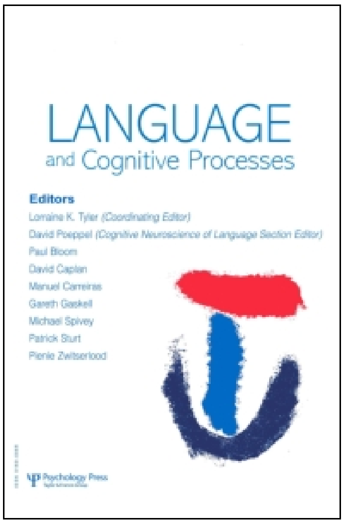

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Homophone density and phonological frequency in Chinese word recognition

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Homophone density and phonological frequency in Chinese word recognition

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The present research factorially examined the effects of homophone density, visual frequency, and phonological frequency (defined here as the cumulative frequency of homophone mates) in Chinese visual word recognition. Stimuli were compound characters matched in semantic and phonetic radical neighbourhood density and in average visual frequency of orthographic neighbours. In contrast to a previous study with Chinese by Ziegler, Tan, Perry, and Montant (2000), no facilitative effect of phonological frequency was observed. Unlike previous findings with English readers of inhibitory effects of homophones, a facilitative effect of homophone density – restricted to low visual frequency words – was obtained for Chinese in both lexical decision (Exp. 1) and naming (Exp. 2), similar to Ziegler et al. (2000). Our results suggest that, when there is less possibility of sublexical competition between similar spellings,

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homophone density effects are facilitatory. This outcome supports theoretical positions regarding the mental representation of homophones that assume a single representation for homophones at the phonological word form level.

Keywords: Homophone density; Phonological frequency; Chinese word recognition; Universal phonology principle; Cross-linguistic approach.

The role of phonology in visual word recognition has been the focus of much debate. Recently, a number of studies have shown across lexical decision (Yates, 2005; Yates, Locker, & Simpson, 2004), naming (Yates, 2005), and semantic categorisation tasks (Yates, 2005) that the presence of many vs. few phonological neighbours of a word speeds word processing. Further, it has been proposed that phonological and orthographic neighbourhood density interact in word recognition (e.g., the cross-code consistency notion; Grainger, Muneaux, Farioli, & Ziegler, 2005).

Studies of neighbourhood effects, like those in visual word recognition in general, have in large part been conducted with readers of writing systems in which orthography and phonology have a high degree of overlap. This has complicated evaluation of phonological variables in word recognition independently from orthographic variables. Furthermore, it has made it difficult to know the extent to which theories of word recognition are generalisable to readers of writing systems in which there is not such a close coupling between phonological and orthographic information and in which phonological and orthographic variables may operate on different units than those typically studied in users of English, French, or German. Thus, for example, orthographic or phonological neighbours have been defined experimentally with reference to units such as graphemes or phonemes that, strictly speaking, have no counterpart in readers of logographic scripts such as Mandarin. If models of word recognition are to be truly comprehensive in their scope, they should be able to capture generalisations that hold across different languages (Share, 2008). For this to occur there needs to be more empirical research done with readers of different types of languages.

The present research investigated the role of phonology in Chinese visual word recognition by studying the effects of varying homophone density and phonological frequency. Homophone density refers to the number of homophone mates of a word; phonological frequency (following Ziegler et al., 2000) refers to the cumulative frequency of a word's homophone mates. Homophones would seem to offer an ideal test case for the study of the influence of phonology on visual word recognition since words that are homophonic by definition sound alike, whether or not they are spelled alike.

Previous studies with readers of English and French found that homophones either had no effect on lexical decision or else had an inhibitory effect, especially in the case of low frequency words with higher frequency homophone mates (Ferrand & Grainger, 2003; Pexman, Lupker, & Jared, 2001; Rubenstein, Lewis, & Rubenstein, 1971). However, homophone *density* effects in these languages have not been examined, perhaps because of the relatively low incidence of words with several homophonic mates. Even if suitable contrasts of high vs. low homophone density stimuli could be found in English or French, it would be very difficult to separate out the effect of spelling from sound similarity in these languages.

