,72)}=2.664$, $p=0.12$, MSe=0.035. The analysis of simple interaction showed that the interaction between the consistency level and regularity was significant in the low frequency condition, $F_{1(1,34)}=22.91$, $p<0.001$, MSe=0.133, but not in the high frequency condition (Fs<1). The simple main effects of consistency were significant for low frequency characters, both regular, $F_{1(1,68)}=137.01$, $p<0.001$, MSe=0.751, and irregular, $F_{1(1,17)}=22.35$, $p<0.001$, MSe=0.122. Consistency effects could be found in naming both low frequency regular characters and low frequency irregular characters.

2.3 Discussion

Experiment 1 replicated the interaction between frequency and character types and yielded several additional interesting results. First, the regularity effect obtained by contrasting irregular/inconsistent and regular/inconsistent characters was restricted to the low frequency characters. This is consistent with Hue (1992). Second, the comparison between the naming latencies of consistent/regular and inconsistent/regular characters showed significant consistency effects in naming both high frequency characters (28 ms) and low frequency characters (17 ms). The consistency effect found in the high frequency characters replicates the results obtained by Fang et al. (1986) and Lien (1985) (both of whom used only high frequency characters as stimuli), but not by Hue (1992). Third, relative to the non-phonograms, the naming of the regular or consistent phonograms is faster and more accurate, whereas naming an irregular and inconsistent phonogram is slower and less accurate than naming a non-phonogram. These results support the claim that phonological information embedded in Chinese characters is used in the naming process.

Furthermore, a significant interaction between the consistency level and regularity was found in naming low frequency characters. This indicates that, in addition to character frequency, a working model of Chinese character pronunciation should address both variables of regularity and consistency. However, the consistency effect observed by comparing the high consistent irregular to the low consistent irregular stimulus sets was restricted to low frequency characters. This conflicts with the consistency effect observed by comparing the consistent/regular and the inconsistent/irregular characters for naming both high and low frequency characters. A possible reason will be discussed and addressed in Experiment 3.

3. Experiment 2

For Chinese phonograms, most of the phonetic radicals are legitimate characters in their own right. Zhou and Marslen-Wilson (1999) found significant sublexical semantic priming effects and suggested that, in reading complex characters, readers automatically decompose the embedded phonetic radicals from the whole complex characters and map them into their own phonological and semantic representation, in parallel to the mapping based on the whole character. Furthermore, the decomposition process is a general reading strategy, explicitly or implicitly learned, and is particularly useful in reading low frequency characters. Low frequency characters are more likely to be decomposed than high frequency ones, because the frequencies of the phonetic radicals are usually much higher than those of the complex characters themselves. Therefore, the interaction of frequency with regularity could be explained in terms of a competition between the pronunciation of phonetic radicals and that of whole characters, in that such competition is more likely to occur in naming low frequency, exceptional characters.

This explanation raises the question of whether phonetic subunits exist as computation units because (a) they are structures that systematically occur within many Chinese characters, or (b) independent phonological and semantic representations of them are required for the recognition of their freestanding versions. One certainty is that the mappings of Chinese orthography and phonology do not depend solely on whether the pronunciation of the phonogram is the same as that of its phonetic radical. Experiment 1, above, showed a significant consistency effect in comparisons of naming performance for high consistency irregular versus low consistency irregular characters. Furthermore, not all of the phonetic radicals are legitimate characters. There are many phonograms, for instance, 搖 *yao2*、遙 *yao2*、謠 *yao2*、瑤 *yao2*, whose phonetic radicals are not legitimate characters. Peng, Yang, and Chen (1994) labeled such characters whose phonetic radicals derive from other characters and which do not exist independently, “independent phonograms”. They found a significant consistency effect for independent phonograms and suggested that the phonological information provided by a phonetic radical is exploited, regardless of whether the sublexical unit exists as an independent lexical unit or not (Peng et al. 1994). Peng et al. (1994), however, did not manipulate the variable of character frequency in their study. Thus, whether consistency interacts with frequency in naming independent phonograms is still unclear. In the following experiment, the frequency and consistency level of independent phonograms are manipulated to address this question.

3.1 Method

3.1.1 Participants

Participants were eighteen undergraduate students recruited from a pool of participants at Yang-Ming University. All were native speakers of Chinese. Their participation partially fulfilled their course requirements.

3.1.2 Apparatus

The apparatus used in Experiment 2 was the same as in Experiment 1.

3.1.3 Materials and design

Eighty Chinese phonograms were selected for this experiment. (See the list in Appendix 2.) Each phonogram contained a phonetic radical that was not a legitimate Chinese character. Half of the stimuli were high frequency characters (more than 150 occurrences per 10 million) and half were low frequency (no more than 80 occurrences per 10 million), according to the *Mandarin Chinese Character Frequency List* (1995). Each of the frequency groups was subdivided into four conditions, comprising three sets of characters with different consistency levels and one set of non-phonograms. Each subset contained ten characters. The definition of non-phonogram was the same as in Experiment 1.

