The Role of Orthographic Neighborhood Size Effects in Chinese Word Recognition

Meng-Feng Li, Wei-Chun Lin, Tai-Li Chou, Fu-Ling Yang & Jei-Tun Wu

Journal of Psycholinguistic Research

ISSN 0090-6905
Volume 44
Number 3

J Psycholinguist Res (2015) 44:219-236
DOI 10.1007/s10936-014-9340-4

Springer

Your article is protected by copyright and all rights are held exclusively by Springer Science +Business Media New York. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your article, please use the accepted manuscript version for posting on your own website. You may further deposit the accepted manuscript version in any repository, provided it is only made publicly available 12 months after official publication or later and provided acknowledgement is given to the original source of publication and a link is inserted to the published article on Springer's website. The link must be accompanied by the following text: "The final publication is available at link.springer.com”.

Springer

Author's personal copy

J Psycholinguist Res (2015) 44:219–236
DOI 10.1007/s10936-014-9340-4

The Role of Orthographic Neighborhood Size Effects in Chinese Word Recognition

Meng-Feng Li · Wei-Chun Lin · Tai-Li Chou · Fu-Ling Yang · Jei-Tun Wu

Published online: 2 December 2014
© Springer Science+Business Media New York 2014

Abstract Previous studies about the orthographic neighborhood size (NS) in Chinese have overlooked the morphological processing, and the co-variation between the character frequency and the the NS. The present study manipulated the word frequency and the NS simultaneously, with the leading character frequency controlled, to explore their influences on word lexical decision (Experiment 1) and naming (Experiment 2). The results showed a robust effect that words with a larger NS produced shorter reaction time than those with a smaller NS, irrespective of the word frequency and the tasks. This facilitative effect may occur due to a semantic network formed by neighbor words, resulting in the semantic activation to accelerate the word recognition. Moreover, the comparison of the effect sizes of word frequency between the two tasks showed that lexical decision responses demonstrated a larger word frequency effect, indicating that the sub-word processing was involved in the multi-character word recognition.

Keywords Character/word recognition · Neighborhood size effect · Frequency effect · Morphological processing

Introduction

Neighborhood size (NS) of a word is the number of words that can be generated by changing one letter at any position within the word (Coltheart et al. 1977). Past alphabetic studies already explored NS, and its influence on word recognition. Some researchers intended to investigate the same topic using similar definition in English but obtained contradictory results in Chinese (Huang et al. 2006; Tsai et al. 2006). They might have overlooked the

M.-F. Li · W.-C. Lin · T.-L. Chou · F.-L. Yang · J.-T. Wu (✉)
Department of Psychology, National Taiwan University, 10617 Taipei, Taiwan
e-mail: jtwu@ntu.edu.tw

T.-L. Chou
Neurobiology and Cognitive Science Center, National Taiwan University,
10617 Taipei, Taiwan

Author's personal copy

fact that the components of a word can be very different in Chinese and the alphabetic system.

For instance, word length in English language usually ranges from 2 to 8 letters, and is easily confused with NS, because longer words have smaller NS, and vice versa (Jalbert et al. 2011; Lavidor and Ellis 2002). However, this is not the case with Chinese, because nearly two-thirds of all Chinese words are formed by two characters. For example, about 60 % of the word database compiled by the National Language Committee (2000) consists of two-character words. Furthermore, the unit of the Chinese writing system is a character which is represented by a morpheme, while the constituent parts of English words, the letters, do not have such morphemic representation. Importantly, a degree of semantic relation exists between a Chinese character within a word and its neighbor words sharing the character.

Neighborhood Size Effects in the Alphabetic System

As a result of the analysis of English materials, Coltheart et al. (1977) found no NS effect on word recognition in lexical decision task (LDT), arguing that the amount of NS does not influence word processing. However, Andrews (1989) pointed out that Coltheart et al. (1977) may have ignored the impact of word frequency. After the manipulation of word frequency and NS in the LDT and naming tasks, a facilitative NS effect was found for low-frequency words. Andrews (1989) interpreted these findings as evidence for the interactive activation model, formulated by McClelland and Rumelhart (1981).

By definition, neighbors may be a group of similar words in terms of orthography, while similar orthography often resembles similar phonology in alphabetic scripts. Within the interactive activation framework, a high-frequency word has a lower threshold for word recognition, which means it can be more easily recognized, and the amount of NS would not have a significant effect. In contrast, a low-frequency word has a higher threshold for word recognition. Hence, to recognize the word correctly, more activation is needed. Under this low-frequency condition, the more neighbors the target word has, the more partially activated orthographic neighbors there are, and thus, the stronger the feedback from the word to the letter nodes. As a consequence, the target word reaches threshold faster, thus resulting in a facilitative NS effect. Indeed, many follow-up studies have confirmed these results (e.g., Andrews 1992; Carreiras et al. 1997; Forster and Shen 1996; Peereman and Content 1995; Pollatsek et al. 1999; Sears et al. 1995).

For French, however, researchers have proposed a different concept called orthographic neighborhood frequency effect. This concept suggests that words with high-frequency neighbors are processed more slowly than those without high-frequency neighbors (Grainger 1990; Grainger et al. 1989, 1992). Using the LDT, Grainger et al. (1989) manipulated words with no neighbors, words with at least one neighbor but none of higher frequency, words with only one higher-frequency neighbor, and words with many higher-frequency neighbors, and instead of NS effect, a significant inhibitory neighborhood frequency effect was observed.

Subsequently, Grainger and collaborators used priming paradigms or masked identification to study the orthographic and phonological information in neighbors. They also found that words with one neighbor of higher frequency leads to inhibitory neighborhood effects (Grainger and Ferrand 1994; Grainger and Jacobs 1996; Grainger and Segui 1990; Segui and Grainger 1990). As a result, the target word that owns higher frequency neighbors in

Author's personal copy

the same lexical unit will compete against each other, reaching recognition threshold more slowly than that for lower-frequency neighbors.

However, Sears et al. (1995) verified the stimuli used by Grainger et al. (1989) and argued that the small range of NS does not mirror a real NS effect. Although Grainger and collaborators reported inhibitory neighborhood frequency effects in the LDT (Grainger 1990; Grainger and Segui 1990), the finding was not presented in the naming task (Grainger 1990). To address this problem and to better understand the process of word recognition, Sears et al. (1995) used these LDT and naming tasks simultaneously and manipulated word frequency, NS, and neighborhood frequency. Their results showed a facilitative NS effect for low-frequency words in both tasks, nevertheless, the inhibitory neighborhood frequency effect advocated by Grainger (1990), and his team (Grainger et al. 1989, 1992) could not be proved. In a more recent research Sears et al. (2006) suggested that neighborhood frequency has no direct effect on reading time, and has little, if any effect on post-identification processing of English words.