The above limitations do not pose problems for readers of logographic scripts, such as Chinese, since in these languages it is possible to control visual characteristics of words without influencing the words' phonological properties. Thus, one can easily obtain homophones in Chinese that do not have orthographically similar referents. Moreover, Chinese has a high incidence of characters with multiple homophones; according to Tan and Perfetti (1998), about 11 Chinese characters share the same pronunciation on average.

One previous study that addressed both homophone density and phonological frequency in Chinese is, therefore, noteworthy. Ziegler et al. (2000) reported, in their first experiment, that when the specific visual word frequency of a character was kept constant, lexical decision and naming responses to characters with few or many homophone mates were faster than those to characters with no homophone mates. In their second experiment they reported that words with high phonological frequency (defined as cumulative surface frequency of the word's homophones) showed faster lexical decision latencies than those with low phonological frequency. Based on these findings, Ziegler et al. (2000) argued that the visual frequency effect may be partially phonological and that their results support the universal phonological principle.

However, a closer look at the Ziegler et al. study suggests two potential concerns. First, as they themselves point out, the effect of homophone density in their study (Exp. 1) was not a linear effect: that is, lexical decision or naming was not differentially affected for words with few homophone mates vs. for those with many homophone mates, but both of these differed from words with no homophone mates. It is, thus, unclear whether the results reflect a slowness in recognising words with no homophone words (these being rather rare words) or a facilitation for words with one or more homophone mates. To decide between the two would require a replication manipulating homophonic density. A second concern is that Ziegler et al.'s (2000) stimuli did not fully control for the nature of sublexical characteristics (radicals).[1] Other studies with Chinese have suggested that sharing semantic

[1] Many Chinese characters are formed by combining different radicals. For example, the character 橡 (pronounced as /shiang4/, where the number denotes the tone, and means *oak*), is produced by combining a semantic radical 木 (pronounced as /mu4/, and means *wood*), and a phonetic radical 象 (pronounced as /shiang4/, and means *elephant*).

or phonetic radicals influences visual word recognition (Feldman & Siok, 1999; Wu & Chen, 2003).

The present study addressed both these concerns. Using a factorial design that manipulated homophone density, visual frequency, and phonological frequency, it provided a test of Ziegler et al.'s claims regarding a facilitative effect of homophone density and phonological frequency. Further, it used a better controlled set of stimuli that were matched for the presence of shared semantic and phonetic radicals.

EXPERIMENT 1: LEXICAL DECISION

Method

Participants. Twenty-five students recruited from the participant pool at a large university in northern Taiwan participated in the experiment to partially fulfil course requirements. All were fluent readers of traditional Chinese and had normal or corrected-to-normal vision.

Design and stimuli. A three-factor within-subjects design was used. The factors manipulated were visual frequency (high vs. low), phonological frequency (high vs. low), and homophone density (high vs. low), yielding a total of eight conditions.

Stimuli consisted of 112 compound Chinese characters, 14 per condition. Based on the database of Wu and Liu (1988), visual frequencies were either higher than 80 or lower than 25 occurrences per million. Phonological frequencies were either higher than 1500 or lower than 250 per million. High homophone density characters referred to those having more than seven homophone mates and low homophone density characters had fewer than five homophone mates. Homophone mates in the present study were defined by Chinese characters sharing exactly the same phonology including tones. Eight sets of stimuli were matched in overall means for each condition on number of strokes, semantic radical neighbourhood density, mean frequency of semantic radical neighbours, phonetic radical neighbourhood density, and mean frequency of phonetic radical neighbours. All values of these linguistic characteristics were obtained or calculated from characters with a visual frequency higher than one occurrence in the database of Wu and Liu (1988) and Wu (2003). See Table 1 for a summary of stimulus characteristics.

Fifty-six Chinese characters were selected as fillers. A set of 168 pseudo-characters was created by combining a semantic radical and a phonetic radical that do not co-occur in real characters.