The characters in the high consistency set were all drawn from completely consistent orthographic neighborhoods, thus their consistency values were 1.0. The average consistency values of characters in the medium and low consistency level sets were 0.66 (range from 0.45 to 0.88) and 0.23 (range from 0.10 to 0.33), respectively. The criteria for each condition and illustrative examples are shown in Table 3.

Table 3 Examples and characteristics of the characters in different frequency groups and consistency levels for Experiment 2

	Character type			
	Consistency level			
Frequency	High	Medium	Low	Non-phonogram
High frequency				
Characters	搖	滴	疏	售
Pronunciation	/yao/	/di/	/shu/	/shou/
Meaning	shake	drip	sparse	sell
Frequency	2833	2614	2368	2585
Consistency value	1	0.62	0.24	*
Low frequency				
Characters	瑙	燐	殮	甩
Pronunciation	/nao/	/lin/	/lian/	/shuai/
Meaning	agate	phosphorus	coffin	swing
Frequency	36	37	31	40
Consistency value	1	0.69	0.23	*

Note The asterisk (*) indicates no consistency value.

3.1.4 Procedure

Participants were individually tested in a small room. They sat in front of the PC at a distance of approximately 60 cm. Before exposure to the experimental items, they underwent ten trial runs, so as to be familiar with the procedure and so that the experimenter could adjust the sensitivity of the voice-key delay.

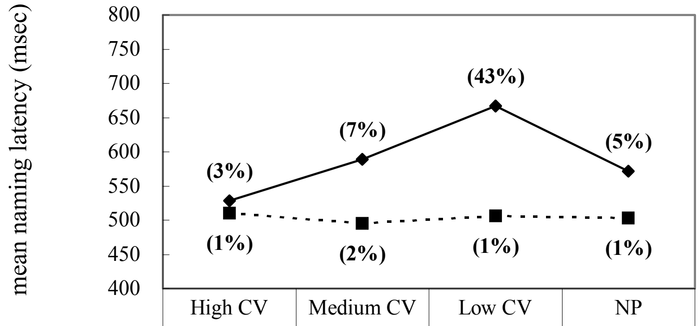
During this experimental period, 80 characters were randomly presented to each participant. The procedure and criteria for selecting valid trials used in Experiment 2 were the same as in Experiment 1.

3.2 Results

There were two variables for this analysis: frequency (high vs. low) and character type (high, medium, low consistency phonograms, and non-phonograms). They were treated as within-subject variables in the analyses by subjects (F_1) and as between-item variables in the analysis by items (F_2). Analyses of variance (ANOVA) were performed on the latency data and accuracy data. The mean reaction time and percent error rate for each condition are presented in Figure 3.

Figure 3: Mean naming latencies and error rates for conditions with different frequencies and character types for Experiment 2

Fig. 3. Mean naming latencies and error rates for conditions with different frequencies and character types in Exp 2



	High CV	Medium CV	Low CV	NP
Low frequency	528	589	667	572
High frequency	510	495	506	503

CV: consistency value;NP:nonphonograms

Participants named high-frequency characters significantly faster than low-frequency characters, $F_{1(1,17)}=87.606$, $p<.001$, $MSe=255256$, and $F_{2(1,72)}=80.291$, $p<.001$, $MSe=138919$, and named them more accurately, $F_{1(1,17)}=83.61$, $p<.001$, $MSe=0.653$, and $F_{2(1,72)}=21.76$, $p<.001$, $MSe=0.363$. The main effects of character type were significant both in the latency data, $F_{1(3,51)}=14.342$, $p<.001$, $MSe=29935$, and $F_{2(3,72)}=7.359$, $p<.001$, $MSe=12733$, and in the accuracy data, $F_{1(3,51)}=101.06$, $p<.001$, $MSe=0.316$, and $F_{2(3,72)}=10.536$, $p<.001$, $MSe=0.176$. The interaction between frequency and consistency was also significant in the latency data, $F_{1(3,51)}=14.515$, $p<.001$, $MSe=32154$, and $F_{2(3,72)}=8.033$, $p<.001$, $MSe=13898$, and in the accuracy data, $F_{1(3,51)}=93.18$, $p<.001$, $MSe=0.334$, and $F_{2(3,72)}=11.071$, $p<.001$, $MSe=0.185$.

Simple main effect analyses showed that the character type effect held only in the low-frequency condition, both for the latency data, $F_{1(3,51)}=28.515$, $p<.001$, $MSe=61343$, and $F_{2(3,72)}=15.093$, $p<.001$, $MSe=26113$, and for accuracy data, $F_{1(3,51)}=109.98$, $p<.001$, $MSe=0.648$, and $F_{2(3,72)}=21.59$, $p<.001$, $MSe=0.360$. The main interest here was in whether the naming latency and the error rate would significantly increase, as character consistency levels get lower. The post hoc comparisons showed that high consistency characters were named faster than medium consistency ones, $F_{1(1,51)}=16.12$, $p<.001$, and $F_{2(1,72)}=19.86$, $p<.001$. The analysis by participant revealed more accurate naming of high consistency characters, $F_{1(1,51)}=5.98$, $p<.02$, but not the analysis by item, $F_2<1$.