The above findings imply that NS can influence word recognition. Previous alphabetic studies mainly attribute facilitative NS effects to the perceived level of orthography, in which orthographic neighbors tend to have similar phonology (e.g., Andrews 1989, 1992; Peereman and Content 1995; Pollatsek et al. 1999). However, as Andrews (1997) pointed out, the relationship between orthography and phonology in other languages results in different NS effects. Unlike alphabetic systems, in Chinese there is only one shared character among the neighbors; hence, orthographic and phonological similarity is lower than that presented in the alphabetic system. Another distinction between the two languages is that characters have their own meaning in Chinese, while English letters are meaningless by themselves.

More importantly, the critical psycholinguistic difference between Chinese and English NS is that, Chinese neighbor words share one character with specific semantics, which led to similar representations at the lemma level and a degree of relation between the meaning of the character and words. When investigating the NS effects in Chinese word recognition, the possibility that activated neighbor words manifest the top-down influences from the semantic level must be taken into consideration, while the past research about English NS rarely mentioned it and merely focused on the bottom-up feedbacks by perceptual representations from the orthographic level. Therefore, it is crucial to explore the possible role of NS effects on Chinese compound word recognition in terms of semantics in the present study.

Neighborhood Size Effects in the Chinese Writing System

Previous studies of the NS effect of Chinese only focused on the character level (e.g., Li et al. 2011; Wang and Zhang 2011), with radical as its main component to carry phonological or even semantic information. Among the few researchers on NS effect in Chinese compound words are Huang et al. (2006), and Tsai et al. (2006), and their definition of NS was very similar to the one used in English. They characterize NS as the number of neighbors that share the same constituent character with the target word. For instance, a two-character word (e.g., 色彩, sè cǎi, color) can have neighbors which contain the leading character (such as 色澤, sè zé, color shades) or neighbors which contain the second character (such as 水彩, shuǐ cǎi, watercolor).

Even though Huang et al. (2006) and Tsai et al. (2006) manipulated the same variables as word frequency and NS, they only obtained similar results for word frequency effect.

Author's personal copy

In terms of the NS effect their studies present contradictory findings. Huang et al. (2006) found no significant main effect of NS but a significant interaction effect between word frequency and NS. High-frequency words with more neighbors were identified faster, while low-frequency words with more neighbors were identified slower. On the other hand, Tsai et al. (2006) obtained a marginally significant main effect of NS of the leading character. Words with more neighbors sharing the same leading character were identified faster. However, there was no interaction effect between word frequency and NS on response latencies.

It should be noted that although the NS of the leading character affects lexical decision latencies, neither of the studies balanced the leading character frequency among different NS conditions. Also, the analyses were not performed by items. Therefore, the present study is to resolve the conflict between these two studies in order to get a clearer image of the NS effect in Chinese compound words.

Contributions of the Present Research

We present three points to emphasize the novel contributions of the present study. First, the NS of an English word is made up of words with orthographic and phonologic similarity. In contrast, most Chinese words consist of two characters. The similarity in orthography and phonology can only reach up to 50 % in Chinese neighbor words. However, the leading character plays an important role in NS effects. And neighbor words form a network of semantically related words which share the same leading character (Wu et al. 2013). For example, when a target word (such as 家族, jīa zú, families) has the same leading character (家, ra, jīa, family), the neighbor words (家人, jīa rén, family member; 家譜, jīa pŭ, family tree; 家產, jīa chăn, family property; 家用, jīa yòng, family expenditure, etc.) are related to each other at the semantic level.

From the mentioned-above example, a character in a Chinese compound word is similar to a morpheme or a stem (lemma) in an English word. Moreover, a Chinese character is not completely equal to an English letter. Therefore, identification of a Chinese compound word should not only consist of the orthographic and phonological processing like letter processing but also of the morphological processing. The role of morphological processing in Chinese word recognition was neglected in previous studies about the NS effects.

Regarding morphological processing, Baayen and his collaborators suggested that morphological productivity is a crucial sub-lexical factor in word recognition (Baayen 1994; Baayen et al. 1997; Schreuder and Baayen 1997). The number of words derived from a stem (lemma) by means of compounding (i.e. mouse: mouser, mousetrap, etc.), derivation (i.e. beautiful: beauty, beautifully, etc.) or inflection (i.e. agree: agreeing, agreed, etc.), has been referred to as the morphological family size (MFS) (De Jong et al. 2000; Schreuder and Baayen 1997). A series of studies showed that lexical decision responses to words with the larger MFS were faster than those to words with the smaller MFS in alphabetic systems (Bertram et al. 2000; De Jong et al. 2000; Dijkstra et al. 2005; Moscoso del Prado Martín et al. 2005, 2004; Schreuder and Baayen 1997). These studies suggested that response latencies are not affected by the overlap in orthography or phonology of the morphological family members. Instead, response latencies are affected by a given stem which activates not only its own semantic representation but also, to a certain extent, the semantic representations of its morphological relatives. The present study aimed to address the issue of morphological processing related to the NS effect.

Author's personal copy

As for the second contribution, previous studies indicated that in Chinese, the NS based on the leading character in two-character words exerts a greater influence on the target word than that on the second character (e.g. Huang et al. 2006; Tsai et al. 2006). This seems to imply that Chinese word recognition involves the sub-lexical processing. To address this issue, we used both the LDT (Experiment 1) and naming task (Experiment 2) to separate pre-lexical component from lexical access, as suggested by Liu et al. (1996).

In one trial of the LDT, participants must process the two characters in order to decide whether the combination of them is a real word. This task can reflect the word frequency effect in Chinese (Wu et al. 1994). However, in the one trial of the naming task, participants have to pronounce the two characters within a word, and they can probably make a respond based on the character before recognizing the entire word. Compared with LDT, such sub-lexical processing tends to diminish word frequency effect (Monsell et al. 1989; Wu et al. 1994). The present study contained two experiments, comparing the effect sizes of word frequency between those two tasks, a complete picture of the process in word recognition can be better captured, as evident in the previous research (e.g., Frost et al. 1987; Liu et al. 1996).