TABLE 1
Characteristics of the stimuli used in Experiments 1 and 2 (mean values)

	High VF				*Low VF*			
	High PF		*Low PF*		*High PF*		*Low PF*	
Characteristic	*High HD*	*Low HD*	*High HD*	*Low HD*	*High HD*	*Low HD*	*High HD*	*Low HD*
NS	12.14	12.14	12.00	12.50	12.79	12.86	12.21	12.50
VF	214.93	225.93	206.93	203.79	9.50	8.86	8.71	8.93
PF	2564.71	2607.21	570.00	544.43	2425.21	2618.14	574.64	534.21
HD	10.07	3.71	9.79	3.64	10.71	3.79	10.43	3.86
SRND	123.00	115.50	135.79	140.57	117.71	112.07	104.29	158.00
Mean VF of SRN	146.83	132.43	139.57	114.07	101.45	132.98	102.11	122.75
PRND	4.79	5.36	6.57	6.14	5.57	5.93	6.21	6.43
Mean VF of PRN	59.22	62.37	56.32	57.89	64.49	57.90	59.40	60.09

Note. VF = visual frequency; PF = phonological frequency; HD = homophone density; NS = number of strokes; SRND = semantic radical neighbourhood density; SRN = semantic radical neighbours; PRND = phonetic radical neighbourhood density; PRN = phonetic radical neighbours.

Apparatus. The experiment was administered on personal computers using software developed by Wu (1995). Reaction times (RTs) and stimulus exposure duration were measured to the nearest millisecond and synchronised with the onset of video frame refreshing.

Procedure. Stimuli were presented in white on a black screen background and presented with a visual arc of approximately 1.2 degrees and a viewing distance of 60 cm.

On each trial a cross, used as a fixation point, was presented at the centre of the screen for 900 ms and was replaced by a blank for 100 ms. Then, a target character was presented at the centre of the screen and remained until the computer detected the onset of the participant's response. Participants were to decide whether the character presented on the screen was a real Chinese character or not and to indicate their choice by pressing one of two assigned keys as quickly and as accurately as possible. The response timing started from the presentation of the target character until the response was made. A 1000 ms blank was shown before the next trial was presented. Participants received 15 practice trials with feedback.

Each participant, tested individually, received a different blocked randomised sequence of stimuli that included 168 real Chinese characters and 168 pseudo-characters. A rest period was administered after every 24 trials.

Results and discussion

In calculating the mean RTs of correct responses for each condition for each participant, those trials with RTs less than 200 ms or higher than 2000 ms were discarded. These cutoffs led to the rejection of less than 1% of the observations. Table 2 shows the accuracy and re-computed means for correct RTs for each experimental condition.

The RT and accuracy data were analysed in a $2 \times 2 \times 2$ three-way repeated measures analysis of variance (ANOVA) that resulted from the factorial combination of Visual frequency, Phonological frequency, and Homophone density. The data were analysed by subjects (F_1) and by items (F_2).

The results of the ANOVA indicated a significant main effect for Visual frequency in RT, $F_1(1, 24) = 98.07$, $p < .001$, $F_2(1, 104) = 77.04$, $p < .001$, and in accuracy, $F_1(1, 24) = 36.85$, $p < .001$, $F_2(1, 104) = 30.52$, $p < .001$, showing an advantage for high visual frequency characters. In addition, a significant main effect for Homophone density was obtained in RT, $F_1(1, 24) = 25.46$, $p < .001$, $F_2(1, 104) = 8.30$, $p < .01$, and in accuracy, $F_1(1, 24) = 31.13$, $p < .001$, $F_2(1, 104) = 10.35$, $p < .01$, indicating an advantage for high homophone density characters. However, no significant main effect of Phonological frequency was obtained in either RT, $F_1(1, 24) < 1$, $F_2(1, 108) < 1$, or in accuracy, $F_1(1, 24) = 3.18$, *ns*, $F_2(1, 108) = 1.07$, *ns*.

TABLE 2
Mean reaction time (ms) and accuracy (%) in Experiment 1 (standard errors in parentheses).