Medium consistency level characters were also named faster than low consistency, $F1_{(1,51)}$=24.87, p<.001, and $F2_{(1,72)}$=78.90, p<.001, and also more accurately, $F1_{(1,51)}$=378.26, p<.001, and $F2_{(1,72)}$=63.21, p<.001.

On the other hand, high consistency level characters were named faster than non-phonograms, $F1_{(1,51)}$=7.10, p<.001, and $F2_{(1,72)}$=9.79, p<.001, but there was no difference in accuracy (Fs<1). There was no difference between non-phonograms and medium consistency characters in latency or accuracy of naming (Fs<1). However, the non-phonograms were named much faster than low consistency characters, $F1_{(1,51)}$=40.16, p<.001, and $F2_{(1,72)}$=33.11, p<.001, and more accurately, $F1_{(1,51)}$=428.15, p<.001, and $F2_{(1,72)}$=71.36, p<.001.

3.3 Discussion

The results of Experiment 2 showed a strong frequency-by-consistency interaction in naming independent phonograms. This interaction cannot simply be attributed to competition between the pronunciation of whole characters and that of their phonetic radicals, since those radicals have no pronunciation of their own. The results also suggests that phonetic radicals exist as computation units mainly because they are structures that systematically occur within Chinese characters, not because they are routinely recognized in their freestanding versions.

4. Experiment 3

Experiments 1 and 2 demonstrated that degree of consistency is a valid index in describing the mapping of Chinese orthography to phonology, no matter whether the phonetic radicals exist as independently characters on their own or not. However, the results of these two studies were not in accord with each other as to whether consistency affects naming performance for high-frequency phonograms or not. Experiment 1 showed that the difference in naming performance between consistent/regular and inconsistent/regular characters was as large for high frequency characters as it was for low. However, in regard to high-versus-low consistency irregular characters, there was no consistency effect at all for the high frequency characters, while there was for the low frequency ones. In Experiment 2, the degree of consistency had no effect at all for the high frequency characters. Therefore, the measure of the consistency might need to be further refined.

Glushko (1979) suggested that performance in the task of naming a word is influenced by the sounds of the word's neighbors, which have similar spelling. Jared and his colleagues (1990) claimed that both the **numbers** and the **frequencies** of a word's friends and enemies affect the naming of a word (Jared et al. 1990). In their study, inconsistent words were defined as those whose "word body" is pronounced differently in different words. Words that share a word body (-AVE) with an inconsistent experimental stimulus word (WAVE) were classified as friends if they were pronounced the same way as in the experimental word (e.g., GAVE, SAVE), but classified as enemies if they were pronounced differently (e.g., HAVE). It was found that the consistency effects could be found in naming high and low frequency words when both the mean summed frequency of friends of the experimental words was low and the mean summed frequency of enemies was high (Jared et al. 1990). The magnitude of the consistency effect depended on the relative frequency of friends and enemies (Jared 1997). However, it is more difficult to find high frequency words with summed frequency of friends lower than the summed frequency of enemies. The reason for this is that the summed frequency of friends for most high-frequency inconsistent characters is fairly high, since the frequency of the character itself should be included. It is therefore less likely for high-frequency characters than for low frequency ones that the summed frequency of a character's enemies will exceed the summed frequency of its friends. Indeed, the post hoc examination of the material in Experiment 1 shows that, about 80% of low consistency characters in the high frequency group with higher summed frequency of friends than the summed frequency of enemies. However, only 10% of low consistency character in the low frequency group has this kind of neighborhood characteristic. In experiment 2, we also found that 40% of the materials of high frequency characters with low consistency value have higher summed frequency of friends than the summed frequency of enemies. But none of the low frequency characters with low consistency shows this tendency. Therefore, the consistency effect appears not to be a factor in naming high frequency characters and may be due to features of these character's neighborhoods, which were not well matched in previous studies.

This experiment sought to determine whether an interaction between frequency and consistency would be observed when high and low frequency characters had the same neighborhood characteristics. The high and low frequency inconsistent characters both had low-frequency friends and high-frequency enemies. The question of interest was whether there would also be a consistency effect for the high frequency characters of this type.

4.1 Method

4.1.1 Participants

Participants were twenty-six undergraduate students recruited from a pool of participants at Yang-Ming University. All were native speakers of Chinese. Their participation partially fulfilled their course requirements.

4.1.2 Apparatus

The apparatus used in Experiment 3 was the same as in Experiment 1.