The third contribution is the revelation of the co-variation between the character frequency and the number of words embedding that character. Character frequency (token frequency) is defined as the summation of frequencies of all words sharing the character in Chinese (Wu et al. 2013). In other words, a character that forms more multi-character words tends to have higher occurrence frequency. This idea is also supported after the analysis of the four main Chinese character databases compiled in Taiwan. We calculated the correlation coefficients between the amount of possible word combinations by each Chinese character and its frequency in each database. The following results were obtained: a coefficient of .46 for the character database by Liu et al. (1975); .50 for the database by Wu and Liu (1988); .62 for the database by Chinese Knowledge Information Processing Group (2001); and .57 for the database by National Language Committee (2000). All results showed significant positive correlation ($p < .001$). To get an unbiased understanding of the NS effect, this covariance was considered in the present study. We intended to manipulate the NS while the leading character frequency was controlled.

The goal of the current study was to examine NS effects for both high- and low-frequency words in Chinese. As suggested by previous studies of alphabetic systems, the NS has no effect for high-frequency words. Studies of Chinese writing system, however, show contradictory results. In light of the contributions above, the two hypothesis of this study can be evolved.

First, we expect to observe facilitative NS effects in Chinese word recognition for both high- and low-frequency words in the LDT and naming tasks. This is because the morphological structure of words could achieve an efficient retrieval scheme for words (Sandra 1994). Bybee (1995) also pointed out that morphological properties of words emerged from associations among semantically-related words in lexical representations. Furthermore, lexical access can be facilitated by activating semantically-related words in the long-term memory representations, because these words form a context in which words are easier to access from memory. The supporting context allows pre-activation of relevant lexical features, making lexical access less effortful (Lau et al. 2008).

Therefore, we hypothesize that the larger the NS in Chinese, the more related words there are in a semantic network, leading to stronger top-down semantic activation from the semantic representations to the lemma nodes. In other words, the more semantically related neighbor words of a target word at the semantic level, the more related nodes activated at the lemma

Author's personal copy

Table 1 Averages and standard deviations (in parenthesis) of word frequency, neighborhood size, and leading character frequency for target words in each condition

Variable	High-WF		Low-WF	
	Large NS	Small NS	Large NS	Small NS
WF	99.64 (91.04)	98.28 (99.26)	3.28 (2.09)	3.48 (2.42)
NS	69.96 (16.54)	18.08 (4.64)	71.00 (23.11)	17.16 (5.87)
LCF	1,041.36 (391.26)	1,049.64 (378.50)	1,042.96 (454.16)	1,044.04 (444.86)

Data from the National Language Committee (2000). *WF* word frequency, *NS* neighborhood size, *LCF* leading character frequency (controlled)

level, lowering the threshold to recognize the target word and accelerating the identification process.

Second, a significant difference between the effect sizes of word frequency in the LDT and naming tasks is also expected to be observed, while lexical decision responses may manifest a larger word frequency effect. Moreover, we hypothesize that in the naming task, there is no need for participants to recognize the entire word, when they pronounce the leading character. It implies the phonology processing may be involved before the word recognition. Therefore, the naming task reflects the earlier stage of the lexical processing, which leads to relatively weaker effect of word frequency. While in the LDT, participants cannot make a correct decision about whether it is a real word until both the characters contained in the word are identified, so it reflects the later stage of the lexical processing, resulting in the gradually distinct effect of word frequency.

Experiment 1 (Lexical Decision Task)

Participants

Forty university students (mean age 20.74, 19 males) participated in the lexical decision task. All of them were native Chinese speakers with normal or corrected-to-normal vision, and they possessed proficiency in listening, speaking, reading and writing Mandarin.

Methods and Materials

A 2×2 two-way within-subjects design was adopted which contained the factors of word frequency (high vs. low) and orthographic NS (large vs. small), with their descriptive statistics summarized as shown in Table 1.

A total of 100 two-character words were selected from four Chinese character databases that were compiled in Taiwan: the database of Liu et al. (1975), the database of Wu and Liu (1988), the database of National Language Committee (2000), and the database of Chinese Knowledge Information Processing Group (2001). All the stimuli were selected from the four databases and the selection standards were consistent across them, that is to say, if a word was high-frequency in one database, in other three databases it must be high-frequency too, which helps to the repetition and validation of other researchers.

In the LDT task, 50 % stimuli were two-character non-word foil targets for the "No response." For the "Yes response," there exist many neighbor words sharing the leading character in the large NS condition, while there exist fewer neighbor words sharing the lead-

Author's personal copy

ing character in the small NS condition. The leading character frequency of the target word and the number of strokes of constituent characters were also balanced under different conditions. Over 90 % of high-frequency words with large and small NS had higher-frequency neighbor words, and 100 % of low-frequency words with large and small NS had higher-frequency neighbor words. The assignment of each target word to different conditions was counter-balanced among participants.

Apparatus and Procedure

The experiment was operated by an IBM PC/486 computer. All stimuli were presented in isolation in the center of a 17-inch VGA-adapted, 60 Hz display. Reaction times (RTs) and the duration of stimulus display were both measured to the nearest millisecond and synchronized with the onset of video frame refreshing. E-Prime v2.0 Professional was adopted for experimental procedures and the software for data handling was the program designed by Wu (1995). Participants received 20 practice trails with feedback, in which they must reach an accuracy no lower than 80 % to enter the subsequent formal trials without feedback.

Participants received a LDT task in which they were asked to judge whether the stimulus appearing in the center of the screen was a real word (e.g., 眾多, zhòng duō, numerous) or not (e.g., 拉能, lā néng). They were instructed to respond as accurately and quickly as possible by pressing one of two keys, one of which was colored in green for ‘real-word’ response, and the other was colored in red for ‘not-a-real-word’ response. In each trial, the following sequence of events occurred: (a) an asterisk, used as a fixation point, appeared at the center of the monitor and lasted for 500 ms accompanied by a 100 Hz warning tone for 200 ms, before a blank screen appeared for 500 ms; (b) the target word occupying a 24 × 50 dot matrix area which subtended a visual arc of approximately 2 degrees, from a 70cm viewing distance, remained there until the computer detected the participant’s key stroke, and the RT was measured from the onset of the target word until a response was made; and (c) the whole screen immediately turned blank for 1,000 ms before an asterisk with a warning tone for the next trial was presented.

In the LDT, 100 real-word trials and 100 non-word trials were evenly and randomly divided into 25 blocks, and all of the stimuli were two-character words. Each block had 4 experimental trials indicating different conditions, one trial for each condition, in addition to four non-word trials. An on-line random assignment with a block randomization shuffling procedure was performed separately so that each participant received an idiosyncratic random sequence of block-arranged stimuli. All participants were tested individually.