		High VF			*Low VF*		
		High HD	*Low HD*	*HD Effect*	*High HD*	*Low HD*	*HD Effect*
High PF	RT	471 (19)	490 (20)	18.5 (7.7)	543 (19)	605 (23)	62.0 (10.3)
	Accuracy	98.3 (0.7)	98.3 (0.7)	0.0 (0.8)	95.7 (1.2)	86.9 (1.8)	8.9 (2.1)
Low PF	RT	468 (18)	477 (21)	8.8 (9.9)	559 (24)	599 (28)	39.9 (16.9)
	Accuracy	99.7 (0.3)	98.3 (0.6)	1.4 (0.7)	95.4 (1.4)	90.6 (1.7)	4.9 (1.6)
PF Effect	RT	−2.9 (7.5)	−12.6 (11.0)		16.2 (12.7)	−5.9 (16.3)	
	Accuracy	−1.4 (0.8)	0.0 (1.1)		0.3 (1.8)	−3.7 (1.7)	

Note. VF = visual frequency; PF = phonological frequency; HD = homophone density. PF effect refers to the difference in performance on the high vs. the low phonological frequency condition. The HD effect refers to the difference in performance on the high vs. the low homophone density condition. A positive value indicates a facilitative effect and a negative value an inhibitory effect.

A significant interaction between Visual frequency and Homophone density was also found in the RT analysis by subjects, $F_1(1, 24) = 8.19$, $p < .01$, $F_2(1, 104) = 2.69$, *ns*, and in the accuracy analysis, $F_1(1, 24) = 19.94$, $p < .001$, $F_2(1, 104) = 6.82$, $p < .05$. Further simple effect analyses suggested that the homophone density effect was restricted to low visual frequency characters both in RT, $F_1(1, 48) = 31.11$, $p < .001$, $F_2(1, 104) = 10.22$, $p < .01$, and in accuracy, $F_1(1, 48) = 50.37$, $p < .001$, $F_2(1, 104) = 16.98$, $p < .001$; it was not obtained for high visual frequency characters in either RT, $F_1(1, 48) = 2.23$, *ns*, $F_2(1, 104) < 1$, or accuracy, $F_1(1, 48) < 1$, $F_2(1, 104) < 1$. No other significant interactions were obtained.

In summary, with a better control of the characteristics of radicals among the neighbours and a cleaner examination of the effects of homophone density and phonological frequency, both RT and accuracy analyses in the present study indicated a facilitative effect of homophone density (restricted to low frequency words) and no effect of phonological frequency. The fact that our homophone density effect was restricted to low visual frequency characters is consistent with other results on neighbourhood density effects (Andrews, 1997; Yates et al., 2004). The facilitative homophone density effect extends Ziegler et al.'s (2000) Exp. 1 results in showing a clear effect of number of homophone mates, but the null effect of phonological frequency calls into question Ziegler et al.'s (2000) finding of a facilitative effect of phonological frequency.

EXPERIMENT 2: NAMING

It could be argued that use of the lexical decision task might have contributed to our failure to replicate the phonological frequency effect reported by Ziegler et al. (2000) given that lexical decision is not a phonologically demanding task (Shen & Forster, 1999). In Experiment 2, we therefore used a naming task, a task that requires phonology. If there is, in fact, a facilitative phonological frequency effect, it should easily show up in a naming task.

Method

Participants. A different group of 32 students were recruited using the same criteria and from the same subject pool as Experiment 1.

Design and stimuli. The design and the stimuli were the same as in Experiment 1 except that pseudo-characters were now excluded.

Apparatus and procedure. The apparatus was the same as in Experiment 1 except that a voice-activated circuit was used to detect naming. Participants' task was to name each stimulus out loud as quickly and as accurately as possible. Each participant received a blocked randomised sequence of stimuli containing 168 Chinese characters. The entire experiment took approximately 20 minutes.

Results and discussion

The same cutoffs as in Exp. 1 were used and led to the rejection of less than 1% of the observations. Table 3 shows the accuracy data and the re-computed means for correct RTs for each experimental condition.