4.1.3 Materials and design

Seventy-six Chinese characters were used in this experiment. (See the list in Appendix 3.) Half were high frequency and half were low frequency. Half of the characters in each frequency group had high consistency values and half had low consistency values. The characters with high or low consistency values within a frequency group were matched for frequency according to the *Mandarin Chinese Character Frequency List* (1995). For each experimental stimulus character, the neighbors were divided into two groups. “Friends” are characters pronounced in the same way as the experimental character. “Enemies” are pronounced in another way. The consistency value weighted by neighbor’s frequency (CV_F) is calculated to represent the ratio of the summed frequency of friends to the summed frequency of the characters within a group of characters sharing a particular phonetic radical. As in Jared et al. (1997), counts of the number and summed frequency of friends for an item included the item itself. Also, in order to avoid having neighborhood statistics inflated by one or two very frequent items, characters with frequencies greater than 1500 were assigned the value 1500. The characters with high consistency value used in this experiment were all consistent characters. They have friends but no enemies. Therefore, the mean CV_F of this group is zero. On the other hand, the characters with lower consistency values in both the high and low frequency conditions all had a low mean summed frequency of friends and a high mean summed frequency of enemies. The CV_F of each character in the low consistency group was constrained to be lower than 0.30. Example characters and statistics for each of the four experimental stimulus groups are presented in Table 4.

Table 4: Examples and the characteristics of the characters in different frequency groups and consistency levels for Experiment 3

	Consistency level	
	High	Low
High frequency		
Example	謠	憐
Pronunciation	yao2	lian2
Meaning	rumor	pity
Frequency	693	613
CV_N	1	0.18
CV_F	1	0.11
Low frequency		
Example	璞	諂
Pronunciation	pu2	chan3
Meaning	uncut jade	to toady
Frequency	26	35
CV_N	1	0.16
CV_F	1	0.03

CV_N: the consistency value defined by number of friends and enemies.
CV_F: the consistency value defined by frequency of friends and enemies.

4.1.4 Procedure

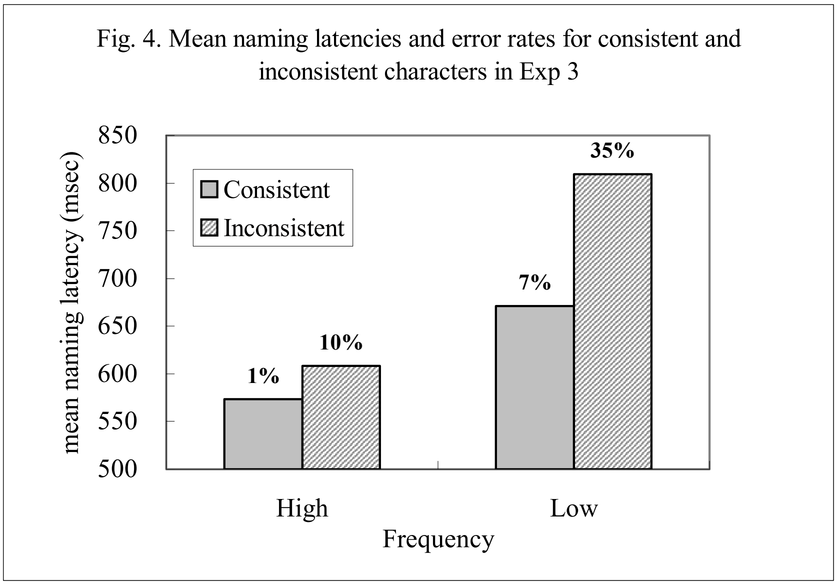
Participants were individually tested in a small room. They sat in front of a PC at a distance of approximately 60 cm. Before exposure to the experimental stimulus items, they underwent ten practice runs, so as to familiarize them with the procedure and so that the experimenter could adjust the sensitivity of the voice-key delay.

During the experimental period, 76 characters were randomly presented to each participant. The procedure and the criteria for selecting valid trials used in this experiment were the same as Experiment 1.

4.2 Results

There were two factors in this experiment: frequency (high vs. low) and consistency level (high vs. low). They were treated as within-subject factors in the analyses by subjects and as between-item factors in the analysis by items. The F values are reported by subject (F_1) and by items (F_2). The mean reaction time and error rate for the four groups are presented in Figure 4.

Figure 4: Mean naming latencies and error rates for consistent and inconsistent characters for Experiment 3