Results

To calculate the mean RT of correct responses for each condition by each participant, trials with RTs less than 250 ms (possible anticipation), or RTs exceeding 2.5 standard deviations from the mean of its condition, were treated as outliers. The percentage of outliers was 3.7 %. The recomputed means of correct RTs and the mean percentages of errors across participants under different conditions of word frequency × NS are shown in Table 2.

Participants responded faster to target words with higher frequency compared to those with lower frequency, while response to target words with large NS also took shorter than to those with small NS. To assess statistical significance of these effects ANOVA was used across participants, F_1, and across stimulus items, F_2.

Mean RTs from all participants showed that the main effect of word frequency was highly significant, $F_1(1, 39) = 198.11$, $MSe = 1{,}668.68$, $p < .001$, $\hat{\omega}^2_{partial}$

Author's personal copy

Table 2 Mean latencies and error percentages (in parenthesis) as a function of word frequency and neighborhood size for word lexical decision (Experiment 1) and naming (Experiment 2)

Task	High-WF	Low-WF
Experimental 1 (LDT)		
Large NS	554 (1.70)	645 (7.30)
Small NS	567 (2.80)	657 (13.50)
Experimental 2 (naming)		
Large NS	461 (2.40)	479 (3.80)
Small NS	472 (2.70)	500 (7.00)

$= .55$; $F_2(1, 96) = 96.65$, $MSe = 2{,}449.02$, $p < .001$, $\hat{\omega}^2_{partial} = .49$, in which the decision latencies was much shorter for high- than for low-frequency words. The main effect of NS was also significant, $F_1(1, 39) = 6.31$, $MSe = 1{,}076.68$, $p < .05$, $\hat{\omega}^2_{partial} = .03$; $F_2(1, 96) = 4.79$, $MSe = 2{,}449.02$, $p < .05$, $\hat{\omega}^2_{partial} = .04$, in which the decision responses was faster for the large NS than for the small NS. The interaction effect between word frequency and orthographic NS was not significant, $F_1(1, 39) < 1$, $p > .88$; $F_2(1, 96) < 1$, $p > .53$.

Interim Discussion

Interestingly, since the main effect of NS was significant, while the interaction of word frequency and NS failed to reach significance, manifesting facilitative NS effects were found for both high- and low-frequency words. And no inhibitory effect in the LDT as Grainger et al. (1989,1990, 1992) was found. It was in line with our first hypothesis as stated above, and more robust facilitative effect was revealed than that in past research of alphabetic languages which demonstrated facilitative NS effect only for low-frequency words (e.g., Andrews 1989, 1992; Forster and Shen 1996; Sears et al. 1995). It also illustrated the stronger facilitative effect cannot be explained merely on the level of orthography or phonology as research in alphabetic systems. Moreover, the semantic activation may also give rise to the results of Experiment 1. Owning to the definite meaning carried by one character in Chinese, the neighbor words sharing the same lemma (the character) also have relevant semantics, which brought about the more activated nodes at the semantic level and stronger top-down influences when the NS was large, compared with those in small NS condition.

However, in previous studies of Chinese word recognition, Huang et al. (2006) observed an inhibitory NS effect for low-frequency words. Since the semantics of the leading character in a Chinese word seemed to play a facilitative role, why did they observe the inhibitory effect? As aforementioned in the third contribution, Huang et al. (2006) probably overlooked the covariance between character frequency and NS, and we indeed obtained a completely different result from theirs after excluding the confounding of the leading character frequency in this experiment.

Besides, the results of Experiment 1 suggest a facilitative word frequency effect as indicated in previous studies (e.g., Andrews 1989; Frost et al. 1987; Grainger 1990; Wu et al. 1994). That is, the response to a high-frequency word was faster than that to a low-frequency word in both the large and small NS conditions. It also illustrated that, adopting the LDT can reflect the word frequency effect sensitively and we also attempted to com-

Author's personal copy

pare results from the LDT in Experiment 1 with those from the naming task in further experiment. To further confirm the results obtained by Experiment 1, Experiment 2 was designed to investigate whether facilitative NS effects could be also observed in the naming task.

Experiment 2 (Naming Task)

Participants

Forty university students (mean age 21.03, 20 males) from the same pool as in Experiment 1 participated in the naming task of this experiment. Participants in Experiment 2 did not take part in the LDT task of Experiment 1. All of them were native Chinese speakers with normal or corrected-to-normal vision, and they possessed proficiency in listening, speaking, reading and writing Mandarin.

Methods and Materials

The same design and stimuli, except for non-word foils, from Experiment 1 were adopted in Experiment 2.

Apparatus and Procedure

The same apparatus and procedure used in Experiment 1 were adopted, with an addition of a voice-activated circuit linked with a microphone used to detect the onset of the participant's pronunciation in Experiment 2. In the naming task, the phonetic symbols used in Taiwan representing the correct pronunciation were presented above the stimulus as feedback during practice trails. Via a remote connection line, the experimenter, seating behind the participant, either pressed one button to indicate the correct pronunciation of the word (e.g., 價值, jià zhí, value), or the other button to indicate an incorrect pronunciation of the word or made some other sound (such as a cough).

Results

Data analyses were similar to that in Experiment 1. The percentage of outliers was 2.9 %. The mean correct RT and the mean percentages of errors across participants under different conditions are shown in Table 2.

If we compare the results of this experiment to those of Experiment 1, a consistent pattern of results can be noticed. A two-way ANOVA revealed a highly significant main effect of word frequency, $F_1(1, 39) = 85.01,\ MSe = 238.51,\ p < .001,\ \hat{\omega}^2_{partial} = .34;\ F_2(1, 96) = 23.87,\ MSe = 586.57,\ p < .001,\ \hat{\omega}^2_{partial} = .19$, the naming latencies being much shorter for high- than for low-frequency words. The main effect of NS was also highly significant, $F_1\ (1, 39) = 57.80,\ MSe = 177.05,\ p < .001,\ \hat{\omega}^2_{partial} = .26;\ F_2(1, 96) = 11.84, MSe = 586.57,\ p < .01, \hat{\omega}^2_{partial} = .10$, the naming responses being faster for the large NS than for the small NS. The interaction effect between word frequency and orthographic NS was not significant, $F_1(1, 39) < 1,\ p > .17;\ F_2\ (1, 96) < 1,\ p > .31$.

Author's personal copy

Interim Discussion

It is commonly known that every task has its own demands; hence, in order to prove the existence of an effect, it must be observed compatibly under different tasks as Andrews (1997) noted in her review paper. The results of naming latencies clearly showed the same pattern as in Experiment 1, which was missing in the studies by Huang et al. (2006) and Tsai et al. (2006). And it added to evidence of our first hypothesis that no matter in the LDT or the naming task, facilitative NS effects in high-frequency and low-frequency words can be observed stably.