The results of the ANOVA indicated a significant main effect for Visual frequency in RT, $F_1(1, 31) = 105.50$, $p < .001$, $F_2(1, 104) = 69.97$, $p < .001$, and in accuracy, $F_1(1, 31) = 107.49$, $p < .001$, $F_2(1, 104) = 14.49$, $p < .001$, indicating an advantage of high visual frequency characters. A significant main effect for Homophone density was also obtained in RT, $F_1(1, 31) = 19.00$, $p < .001$, $F_2(1, 104) = 3.55$, $p = .06$, and in accuracy, $F_1(1, 31) = 21.80$, $p < .001$, $F_2(1, 104) = 3.83$, $p = .05$, indicating an advantage of high homophone density. A significant main effect of Phonological frequency was also found in the analysis by subjects: for RT, $F_1(1, 31) = 8.95$, $p < .01$, $F_2(1, 104) = 1.57$, *ns*, and for accuracy, $F_1(1, 31) = 12.23$, $p < .01$, $F_2(1, 104) = 1.07$, *ns*. However, the nature of the effect was that high phonological frequency characters were responded to more *slowly* and *less* accurately than low phonological frequency characters.

A significant interaction between Homophone density and Visual frequency was found in the RT analysis by subjects, $F_1(1, 31) = 11.00$, $p < .01$, $F_2(1, 104) = 2.07$, *ns*, and in both of the accuracy analyses, $F_1(1, 31) = 21.93$, $p < .001$, $F_2(1, 104) = 4.11$, $p < .05$. Further simple effect analyses suggested that words with high homophone density were responded to faster and more accurately than those with low density for low frequency characters only; RT, $F_1(1, 62) = 29.66$, $p < .001$, $F_2(1, 104) = 5.52$, $p < .05$; accuracy, $F_1(1, 62) = 43.72$, $p < .001$, $F_2(1, 104) = 7.94$, $p < .01$.

In the accuracy analysis a significant interaction between Phonological frequency and Visual frequency was found in the by-subjects analysis, $F_1(1, 31) = 10.68$, $p < .01$, $F_2(1, 104) = 1.21$, *ns*. Simple effect analyses suggested a significant inhibitory phonological frequency effect for low visual frequency characters, $F_1(1, 62) = 22.69$, $p < .001$, $F_2(1, 104) = 2.28$, *ns*, but no effect of phonological frequency for high visual frequency characters, $F_1(1, 62) < 0.1$, $F_2(1, 104) < 1$. No other significant interactions were found.

Taken together, our Experiment 2 results using a naming task were similar to those obtained in Experiment 1 using a lexical decision task: in both experiments we found a *facilitative* homophone density effect and an absence of a facilitative phonological frequency effect. Importantly, we were unable

TABLE 3
Mean reaction time (ms) and accuracy (%) in Experiment 2 (standard errors in parentheses).

		High VF			*Low VF*		
		High HD	*Low HD*	*HD Effect*	*High HD*	*Low HD*	*HD Effect*
High PF	RT	471 (15)	469 (16)	−1.9 (8.0)	568 (21)	610 (26)	42.6 (11.4)
	Accuracy	99.1 (0.4)	99.8 (0.2)	−0.7 (0.4)	95.1 (1.1)	88.4 (1.5)	6.7 (2.1)
Low PF	RT	454 (13)	468 (15)	14.5 (6.5)	548 (18)	583 (23)	34.4 (13.4)
	Accuracy	99.6 (0.3)	99.1 (0.4)	0.4 (0.4)	98.0 (1.0)	92.2 (1.0)	5.8 (1.6)
PF Effect	RT	−17.5 (7.5)	−1.2 (8.0)		−19.4 (9.7)	−27.6 (14.2)	
	Accuracy	−0.4 (0.5)	0.7 (0.5)		−2.9 (1.4)	−3.8 (1.7)	

Note. VF = visual frequency; PF = phonological frequency; HD = homophone density. PF effect refers to the difference in performance on the high vs. the low phonological frequency condition. HD effect refers to the difference in performance on the high vs. the low homophone density condition. A positive value indicates a facilitative effect and a negative value an inhibitory effect.

to replicate the facilitative phonological frequency effect reported by Ziegler et al. (2000) on a naming task.

GENERAL DISCUSSION

Our results showed that for both Chinese lexical decision and naming the presence of many vs. few homophone mates facilitated visual word recognition, all other things being equal. As such, our results provide a clearer demonstration of a homophone facilitation effect than that reported by Ziegler et al. (2000) and support the view that homophones have a single shared representation in the lexicon (Biedermann & Nickels, 2008; Levelt, Roelofs, & Meyer, 1999) rather than separate representations (Caramazza, 1997; Caramazza, Costa, Miozzo, & Bi, 2001).

