行政院國家科學委員會專題研究計畫成果報告

漢字辨識與唸讀裡的形似抑制效果：

檢驗促發程序的推論邏輯（二）

Graphemic inhibition effect: Evaluating the rationale of priming procedures (II)

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中 文 摘 要

漢字辨認與唸讀裡的形似促發字相對出現頻率效果

最近的研究一再顯示語意促發對漢字的辨認與唸讀有穩定的增快效果，但同音促發卻對唸字及認字沒有穩定的增快效果或沒有效果，反駁了流行的認為漢字辨識或提取語義之前一定介入語音處理歷程的看法。這些研究同時闡明了某些情況下穩定的形似促發之抑制效果。本文提出四個更進一步的實驗，希望深入探討形似促發字之抑制效果。目標字設定在中高頻字，採用非遮蔽促發程序的認字及唸字作業。實驗一操弄促發字之相對出現頻率、字形相似與否、及促發字呈現時間，測量反應時間。結果在兩種作業下都發現，較目標字更高頻的形似促發字在呈現時間為 50 及 500 毫秒時皆產生明顯的抑制作用。實驗二把實驗一的促發字呈現時間延長到 1000 毫秒，結果除了較目標字更高頻的形似促發字仍維持明顯的抑制作用外，較目標字更低頻的形似促發字也產生抑制作用效果。實驗三採用了與實驗一相同的設計，但加入了假字促發字的情況，結果重複了實驗一的結果，但假字不產生任何顯著效果。實驗四採用了實驗三相同的設計，同時加入了單獨部件出現的額外促發情境。結果複製了實驗三的結果，而且，單獨出現目標字內含部件的促發情況對目標字認字產生增快作用，但對唸字則不產生顯著影響效果。這些結果運用了神經機制模型的概念加以解釋，同時也闡明了漢字的文字特性導致某些異於拼音文字的認知功能。

關鍵字: 字彙接觸、單字辨認、念字、頻率效果、單字出現頻率、
認字歷程的語音處理、鄰近字頻率效果、形似促發抑制。

Abstract

Accompanied with the reliable facilitation effect of semantic (instead of homophonic) priming on character recognition and naming found in previous research, it was also observed repeatedly that the prime with orthographically similar characters inhibits recognition and naming of targets. Four experiments are presented in the present article. The first two experiments manipulated prime character frequency, orthographic similarity, and SOA in the lexical decision and naming tasks. In the lexical decision task, the target characters preceded by an unmasked orthographically similar prime of higher frequency were responded to slower than their dissimilar pair controls both under the SOA was 50 ms and 500ms. A similar effect of inhibition was also observed in the naming task. When the SOA duration was extended to 1000 ms in Experiment 2, a significant inhibition effect was observed not only under conditions with primes of higher frequency but also with primes of lower frequency. In Experiment 3, pseudo-character primes were included. It was found that pseudo-character primes obtained no effect upon target recognition while manifested a small inhibition effect on target naming under prime exposure duration of 500 ms. In Experiment 4, an additional prime condition of free radicals in isolation was included. It was found in Experiment 4 that with preceded presentation duration of 50 ms or 500 ms, the embedded right component radical in isolation facilitated the recognition of the target character embedding it, while did not exerted any effect on character naming at all.

Keywords: lexical access, character recognition, character naming, frequency effect, character frequency, prelexical phonology, neighborhood frequency effect, orthographic prime inhibition.

The role of relative frequency on orthographic priming in character recognition and naming

On the orthographic depth hypothesis

For more than a decade, many researchers have suggested that the word recognition process is different for orthographies differing in the degree of representing phonology (e.g., Frost, 1994; Frost & Bentin, 1992; Frost, Katz, & Bentin, 1987; Katz & Feldman, 1983; Katz & Frost, 1992). They stated that the processes of pre-lexical analysis of phonology will be more functional in reading shallow orthographies like Serbo-Croatian, while reading deep orthographies like Hebrew will rely more on the orthographically based direct route for addressing the mental lexicon. The typical research paradigm is to evaluate the relative magnitude of frequency effects and semantic priming effects on lexical decision and naming tasks, among different orthographies. If high frequency words are responded to faster than low frequency words, and if semantic priming facilitates the response, then it is inferred that the lexical identification process should be involved in the tasks. If the naming task necessitates lexical identification, then it will be logically circular to infer that there is involved with phonological process in lexical identification. To challenge the above view of the orthographic depth hypothesis, there is still opposite evidence that supported direct route in lexical access for shallow languages(e.g., Baluch & Besner, 1991; Sebastian-Galles, 1991; Tabossi & Laghi, 1992). Nevertheless it is without doubt that lexical identification is always involved in word naming in deep orthographies.