Moreover, the research by Frost et al. (1987) revealed that, in the naming task participants were required to read the word aloud and they might pronounce it based on some rules (such as grapheme-to-phoneme conversion) rather than identify the entire word, which led to the weaker word frequency effect than that in the LDT. It signified that, in the languages with shallow orthography, the phonology processing may be involved before the entire word was identified. Given this, after comparing the effect sizes of character frequency between those two tasks in Chinese character recognition, Liu et al. (1996) found the stronger character frequency effect in the naming task instead of the LDT, which was widely different from results in the alphabetic systems. It can be inferred that the pre-lexical phonology was not involved in Chinese character recognition, and the phonology of characters was launched in the post-lexical processing.

However, since the characters in the word possessed the fair degree of influence, it is reasonable to observe the character processing in Chinese word recognition. In light of the different stages in the lexical processing reflected by the LDT and the naming task, we compared the results between Experiments 1 and 2 to uncover additional insights as suggested by previous studies (e.g., Frost et al. 1987; Liu et al. 1996).

Comparison of Data Between Experiment 1 and Experiment 2

Methods

To compare the results of the two experiments, a three-way ANOVA with the within-subjects factors of word frequency (higher vs. lower) and orthographic NS (larger vs. smaller), and the between-subjects factor of task (lexical decision vs. naming), was performed on the RT data.

Results

The results demonstrated that significant sources of variation were word frequency, $F_1(1, 78) = 269.80$, $MSe = 953.71$, $p < .001$, $\hat{\omega}^2_{partial} = .46$; $F_2(1, 96) = 88.54$, $MSe = 2{,}066.22$, $p < .001$, $\hat{\omega}^2_{partial} = .30$, NS, $F_1(1, 78) = 26.91$, $MSe = 626.97$, $p < .001$, $\hat{\omega}^2_{partial} = .08$; $F_2(1, 96) = 8.89$, $MSe = 2066.22$, $p < .01$, $\hat{\omega}^2_{partial} = .04$, $task$, $F_1(1, 78) = 127.98$, $MSe = 10{,}275.09$, $p < .001$, $\hat{\omega}^2_{partial} = .28$; $F_2(1, 96) = 873.92$, $MSe = 969.37$, $p < .001$, $\hat{\omega}^2_{partial} = .81$, and word frequency × task, $F_1(1, 78) = 98.09$, $MSe = 953.71$, $p < .001$, $\hat{\omega}^2_{partial} = .23$; $F_2(1, 96) = 69.91$, $MSe = 969.37$, $p < .001$, $\hat{\omega}^2_{partial} = .26$. The other interactions were not significant, word frequency × NS, $F_{1s}(1, 78) < 1$, $p > .62$; $F_{2s}(1, 96) < 1$, $p > .60$, NS × task, $F_{1s}(1, 78) < 1$, $p > .62$; $F_{2s}(1, 96) < 1$, $p > .57$, and word frequency × NS ×

Author's personal copy

task, $F_{1s}(1, 78) < 1.28$, $p > .26$; $F_{2s}(1, 96) < 1$, $p > .86$. A further analysis showed that the simple main effect of word frequency was significant under the LDT, $F_1(1, 78) = 346.63$, $MSe = 953.71$, $p < .001$, $\hat{\omega}^2_{partial} = .52$; $F_2(1, 192) = 155.95$, $MSe = 1{,}517.79$, $p < .001$, $\hat{\omega}^2_{partial} = .44$, and it was also significant albeit weaker under the naming task, $F_1(1, 78) = 21.26$, $MSe = 953.71$, $p < .001$, $\hat{\omega}^2_{partial} = .06$; $F_2(1, 192) = 9.23$, $MSe = 1{,}517.79$, $p < .01$, $\hat{\omega}^2_{partial} = .04$. This illustrates that facilitative NS effects in Experiments 1 and 2 would not change across tasks.

Interim Discussion

According to the aforementioned research by Frost et al. (1987) and Liu et al. (1996), either the LDT or the naming task can capture the processing of the word recognition and provide clear reflections about the word frequency effect. Nevertheless, if participants can retrieve the pronunciation just via sub-lexical phonology (i.e., componential information) before lexical access is finished, there will be smaller frequency effects and shorter RTs in the naming task than those in the LDT (e.g., Frost et al. 1987). In contrast, if participants have to retrieve the pronunciation after lexical access, there will be larger frequency effects and longer RTs in the naming task relative to the LDT (e.g., Liu et al. 1996). Thus, comparing the results of these two tasks can show more evidence as to whether the processing of characters within the word (i.e., its components) is involved in Chinese word recognition (Wu et al. 1994, 2013).

The frequency of one word usually reflects the familiarity for people to recognize it in the mental lexicon, and then the two tasks should supposedly yield similar effect sizes. However, the results indicated otherwise. The comparison of the effect sizes of word frequency between those two tasks in the present study revealed that, lexical decision responses manifested a larger word frequency effect than that for naming responses, and the response latencies for lexical decisions were distinctly slower than those for naming. It also verified our second hypothesis that the experimental results exhibited a very similar pattern as that found by Frost et al. (1987), indicating a pre-lexical phonology was involved in multi-character word processing.

In Experiment 1, in order to be able to decide whether a target word was a real word or not, participants had to correctly identify both characters of the target word. However, in Experiment 2, participants were instructed to read aloud the target word in the naming task, and RT was recorded with the onset of the pronunciation of the leading character. It is possible that the participants were able to pronounce the leading character before identifying the target word, diminishing the effect sizes of word frequency in turn. In addition, if the acquisition of word pronunciation takes place after lexical access in Chinese, word frequency effect in the naming task should be stronger than that for LDT, as validated by the pattern obtained in the study by Liu et al. (1996). Whereas, the present research showed the opposite results, revealing that the process of word recognition is influenced by its characters.