The present findings are consistent with models claiming that a word can benefit from feedback from connected representations from its homophonic mates at different levels (e.g., Levelt et al., 1999). The dual route cascaded (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) had been challenged for its prediction of a facilitative homophone effect since it went against previous inhibitory findings because it did not acknowledge sublexical competition from similarly spelled homophones (Biedermann, Coltheart, & Nickels, 2007). However, the present results suggest that a homophone density effect could be facilitative if competition among similar orthographic representations is reduced, as is the case in Chinese homophones.

We suggest two possible explanations for our finding of a facilitative effect of homophone density, one that applies mainly to the lexical decision task and the other to the naming task. The former explanation relies on a model with a mechanism sensitive to global lexical activation (Grainger & Jacobs, 1996). In this view, words with higher homophone density activate more representations in the mental lexicon.

The explanation of global lexical activation, of course, cannot fully explain why we saw a facilitative effect on the naming task as well. To explain the latter effect we propose that the facilitation was a net outcome of excitatory feedback and feedforward connections between the orthographic and phonological lexicons. Because naming is a phonologically demanding task compared with lexical decision (Shen & Forster, 1999), one might have expected a larger phonological effect (namely, of homophone density) for naming. However, our data suggest that the size of the homophone density effect did not differ across the two tasks of lexical decision and naming, $F(1, 55) = 1.49$, $p = .23$. Thus, we cannot conclude that there was a greater degree of phonological processing in the naming task. In fact, there is other evidence to suggest that there is greater lexical involvement in Chinese naming tasks than one might have expected based on studies with English: Liu, Wu, and Chou (1996) found that the word frequency effect, which is commonly taken as an indicator of lexical processing, was actually larger in naming than in lexical decision for Chinese. Thus, we feel that it may be premature to reject the global lexical activation account of our results even though we found a facilitative effect of homophone density in naming as well.

Nevertheless, the finding of a homophonic effect in naming suggests that mechanisms other than global lexical activation may also be at work in the Chinese homophone density effect. One possible candidate, namely, feedback consistency (Stone, Vanhoy, & Van Orden, 1997; Ziegler, Montant, & Jacobs, 1997), has been suggested to be the cause of the inhibitory homophonic effect (e.g., Pexman et al., 2001), which would challenge the facilitative homophone density effect obtained in Chinese. However, Chinese homophones do not necessarily share similar spellings which may be the main cause of competition among homophones of alphabetic writing systems. As such, Chinese homophone processing could benefit from the accumulation by a group of homophone mates in phonological lexicon as predicted by the DRC model with minimal inhibitory influences from similar spellings in orthographic lexicon. Alternatively, inhibitory effects arising from feedback consistency may be offset by facilitative effects.

The seemingly contradictory findings between previous studies of homophone density and the present study may also reflect the fact that previous studies tested different aspects of homophones than our own study did. Whereas previous studies examining homophonic effects mainly compared word pairs with vs. without a single homophonic mate, the present study compared Chinese characters with many vs. few homophonic mates. The difference is analogous to studies of the orthographic neighbourhood *frequency* effect vs. the orthographic neighbourhood *density* effect. Whereas the former compared words with vs. without a higher frequency orthographic neighbour, the latter compared words with many vs. few orthographic neighbours. Studies have suggested that whereas the orthographic neighbourhood *frequency* effect tends to be *inhibitory*, which suggests orthographic competition (Perea & Pollatsek, 1998), the orthographic neighbourhood *density* effect tends to be *facilitative*, which is supported by a global lexical activation account (Grainger & Jacobs, 1996) and/or facilitative effects caused by bi-directional connections between lexical and sublexical representations that offset the lexical competition (Andrews, 1997). As such, whereas inhibitory homophonic effects obtained in alphabetic writing systems presumably reflect competition arising from feedback consistency, our facilitative Chinese homophonic density effect may reflect global lexical activation as well as feedback/feedforward connections that offset the competition among lexical representations.