Participants named high-frequency characters significantly faster than low-frequency characters, $\underline{F_1}(1,25)=103.17$, $\underline{p}<.001$, $\underline{MSe}=490270$, and $\underline{F_2}(1,72)=60.03$, $\underline{p}<.001$, $\underline{MSe}=396606$, and more accurately, $\underline{F_1}(1,25)=132.86$, $\underline{p}<.001$, $\underline{MSe}=0.632$, and $\underline{F_2}(1,72)=15.09$, $\underline{p}<.001$, $\underline{MSe}=0.463$. Naming latencies were significantly longer for low consistency characters than for high consistency characters, $\underline{F_1}(1,25)=88.11$, $\underline{p}<.001$, $\underline{MSe}=169365$, and $\underline{F_2}(1,72)=25.40$, $\underline{p}<.001$, $\underline{MSe}=167782$. Participants were significantly more accurate on naming high consistency characters than on low consistency characters, $\underline{F_1}(1,25)=206.20$, $\underline{p}<.001$, $\underline{MSe}=0.884$, and $\underline{F_2}(1,72)=21.20$, $\underline{p}<.001$, $\underline{MSe}=0.650$. The interaction between frequency and consistency level was significant in the latency data, $\underline{F_1}(1,25)=19.18$, $\underline{p}<.001$, $\underline{MSe}=48444$, and $\underline{F_2}(1,72)=4.10$, $\underline{p}<.05$, $\underline{MSe}=27071$. The consistency effect was 37 ms for high-frequency characters and 124 ms for low-frequency characters. The interaction between frequency and consistency in the accuracy data was significant in the analysis by participants, $\underline{F_1}(1,25)=65.90$, $\underline{p}<.001$, $\underline{MSe}=0.203$, and by items, $\underline{F_2}(1,72)=4.93$, $\underline{p}<.03$, $\underline{MSe}=0.151$. The main interest here is in whether the consistency effect could be found in naming high frequency characters. The simple main effect revealed that the consistency effect for high-frequency characters was significant in the latency data, $\underline{F_1}(1,50)=8.24$, $\underline{p}<.01$, $\underline{MSe}=18321$, and $\underline{F_2}(1,72)=4.546$, $\underline{p}<.05$, $\underline{MSe}=30031$. As to the accuracy data, the consistency effect for high-frequency characters was only significant in the analysis by participants, $\underline{F_1}(1,50)=32.65$, $\underline{p}<.001$, MSe=0.120, but not in the analysis by items, $F2_{(1,72)}$=2.842, p=.12, MSe=0.087.

4.3 Discussion

The results of this experiment demonstrate that high and low frequency characters both show significant consistency effects when they have low summed frequencies of friends and high summed frequencies of enemies. Thus, we have replicated the results of Jared et al. (1997). These results suggest that the reason previous experiments failed to find significant consistency effects in naming high-frequency characters might be that the low frequency character stimuli used in those studies were not sufficiently inconsistent to produce observable effects. The present findings further support the conclusions drawn from the results of Experiments 1 and 2; specifically, that performance in character naming is affected by the pronunciations of the character's neighbors that contain the same phonetic radical. They indicate as well that the impact of amount of exposure to each neighbor must be considered not only variation across the neighbors in terms of pronunciation.

5. General discussions

5.1 Main findings

The present experiments yielded several important findings. Experiment 1 showed that the regularity effect obtained by contrasting irregular/inconsistent and regular/ inconsistent characters is restricted to low frequency characters. This is in accord with Hue's (1992) findings. In Experiments 2 and 3, the consistency effects were found in naming phonograms whose phonetic radicals are not legitimate characters in their own right. It suggests that phonological information embedded in Chinese characters is used in the naming processes. Furthermore, the reason phonetic radicals exist as computation units is mainly because they are structures that systematically occur within Chinese characters, not that they are routinely recognized in their freestanding versions.

In addition, our findings suggest that regularity and consistency both play roles in Chinese character naming for the following reasons. First, the consistency effect observed in comparisons of naming latencies for consistent/regular and inconsistent/regular characters is found for both high and low frequency conditions. If regularity were an undifferentiated category, both consistent and inconsistent regular words should be named with the same latency. Yet, they are not; thus, regularity is not the only mapping between Chinese orthography and phonology that affects Chinese character naming. Second, there is a significant interaction between consistency and regularity in naming low frequency characters (Experiment 1). This suggests that neither consistency nor regularity fully explains naming performance.

Third, the consistency effect appears to hold for both high and low frequency conditions, unlike the regularity effect, found only in naming low frequency characters. Experiments 1 and 2, however, left unanswered certain questions about whether there is a consistency effect in naming high frequency characters; for example, considering the different consistency levels in Experiments 1 and 2, consistency effects were restricted to low frequency characters. However, the results of Experiment 3 suggest that a possible reason for these paradoxical results concerns the way consistency is defined. There, we saw that the consistency effect was significant in naming high-frequency phonograms when both high and low frequency inconsistent characters were matched for the summed frequency of friends and enemies. Heretofore, no other study of Chinese phonograms has used high frequency phonograms meeting the criteria of having low summed frequency of friends and high summed frequency of enemies; yet, it is this type of inconsistent word that produces the most robust consistency effect (Jared 1997). In sum, our findings suggest that naming performance for high frequency characters is sensitive to consistency, but not to regularity. This further supports the notion that regularity and consistency are distinguishable factors affecting naming performance for Chinese characters. Furthermore, we concur with Jared (1997), that not only the relative numbers, but also the frequencies of friends and enemies need to be considered in calculating the consistency of orthography-phonology correspondence.