General Discussion

In summary, the present study highlights several points. First and foremost, we demonstrated that orthographic neighbor words exert a robust facilitative NS effect on both word decision and naming in Chinese. In alphabetic systems, neighbors are defined as a group of words with very similar orthography, often with similar phonology as well. Therefore, facilitative NS effects on low-frequency words may be caused by influences from the orthographic and phonological levels (e.g., Andrews 1989, 1992; Forster and Shen 1996; Sears et al. 1995). However, this is not the case in Chinese, because we found facilitative effects for both high-

Author's personal copy

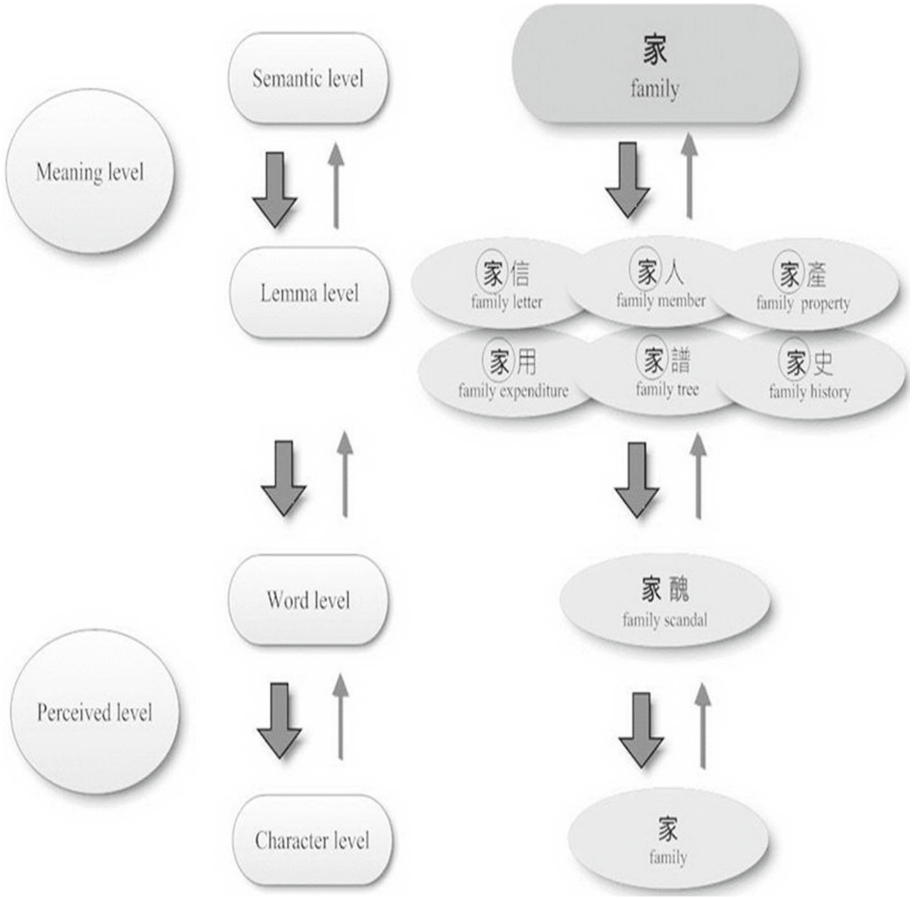

Fig. 1 Semantic activation model in Chinese word recognition

and low-frequency words. As aforementioned, orthographic and phonological similarity of Chinese neighbor words is much lower than that in the alphabetic system. So it would be difficult for us to explain such robust facilitative effects on the orthographic and phonological level.

What is more, past studies which investigated the topic of NS in Chinese used the same definitions and notions with English, but they overlooked the morphological processing in Chinese word recognition. According to our calculations based on the four main character databases as aforementioned, the Chinese writing system contains more than 100,000 words constituted by about 5,000 common characters. And the neighbor words with the same constituent character have overlapping semantics (Wu et al. 2013).

Importantly, combining the interactive activation model (McClelland and Rumelhart 1981) and the model of morphological processing (Schreuder and Baayen 1997), a possible cognitive mechanism in Chinese word recognition is shown in Fig. 1. In addition to the bottom-up feedbacks from the perceived level to the meaning level, there are top-down influences from the meaning level to the perceived level. When a target word shares the same character with neighbor words at the character level, semantic activation will provide top-down influences

Author's personal copy

from the semantic level to activate the related nodes at the lemma level. Therefore, the larger NS will lead to more words with related meaning in Chinese, which results in the stronger semantic activation in the network. Under the circumstances, the process to complete the target word identification will be accelerated. Compared with the orthographic and phonological processing in the alphabetic system, such semantic processing plays a greater role in Chinese word recognition.

Second, character frequency (token frequency) in Chinese is defined as the summation of frequencies of all words sharing a particular character (Wu et al. 2013). As previously indicated, character frequency may co-vary with the number of words containing particular character. Furthermore, the NS of the leading character in two-character words exerts a great influence on word recognition. Any experiment which manipulates NS without controlling the frequency of the shared leading character would only lead to biased conclusions. We infer that, such bias caused by the frequency of the leading character, and the selection of inappropriate stimuli (by items analyses were not performed), are the reasons why the experiments of Huang et al. (2006) and Tsai et al. (2006) have obtained conflicting results.

Moreover, after the leading character frequency was controlled, if the participant gave a response after combining two characters of the target word in the naming task, the effect sizes of word frequency should be similar to that in the LDT, not weaker. This might be because in the earlier stage of the lexical processing, participants were able to pronounce it after merely identifying the leading character, with no need for recognizing the entire word, diminishing the supposed effect sizes of word frequency in the naming task (e.g., Wu et al. 1994). While in the LDT, the complete word recognition must be fulfilled, and the due effect sizes of word frequency were manifested. The pattern of the two experimental results in this study is similar to that found by Frost et al. (1987), demonstrating the processing of sub-word phonology involved in pre-lexical stage of Chinese word recognition. Such results imply that the basic recognition unit may be a character rather than a word. Huang et al. (2006) and Tsai et al. (2006) clearly overlooked this possibility in their experiments.

Conclusion

The present study examined orthographic NS effects in Chinese word lexical decision and naming, and compared the results between the two experiments. We not only proposed possible cognitive mechanism of NS effects in Chinese word recognition, but also showed that a pre-lexical phonology was involved in multi-character word processing. Our findings suggest that the leading character of neighbor words plays a dominant role during word recognition in the Chinese writing system. In Chinese, one may associate neighbor words based on semantics of the particular character they shared, and this will help to process various kinds of lexical meanings of Chinese words.

Acknowledgments This research was supported by grants from the National Science Council of Taiwan (NSC 98-2410-H-002-027) to Jei-Tun Wu and (NSC 101-2410-H-002-093-MY2) to Tai-Li Chou. Our special gratitude goes to the anonymous reviewers for their valuable comments. Besides, thank Xin-Yu Gao for her precious support in our cooperation.