Although Ziegler et al. (2000) found a facilitative phonological frequency effect in both lexical decision and naming, we obtained an inhibitory phonological frequency effect in naming and no phonological frequency effect in lexical decision when controlling for the presence of shared radicals that has been shown to influence Chinese visual word recognition (Feldman & Siok, 1999; Wu & Chen, 2003). As shown in Table 4, characteristics of radical neighbours may covary with phonological frequency. Ziegler et al.'s (2000) study mainly controlled for neighbourhood density of *semantic* radicals, which we found to be the only non-significant variable of those summarised in Table 4. We suggest that our results differ from those found by Ziegler et al. (2000) because Ziegler et al. failed to control for other radical variables.

The fact that phonological frequency effects were only revealed in low visual frequency characters suggests that this effect may stem from competition among homophone mates with higher surface frequencies. A character with low surface frequency but high phonological frequency would likely have homophone mates with high surface frequency. The slower and less accurate naming responses for characters with low surface but high phonological frequencies, compared with those with low surface and low phonological frequencies, indicates stronger competition from homophone mates. Because an inhibitory phonological frequency effect was only found in naming, a phonologically demanding task, and not in lexical decision, this effect may be restricted to conditions mandating phonological activation. The phonological frequency manipulation in the present study, which is defined by Ziegler et al. (2000), could be conceptualised by how many times a specific phonology is recovered in the phonological lexicon and implicitly suggests that phonology is recovered every time one encounters a Chinese character. In this sense, the definition of phonological frequency in visual word recognition by Ziegler et al. (2000) is more like *recovered* phonological frequency, which is different

TABLE 4
Characteristics of high and low phonological frequency characters (mean values).

Characteristic	*PF ≤ 1000 per million*	*PF > 1000 per million*	*t*	*p*
SRND	102.12	97.55	1.60	ns
Mean VF of SRN	128.22	153.23	3.82	<.001
PRND	9.57	13.15	2.61	<.01
Mean VF of PRN	102.81	153.54	4.73	<.001

Note. PF = phonological frequency; SRND = semantic radical neighbourhood density; SRN = semantic radical neighbours; PRND = phonetic radical neighbourhood density; PRN = phonetic radical neighbours. All values were calculated from Chinese characters with a visual frequency higher than 1 occurrence per million in the database of Wu (2003).

from the typical understanding of phonological frequency in studies of auditory word recognition. The present study obtained no evidence of a facilitative phonological frequency effect in Chinese reading, whether in lexical decision or naming. The inhibitory phonological frequency effect obtained in our naming experiment actually reflected competition among homophonic mates instead of an effect of phonological frequency per se. Since the effect of 'recovered phonological frequency' was not consistently obtained, the view of strong recovered phonology in Chinese single character recognition was not supported by the present study and thus suggests that the phonological frequency effect (at least as defined in the present study following Ziegler et al., 2000) cannot be used as support for the universal phonology hypothesis. This is in line with the suggestion from other studies that phonological processing may not be as central in morphosyllabic writing systems as it is in alphabetic writing systems (see Chen & Shu, 2001; Chen, Yamauchi, Tamaoka, & Vaid, 2007; Wu & Chen, 2000). Nevertheless, to the extent that we obtained a clear, facilitative effect of homophone density, there is evidence for phonological processing even in morphosyllabic writing systems. However, since we did not compare readers of these scripts with those of alphabetic scripts in the same study it remains to be seen whether the size of the homophone density effect may vary as a function of writing system characteristics.

Our research approach, which exploits properties of the Chinese writing system, provided a means for examining visual word recognition processes that cannot as easily be achieved by studying alphabetic writing systems. The important and robust finding from our study is that of a facilitative homophone density, found in both lexical decision and naming. We suggest that this outcome can be explained in part by models that posit a mechanism sensitive to global activation and in part by feedback/feedforward connections in the mental lexicon.

REFERENCES

Andrews, S. (1997). The effects of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin and Review*, *4*, 439–461.

Biedermann, B., Coltheart, M., & Nickels, L. (2007, September). *The representation of homophones in spoken word production: Evidence from reading aloud.* Poster session presented at the 4th International Workshop on Language Production (IWOLP), Muenster, Germany.

Biedermann, B., & Nickels, L. (2008). The representation of homophones: More evidence from the remediation of anomia. *Cortex*, *44*, 276–293.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology*, *14*, 177–208.