Finally, both Experiments 1 and 2 showed that naming for regular or consistent phonograms is faster and more accurate than naming for non-phonograms, which is faster and more accurate than naming for irregular and inconsistent phonograms. All of the above findings suggest that the pronunciation of Chinese phonograms is not retrieved holistically from the lexicon, but that rather pronunciation is influenced by the pronunciations of other phonograms that contain the same phonetic radical. Relative to non-phonograms, the naming performance for phonograms the pronunciations of which are identical to those of most of their neighbors will be facilitated. This is further evidence in support of claims that phonological information encoded in the phonetic radical is involved in Chinese character naming.

5.2 The implications for a model of pronunciation in Chinese

The present findings suggest that consistency is a better index for describing the mappings between Chinese orthography and phonology than regularity. Consistency completes the specification of the mappings between Chinese orthography and phonology for those phonograms whose phonetic radical do not function as freestanding characters on their own. Furthermore, Experiment 3 demonstrated the consistency effect for naming high frequency phonograms when consistent and inconsistent characters were matched in terms of their numbers of low frequency friends and high frequency enemies. This result is congruent with the findings of Jared et al. (1997) and suggests that this effect is a language universal.

The present cross-linguistic evidence provides a great opportunity to assess the strengths of the different pronunciation models that have been developed with reference to alphabetic writing systems. Among these models, the dual-route model and connectionist approach are most well known. The dual-route account holds that the fundamental explanatory principle in the domain of word reading is that distinctly different mechanisms are necessary for reading non-words on the one hand, and exception words on the other. According to this account, one assembles pronunciations from phonemes generated by the applications of GPC rules. The sublexical GPC procedure in the dual-route account cannot be sensitive to whole-word frequency. An older version of the dual route account (Coltheart 1978, 1983) maps the orthographic input to the phonological output using a lexical lookup procedure. This procedure assumed that whole-word pronunciations were stored in the lexical system. Words were retrieved with no influence from other similarly spelled words. Therefore, this older version is unable to account for the consistency effect. The more recent version—the dual-route cascade (DRC) model—retains the sublexical GPC procedure but used McClelland and Rumelhart's (1981) interactive activation and competition (IAC) model for the addressed lexical process (Coltheart et al. 1993, Coltheart & Rastle 1994). In this version, the consistency effect arises from addressed lexical processing.

Since there are no GPC rules in Chinese, if we adopt the DRC model, the assembled GPC procedure would serve no function in Chinese character naming, whereas the revised lexical processing could account for the consistency effect found in naming Chinese phonograms as follows. The presented word activates lexical entries from the word itself and other visually similar words. Activation spreads from the visual lexicon to the phonological output lexicon that stores whole-word pronunciations of lexical entries. These activated whole-word pronunciations compete with one another and send activation to the phoneme system used to produce speech. Inconsistent words will face more competition and receive less support from their neighbors than that of the consistent words; therefore, the inconsistent words will take longer to pronounce. However, one should consider carefully whether the DRC model is an adequate account of pronunciation cross-linguistically, if it must specify the GPC sublexical route that plays a role in languages with alphabetic scripts but that plays no role in Chinese character naming. It is hard to imagine that a cognitive process serving no function could ever be developed. In addition, the fundamental assumptions that the assembled route is necessary for reading non-words while the addressed route is necessary for exception words make the DRC model predict that Chinese pseudo-characters should be unpronounceable. However, previous research has demonstrated that Chinese pseudo-characters containing phonetic radicals are pronounceable; further, that the consistency effect holds for pseudo-character naming as well (Fang et al. 1986, Lee 2000).

The alternative is to say that the DRC model as a whole is inappropriate for Chinese character naming but that its IAC model component must be sufficient. The bulk of existing research, including the present experiments, have demonstrated that Chinese radicals function as psychologically real entities (Fang & Wu 1989, Feldman & Siok 1997, Taft & Zhu 1997, Feldman & Siok 1999, Taft et al. 1999, Zhou & Marslen-Wilson 1999). Taft and colleagues (1997, 1999) adapted the IAC framework to conceptualize the lexical processing of Chinese characters and words. The Taft et al. version of this lexical processing system includes orthographic, phonological, and semantic subsystems. When a word is visually presented, the system is entered through the lowest feature level of the orthographic subsystem (i.e., strokes and stroke combinations and relationships). Activation then can pass to the relevant phonological and semantic units linked at the radical level, character level, as well as the multi-character character level. Therefore, in this model, character-level processing could be affected by the properties of the components of the characters. The regularity or consistency effect could be explained with reference to the influence of the phonetic radical, arising at the radical level, and that the phonological characteristics of the radical are activated when pronouncing the character that contains it. It can also be explained in terms of there being competition among a range of pronunciations generated at the character level as a result of all the characters containing that radical being activated (Taft & Zhu 1997). Furthermore, in this version of the IAC model, there is no need to specify separate processes for naming characters or pseudo-characters.