Author's personal copy

Appendix 1: High-Frequency Words Used in Experiments 1 and 2

Larger NS	Smaller NS
特權 (a privilege)	任務 (a mission)
原則 (a principle)	區域 (an area)
投機 (opportunistic)	價值 (value)
指定 (designate)	完善 (perfect)
改變 (a change)	組織 (an organization)
反對 (oppose)	局部 (in part)
熱烈 (enthusiastic)	器材 (equipment)
死亡 (a death)	習俗 (a custom)
青年 (a youth)	確實 (true)
領袖 (a leader)	協助 (assist)
轉移 (shift)	辦理 (transact)
獨立 (independent)	屬於 (belong to)
農民 (a farmer)	維持 (keep)
酒會 (a drinking party)	貨物 (goods)
鐵路 (a railroad)	剛好 (just)
正常 (normal)	設備 (an apparatus)
結果 (a result)	今天 (today)
戰爭 (a war)	必要 (necessity)
清楚 (clear)	眾多 (numerous)
招待 (entertain)	汽油 (gasoline)
落後 (fall behind)	響應 (an echo)
排隊 (line up)	規範 (standards)
精彩 (wonderful)	園地 (a garden plot)
收藏 (a collection)	制裁 (punish)
強調 (emphasize)	議員 (a member of parliament)

Over 90 % of the above high-frequency words with larger and smaller NS had higher frequency neighbor words.

Author's personal copy

Appendix 2: Low-Frequency Words Used in Experiment 1 and 2

Larger NS	Smaller NS
百合 (a lily)	友情 (friendship)
海苔 (seaweed)	網羅 (gather and collect)
總稱 (generally speaking)	讓與 (yield)
安頓 (get everything settled)	色澤 (color shades)
通商 (having trade relations)	題字 (an inscription)
風評 (an evaluation)	界線 (a demarcation line)
光點 (a radiant)	治標 (take stopgap measures)
神似 (the similarity)	技師 (a technician)
南瓜 (a pumpkin)	容身 (shelter oneself)
推選 (put forward)	較量 (contest)
軍費 (military expenditure)	黨章 (the political party constitution)
消受 (enjoy)	語音 (phonology)
深意 (a deep meaning)	廠址 (the location of a factory)
警車 (a police patrol car)	念經 (recite Buddhist scripture)
眼疾 (diseases of the eye)	驗證 (confirm)
輕度 (a small extent)	景象 (scenes)
香檳 (champagne)	房產 (house property)
低等 (inferior)	陽台 (a balcony)
省水 (conserve water)	劇照 (a stage photo)
雙親 (parents)	港星 (a star in Hong Kong)
細看 (upon closer examination)	晚報 (an evening paper)
魚鰭 (fins)	充公 (confiscate)
苦工 (manual labor)	答腔 (reply)
退錢 (refund)	床單 (a bedcover)
沙場 (the battleground)	效命 (homage)

100 % of the above low-frequency words with larger and smaller NS had higher frequency neighbor words.

Author's personal copy

Appendix 3: Non-words Used in Experiment 1

萬走, 感裡, 建影, 專面, 直處, 土就, 飛慶, 火冠, 石來, 防馳, 聯逐, 黃告,
周者, 阿為, 遺去, 保從, 愛期, 陳委, 白貿, 黑訴, 拉能, 古班, 李牙, 連寶,
廣類, 品進, 料署, 幾修, 未密, 準隆, 院重, 象倫, 若緣, 據美, 健河, 導業,
播性, 榮團, 降明, 街分, 展速, 別長, 候可, 往臺, 甚步, 銷問, 即胞, 質動,
認尊, 被程, 本政, 馬咒, 接鄉, 花諾, 傳科, 東刻, 門數, 林症, 流援, 放間,
空達, 紅次, 張道, 滿方, 華摩, 草見, 書饋, 畫如, 冷文, 聖護, 翻都, 血墩,
急名, 巴帶, 木體, 每開, 種盤, 覺現, 向齒, 育察, 位爾, 視銀, 話運, 邊利,
媽形, 童樓, 聞斯, 極望, 續曼, 始電, 策興, 底請, 論金, 素所, 衛條, 錄信,
透案, 列和, 夏采, 掉型

References

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(5), 802–814. doi:10.1037/0278-7393.15.5.802.

Andrews, S. (1992). Frequency and neighborhood effects on lexical access: Lexical similarity or orthographic redundancy? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(2), 234–254. doi:10.1037/0278-7393.18.2.234.

Andrews, S. (1997). The effect of orthographic similarity on lexical retrieval: Resolving neighborhood conflicts. *Psychonomic Bulletin & Review*, *4*(4), 439–461. doi:10.3758/BF03214334.

Baayen, R. H. (1994). Productivity in language production. *Language and Cognitive Processes*, *9*(3), 447–469. doi:10.1080/01690969408402127.

Baayen, R. H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a parallel dual route model. *Journal of Memory and Language*, *37*(1), 94–117. doi:10.1006/jmla.1997.2509.

Bertram, R., Baayen, R. H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory and Language*, *42*(3), 390–405. doi:10.1006/jmla.1999.2681.

Bybee, J. (1995). Regular morphology and the lexicon. *Language and Cognitive Processes*, *10*(5), 425–455. doi:10.1080/01690969508407111.

Carreiras, M., Perea, M., & Grainger, J. (1997). Effects of orthographic neighborhood in visual word recognition: Cross-task comparisons. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*(4), 857–871. doi:10.1037/0278-7393.23.4.857.

Chinese Knowledge Information Processing Group. (2001). *Word list with accumulated word frequency in Sinica Corpus 3.1*. Taipei: Institute of Information Science, Academic Sinica

Coltheart, M., Davelaar, E., Jonasson, J. T., & Besner, D. (1977). Access to the internal lexicon. In S. Domic (Ed.), *Attention and performance VI* (pp. 535–555). New York: Academic Press.

De Jong, N. H., Schreuder, R., & Baayen, R. H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes*, *15*(4–5), 329–365. doi:10.1080/01690960050119625.

del Prado, M., Martín, F., Kostić, A., & Baayen, R. H. (2004). Putting the bits together: An information theoretical perspective on morphological processing. *Cognition*, *94*(1), 1–18. doi:10.1016/j.cognition.2003.10.015.

del Prado, M., Martín, F., Kostić, A., & Baayen, R. H. (2004). Putting the bits together: An information theoretical perspective on morphological processing. *Cognition*, *94*(1), 1–18. doi:10.1016/j.cognition.2003.10.015.