Caramazza, A., Costa, A., Miozzo, M., & Bi, Y. (2001). The representation of homophones: evidence from the frequency effect in picture naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 1430–1450.

Chen, H.-C., & Shu, H. (2001). Lexical activation during the recognition of Chinese characters: Evidence against early phonological activation. *Psychonomic Bulletin and Review*, *8*, 511–518.

Chen, H.-C., Yamauchi, T., Tamaoka, K., & Vaid, J. (2007). Homophonic and semantic priming of Japanese kanji words: A time course study. *Psychonomic Bulletin and Review*, *14*, 64–69.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*, 204–256.

Feldman, L. B., & Siok, W. W. T. (1999). Semantic radicals contribute to the visual identification of Chinese characters. *Journal of Memory and Language*, *40*, 559–576.

Ferrand, L., & Grainger, J. (2003). Homophone interference effects in visual word recognition. *Quarterly Journal of Experimental Psychology*, *56A*, 403–419.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, *103*, 518–565.

Grainger, J., Muneaux, M., Farioli, F., & Ziegler, J. (2005). Effects of phonological and orthographic neighborhood density interact in visual word recognition. *Quarterly Journal of Experimental Psychology*, *58A*, 981–998.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75.

Liu, I.-M., Wu, J.-T., & Chou, T.-L. (1996). Encoding operation and transcoding as the major loci of the frequency effect. *Cognition*, *59*, 149–168.

Perea, M., & Pollatsek, A. (1998). The effects of neighborhood frequency in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 767–779.

Pexman, P. M., Lupker, S. J., & Jared, D. (2001). Homophone effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*, 139–156.

Rubenstein, H., Lewis, S. S., & Rubenstein, M. A. (1971). Evidence for phonemic recoding in visual word recognition. *Journal of Verbal Learning and Verbal Behavior*, *10*, 645–657.

Share, D. (2008). On the Anglocentricities of current reading research and practice: The perils of overreliance on an "outlier" orthography. *Psychological Bulletin*, *134*, 584–615.

Shen, D., & Forster, K. I. (1999). Masked phonological priming in reading Chinese words depends on the task. *Language and Cognitive Processes*, *14*, 429–459.

Stone, G. O., Vanhoy, M., & Van Orden, G. C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory and Language*, *36*, 337–359.

Tan, L. H., & Perfetti, C. A. (1998). Phonological codes as early sources of constraint in reading Chinese: A review of current discoveries and theoretical accounts. *Reading and Writing: An Interdisciplinary Journal*, *10*, 165–220.

Wu, J.-T. (1995). A PC software system of lab automation for Chinese psychological experiments. *Chinese Journal of Psychology*, *37*, 1–21.

Wu, J.-T. (2003). *The role of radical in character recognition and naming (I)*. National Science Council Technical Report: NSC 91-2413-H002-012 [Taiwan].

Wu, J.-T., & Chen, H.-C. (2000). Evaluating semantic priming and homophonic priming in recognition and naming of Chinese characters. *Chinese Journal of Psychology*, *42*, 65–86.

Wu, J.-T., & Chen, H.-C. (2003). Chinese orthographic priming in lexical decision and naming. *Chinese Journal of Psychology*, *45*, 75–95.

Wu, J.-T., & Liu, I.-M. (1988). A data base system about the psychological features of Chinese characters and words. In I. M. Liu, H. C. Chen, & M. J. Chen (Eds.), *Cognitive aspects of the Chinese language* (pp. 171–186). Hong Kong: Asian Research Service.

Yates, M. (2005). Phonological neighbors speed visual word recognition: Evidence from multiple tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*, 1385–1397.

Yates, M., Locker, L., & Simpson, G. B. (2004). The influence of phonological neighborhood on visual word perception. *Psychonomic Bulletin and Review*, *11*, 452–457.

Ziegler, J. C., Montant, M., & Jacobs, A. M. (1997). The feedback consistency effect in lexical decision and naming. *Journal of Memory and Language*, *37*, 533–554.

Ziegler, J. C., Tan, L. H., Perry, C., & Montant, M. (2000). Phonology matters: The phonological frequency effect in written Chinese. *Psychological Science*, *11*, 234–238.