The results of Experiment 1 revealed a significant regularity by consistency interaction, suggesting different roles for these two properties in an adequate model for the pronunciation of Chinese. Unlike consistency (defined as a continuous variable for the purpose of our studies), regularity is necessarily a dichotomous notion that can only be applied to a phonogram containing a phonetic radical that is a legitimate character. This fact highlights the uniqueness of Chinese phonetic radicals. When a radical can be a character in its own right, it must obviously have a character-level representation. It seems reasonable to suppose that the consistency effect arises at the radical level, whereas the regularity effect arises at the character level. We may suppose that there is a time lag between processing which links to the phonological unit from the level of the radical and from the level of the character. For a regular character, regardless of its consistency level, the resultant pronunciation, activated by the radical level, is the same as that activated by the character level later on. Therefore, there is no consistency effect in naming regular characters. In contrast, pronunciations arising at the radical and character levels for irregular characters will compete; however, a consistent character will cause stronger activation for the resultant phonological unit than will the inconsistent character. For the consistent irregular character, it will be easier to compete with the pronunciation generated at the character level.

However, the IAC model is actually a precursor of Seidenberg and McClelland's (1989) PDP model for word reading. The main distinction is that the IAC model specifies functional representation levels and relies on excitatory and inhibitory interactions among units; whereas the PDP model is typically based on a network with three layers (input, hidden, and output units) and relies on a learning algorithm (Coltheart et al. 2001). The connectionist approach does not model word pronunciation in terms of different types of processing mechanisms that apply to different types of stimuli, but rather, in terms of computation states involving different types of information (orthography, phonology, semantics; Plaut et al. 1996, Harm & Seidenberg 1999). The current connectionist model can simulate the effects of frequency and consistency of naming performance, both in normal and impaired readers (Plaut et al. 1996, Harm & Seidenberg 1999). Since the index of consistency for Chinese orthography-to-phonology mapping is analogous to the definition of consistency in an alphabetic writing system. Ideally, we could implement the connectionist approach for modeling Chinese character naming. For example, we can adapt the radicals as input units and specify an output coding system similar to that for an alphabetic writing system. If necessary, the tonal information could also be presented at the output layer. However, these are speculative. Further connectional modeling for Chinese character naming is needed in the future research.

5.3 Summary

In conclusion, the findings of the present study suggest that the index of consistency provides a good way of describing the orthography-to-phonology correspondence across different orthographies. It seems that both the IAC and the connectionist model could account for Chinese character naming. In adapting these two models to the process of Chinese character naming, the major difference will be whether we should place something like a lexical node or entry where specific information about particular input is stored. Further research is needed to distinguish which of these two alternatives is better suited to account for the performance of naming Chinese characters. For example, research is needed to determine whether the influence of the phonetic radical arises at radical level or at character level; connectional modeling will also be helpful to address this issue. On the other hand, it is important to keep in mind that the present results do not bear on the issue of whether a word's meaning is phonologically mediated. The results of this study are based on a naming task, which can provide insights for modeling how phonological representations arise in reading character-based orthography. More converging evidence from different paradigms, like lexical decision and priming paradigms will also assist in developing an understanding of the overall word recognition process.

Appendix 1: The complete set of material for Experiment 1

	Character type							
	Consistent/regular		Inconsistent/regular		Inconsistent/irregular		NP	
Frequency	Consistency level							
			High	Low	High	Low		
High	鑼 luo2	濃 nong2	週 zhou1	描 miao2	冷 leng3	稻 dao4	壺 hu2	茶 cha2
	纜 lan3	糖 tang2	輔 fu3	姻 yin1	灑 sa3	濫 lan4	恥 chi3	棄 qi4
	烤 kao3	銘 ming2	驅 qu1	援 yuan2	横 heng2	偏 pian1	爽 shuang3	拿 na2
	躲 duo3	距 ju4	佔 zhan4	階 jie1	硬 ying4	浪 lang4	傘 san3	印 yin4
	錶 biao3	鋼 gang1	橋 qiao2	燈 deng1	抽 chou1	詞 ci2	划 hua2	飛 fei1
	胸 xiong1	授 shou4	磚 zhuan1	銅 tong2	獨 du2	娛 yu2	牽 qian1	岸 an4
	憶 yi4	網 wang3	返 fan3	誠 cheng2	棒 bang4	媒 mei2	弄 nong4	急 ji2
	攔 lan2	換 huan4	評 ping2	遵 zun1	透 tou4	饋 kui4	尖 jian1	算 suan4
	誌 zhi4	試 shi4	詐 zha4	珠 zhu1	語 yu3	握 wo4	蛋 dan4	套 tao4
	慢 man4	採 cai3	胞 bao1	爐 lu2	混 hun4	松 song1	森 sen1	巡 xun2
Low	蝗 huang2	瀝 li4	桅 wei2	棕 zong1	儕 chai2	躊 chou2	繭 jian3	卵 luan3
	瞑 ming2	眶 kuang4	鑲 xiang1	殃 yang1	踝 huai2	憔 qiao2	茸 rong2	蠶 can2
	褥 ru4	胰 yi2	駭 hai4	蹊 xi1	犒 kao4	輓 wan3	吝 lin4	匠 jiang4
	獰 ning2	燼 jin4	躡 nie4	縊 yi4	咄 duo4	謗 bang4	禿 tu1	蕊 rui3
	擂 lei2	愕 e4	鉀 jia3	醺 xun1	漬 zi4	鈍 dun4	婪 lan2	屜 ti4
	膳 shan4	熔 rong2	瞳 tong2	膛 tang2	誨 hui4	殞 yun3	棗 zao3	宦 huan4
	猿 yuan2	曖 ai4	揀 jian3	猙 zheng1	聒 gua1	饌 zhuan4	盥 guan4	咒 zhou4
	嚎 hao2	傭 yong1	絆 ban4	跤 jiao1	緘 jian1	垢 gou4	羹 geng1	潸 shan1
	悽 qi1	朦 meng2	碇 ding4	鞍 an1	蹄 ti2	犢 du2	孽 nie4	夙 su4
	惺 xing1	扼 e4	鯨 jing1	趾 zhi3	贍 shan4	涕 ti4	侃 kan3	矗 chu4