Dijkstra, T., del Prado, Moscoso, Martín, F., Schulpen, B., Schreuder, R., & Baayen, R. H. (2005). A roommate in cream: Morphological family size effects on interlingual homograph recognition. *Language and Cognitive Processes*, *20*(1–2), 7–41. doi:10.1080/01690960444000124.

Forster, K. I., & Shen, D. (1996). No enemies in the neighborhood: Absence of inhibitory neighborhood effects in lexical decision and semantic categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*(3), 696–713. doi:10.1037/0278-7393.22.3.696.

Author's personal copy

Frost, R., Katz, L., & Bentin, S. (1987). Strategies for visual word recognition and orthographical depth: A multilingual comparison. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(1), 104–115. doi:10.1037/0096-1523.13.1.104.

Grainger, J. (1990). Word frequency and neighborhood frequency effects in lexical decision and naming. *Journal of Memory and Language*, *29*(2), 228–244. doi:10.1016/0749-596X(90)90074-A.

Grainger, J., & Ferrand, L. (1994). Phonology and orthography in visual word recognition: Effect of mask homophone primes. *Journal of Memory and Language*, *33*(2), 218–233. doi:10.1006/jmla.1994.1011.

Grainger, J., & Jacobs, A. M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review*, *103*(3), 518–565. doi:10.1037/0033-295X.103.3.518.

Grainger, J., & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies. *Perception and Psychophysics*, *47*(2), 191–198. doi:10.3758/BF03205983.

Grainger, J., O'Regan, J. K., Jacobs, A. M., & Segui, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception and Psychophysics*, *45*(3), 189–195. doi:10.3758/BF03210696.

Grainger, J., O'Regan, J. K., Jacobs, A. M., & Segui, J. (1992). Neighborhood frequency effect and letter visibility in visual word recognition. *Perception and Psychophysics*, *51*(1), 49–56. doi:10.3758/BF03205073.

Huang, H. W., Lee, C. Y., Tsai, J. L., Lee, C. L., Hung, D. L., & Tzeng, O. J. L. (2006). Orthographic neighborhood effects in reading Chinese two-character words: Reaction time and ERP measurements. *Neuroreport*, *17*(10), 1061–1065. doi:10.1097/01.wnr.0000224761.77206.1d.

Jalbert, A., Neath, I., Bireta, T. J., & Surprenant, A. M. (2011). When does length cause the word length effect? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *37*(2), 338–353. doi:10.1037/a0021804.

Lau, E. F., Phillips, C., & Poeppel, D. (2008). A cortical network for semantics: (De)constructing the N400. *Nature Reviews Neuroscience*, *9*, 920–933. doi:10.1038/nrn2532.

Lavidor, M., & Ellis, A. W. (2002). Word length and orthographic neighborhood size effects in the left and right cerebral hemispheres. *Brain and Language*, *80*(1), 45–62. doi:10.1006/brln.2001.2583.

Li, Q. L., Bi, H. Y., Wei, T. Q., & Chen, B. G. (2011). Orthographic neighborhood size effect in Chinese character naming: Orthographic and phonological activations. *Acta Psychologica*, *136*(1), 35–41. doi:10.1016/j.actpsy.2010.09.012.

Liu, I. M., Chuang, C. J., & Wang, S. C. (1975). *Frequency count of 40,000 Chinese words*. Taipei: Lucky Books.

Liu, I. M., Wu, J. T., & Chou, T. L. (1996). Encoding operation and transcoding as the major loci of the frequency effect. *Cognition*, *59*(2), 149–168. doi:10.1016/0010-0277(95)00688-5.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, *88*(5), 375–407. doi:10.1037/0033-295X.88.5.375.

Monsell, s, Doyle, M. C., & Haggard, P. N. (1989). Effects of frequency on visual word recognition tasks: Where are they? *Journal of Experimental Psychology: General*, *118*(1), 43–71. doi:10.1037/0096-3445.118.1.43.

National Language Committee. (2000). *Report of frequently used characters and words*. Taipei: Ministry of Education.

Peereman, R., & Content, A. (1995). Neighborhood size effect in naming: Lexical activation or sublexical correspondences? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *21*(2), 409–421. doi:10.1037/0278-7393.21.2.409.

Pollatsek, A., Perea, M., & Binder, K. S. (1999). The effects of "neighborhood size" in reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance*, *25*(4), 1142–1158. doi:10.1037/0096-1523.25.4.1142.

Sandra, D. (1994). The morphology of the mental lexicon: Internal word structure viewed from a psycholinguistic perspective. *Language and Cognitive Processes*, *9*(3), 227–269. doi:10.1080/01690969408402119.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory and Language*, *37*(1), 118–139. doi:10.1006/jmla.1997.2510.

Sears, C. R., Campbell, C. R., & Lupker, S. J. (2006). Is there a neighborhood frequency effect in English? Evidence from reading and lexical decision. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(4), 1040–1062. doi:10.1037/0096-1523.32.4.1040.

Sears, C. R., Hino, Y., & Lupker, S. J. (1995). Neighborhood size and neighborhood frequency effects in word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(4), 876–900. doi:10.1037/0096-1523.21.4.876.

Author's personal copy

Segui, J., & Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency. *Journal of Experimental Psychology: Human Perception and Performance*, *16*(1), 65–76. doi:10.1037/0096-1523.16.1.65.

Tsai, J. L., Lee, C. Y., Lin, Y. C., Tzeng, O. J. L., & Hung, D. L. (2006). Neighborhood size effects of Chinese words in lexical decision and reading. Language and Linguistics, **7**(3), 659–675. Retrieved from http://www.ling.sinica.edu.tw/publ_j_en.asp-aid=23.htm

Wang, Q. H., & Zhang, J. W. (2011). N400 solution effect of Chinese character fragments: An orthographic neighborhood size effect. *Brain Research Bulletin*, *86*(3–4), 179–188. doi:10.1016/j.brainresbull.2011.07.006.

Wu, J. T. (1995). A PC software system of lab automation for Chinese psychological experiments. Chinese Journal of Psychology, **37**(1), 1–21. Retrieved from http://ntur.lib.ntu.edu.tw/handle/246246/137216

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.

Wu, J. T., Chou, T. L., & Liu, I. M. (1994). The locus of the character/word frequency effect. In H. W. Chang, J. T. Huang, C. W. Hue, & O. J. L. Tzeng (Eds.), *Advances in the study of Chinese language processing* (pp. 31–58). Taipei: National Taiwan University.

Wu, J. T., Yang, F. L., & Lin, W. C. (2013). Beyond phonology matters in character recognition. *Chinese Journal of Psychology*, *55*(3), 289–318. doi:10.6129/CJP.20130608.