Appendix 2: The complete set of material for Experiment 2

	Consistency level			
Frequency	High	Median	Low	Non-phonogram
High	搖 yao2	碌 lu4	浸 jin4	售 shou4
	撲 pu1	滴 di1	湯 tang1	突 tu2
	陶 tao2	璃 li2	疏 shu1	毒 du2
	峰 feng1	聰 cong1	禍 huo4	泰 tai4
	捐 juan1	珍 zhen1	倍 bei4	寬 kuan1
	懷 huai2	俊 jun4	逮 dai3	患 huan4
	游 you2	遇 yu4	探 tan4	厚 hou4
	樣 yang4	織 zhi1	邀 yao1	焚 fen2
	傷 shang1	構 gou4	假 jia3	奔 ben1
Low	滿 man3	環 huan2	護 hu4	幽 you1
	瑙 nao3	燐 lin2	愎 bi4	簒 cuan4
	殭 jiang1	蝠 fu2	殮 lian4	黍 shu3
	潦 liao2	掬 ju2	臊 sao4	胤 yin4
	璨 can4	儡 lei3	揖 yi1	釜 fu3
	佇 zhu4	湮 yin1	掐 qia1	虱 shi1
	榻 ta4	跋 ba2	褐 he2	叩 kou4
	睫 jie2	檀 tan2	溥 pu3	甩 shuai3
	楞 leng4	蠟 la4	綴 zhui4	弔 diao4
	珮 pei4	諜 die2	噱 xue1	磊 lei3
	瑣 suo3	訣 jue2	棧 zhan4	皂 zao4

Appendix 3: The complete set of material for Experiment 3

High frequency		Low frequency	
High consistency	Low consistency	High consistency	Low consistency
懇 ken3	毓 yu4	璞 pu2	孿 luan2
撲 pu1	蠻 man2	殭 jiang1	竅 qiao4
僵 jiang1	憐 lian2	燎 liao2	諂 chan3
鷹 ying1	寒 han4	殤 shang1	痠 suan1
髓 sui2	逼 bi1	榻 ta4	殄 tian3
僚 liao2	隸 li4	瑣 suo3	懺 chan4
謠 yao2	琛 chen1	瑙 nao3	擢 zhuo2
鎖 suo3	倍 bei4	楞 leng4	噱 xue1
惱 nao3	梭 suo1	犛 li2	戮 lu4
佩 pei4	釀 niang4	珮 pei4	喙 hui4
迅 xun4	險 xian3	愜 qie4	愎 bi4
氾 fan4	謬 miu4	薔 qiang2	媧 wa1
壞 huai4	津 jin1	漾 yang4	揖 yi1
燦 can4	湯 tang1	鷂 yao2	湍 tuan1
曆 li4	窩 wo1	琢 zhuo2	謁 ye4
游 you2	揣 chuai3	睫 jie2	盞 zhan3
陶 tao2	暖 nuan3	啕 tao2	誦 song4
娟 juan1	睦 mu4	涓 juan1	袂 mei4
鋒 feng1	勁 jin4	烽 feng1	耽 dan1

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漢字唸名的一致性，規則性，與頻率效果

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本研究一共包含三個實驗，用以探討中文的字頻，表音一致性，以及表音規則性如何影響唸字的歷程。三個實驗中，不論形聲字的音旁是否能夠單獨存在成爲一個合法的字，均可發現顯著的字頻與表音一致性的交互作用。這些研究結果用來支持，音旁所具有的語音訊息，在認字的歷程中會被解離出來，進而影響唸字的速度與正確率。而這些語音訊息的解離，並不單純是因爲這些音旁本身是否具有讀音，而是因爲這個結構系統性的出現在不同的形聲字當中，進而具有對應的語音訊息。此外，實驗一的結果發現表音的一致性與規則性對於唸字的歷程有不同的影響。這些研究結果可以用交互激發模型與連結模型來討論。

關鍵詞：字頻，一致性，規則性，唸名作業