Chinese may be the deepest orthography around the world. It is a logograph without any stable orthography-to-phonology correspondence. There is no way to pronounce a character with certainty before it is recognized. For instance, with an identical stem or phonetic radical, 也 (pronounced as /ye3/, translated as ‘besides’), embedded in, there are many different but orthographically similar (called ‘neighborhood’) characters with different pronunciations, 地 (/di4/, ‘earth’, with the left part radical pronounced as /tu3/, translated as ‘soil’), 池 (/chi2/, ‘pond’, with the left radical as /sui3/, ‘water’), 馳 (/chi2/, ‘run’, with the left radical as /ma3/, ‘horse’), and 他 (/ta1/, ‘he’, with the left radical as /jun2/, ‘person’), etc.. Unlike any alphabetic system, phonology does not covariate with the orthography. It is then possible for Chinese to demonstrate a clear single route picture of direct lexical access. Empirical evidence has been provided to argue against the viewpoint of pre-lexical or pre-semantic phonology in identifying Chinese characters. Some are from studies of comparing frequency effects on lexical decision and naming (Liu, Wu, & Chou, 1996; Wu, Chou, & Liu, 1994; Wu & Liu, 1997). Other related experiments used lexical decision or naming with priming procedures (e.g., Wu & Chen, 2000; Wu & Chou, 2000). Using Japanese Kanji and Katakana to compute the relative frequency effects in naming and lexical decision, Hino and Lupker (1998) found the sizes of frequency effects for Kanji (a deep script) were comparable in the tasks of lexical decision and naming, while for Katakana (a shallow script) the frequency effect in the naming was smaller than that in the lexical decision. This is in line with the results of Liu and colleagues in their studies using Chinese characters (cf. Liu, Wu, & Chou, 1996). These results are consistent with those from studies of the orthographic depth hypothesis.

Nevertheless, there are still some studies reported to propose that, the same as alphabetic systems, the phonological activation is a pre-lexical or at-lexical automatic process in the recognition of Chinese characters (e.g., Cheng, 1992; Cheng & Shih, 1988; Perfetti & Zhang, 1991, 1995, 1996). Their most important evidence came from the studies of homophonic priming effects on lexical decision and naming. Cheng (1992) showed a significant homophonic priming facilitation effect on lexical decision to support his obligatory phonological recording view of Chinese character recognition. Perfetti and Zhang (1991) found that homophonic primes, compared to semantic primes, showed greater facilitation effects on naming target characters. That was important evidence for them to claim that the character identification is accompanied with the activation of phonology automatically and pre-semantically (Perfetti & Zhang, 1996). Their view of universal phonology were further supported (e.g., Perfetti & Tan, 1998 ; Tan & Perfetti, 1997). Despite the replication of their experiments had been questioned from not only one single laboratory. In the study of Perfetti and Tan (1998), they attempted to demonstrate the time courses of activation of orthographic and phonological information in experiments using primed naming tasks with SOAs varying from 43 ms to 180 ms. When the SOA was 43 ms graphic (orthographically similar) primes produced facilitation on target naming. When the SOA was 57 ms, this graphic facilitation effect disappeared and turned out to be inhibitory, and a strong homophonic facilitation effect appeared. When the SOA was 85 ms, a greater graphic inhibition showed, homophonic primes kept maintaining facilitation, and semantic primes began to show facilitation. When the SOA was extended to be 115 ms, both semantic and homophonic primes exerted a compatible amount of facilitation effect. This time-course pattern, linked with the result of Experiment 4 (180 ms SOA) in Perfetti and Zhang (1991), thus portrayed an ideal picture to support their pre-semantic phonology claim. It is noted that neither in

Perfetti and Tan (1998) nor Experiment 4 in Perfetti and Zhang (1991) there was any graphic inhibition effect reported when the SOA was longer than 115 ms. There existed some reasons to improve their design of experiments. First of all, their experiments only used naming task which demands participants to pronounce and then might exaggerate the effect of factors concerning phonology. Secondly, the most important influencing factor, target character frequency, was not introduced. And also, the SOA was manipulated between participants and the discrepancies among varying levels were very small so that the proposed fluctuated pattern of time course may also be attributed to the sampling fluctuation of group differences. Wu with colleagues (Wu & Chen, 2000; Wu & Chou, 2000) thus conducted four experiments using Taiwan's traditional Chinese characters to examine their results. In these four experiments, not only the factors of prime type and SOA were manipulated as Perfetti's naming studies, but also (1) target frequency was manipulated, (2) SOA was manipulated between participants and within participants, and (3) both tasks of lexical decision and naming were evaluated. The result pattern of Chinese character naming and recognition is summarized as follows. (1). Substantial reliable semantic facilitation effect was observed on lexical decision and on naming for targets of low frequency under all conditions of SOA, while the homophonic facilitation effect was observed under certain conditions for targets of low frequency on lexical decision or even on naming. (2). When homophonic priming facilitation was observed, there always existed stronger facilitation effect of semantic primes. (3) A long lasting graphic inhibition effect was obviously observed on target characters of high frequency, both in naming and lexical decision. A year later, Hong Kong and mainland China re-conducted the experiment of Perfetti and Tan (1998), with the same materials (of simplified Chinese characters), design, and program. Chen and Shu (2001) published a result just like that predicted by Wu and colleagues. Without manipulation of target character frequency, under the SOA of across 43 to 85 ms, the homophonic priming effect was negligible while semantic primes exerted facilitation effect and graphic primes exerted inhibition effect on naming.

It might be appropriate now to consider the possible factors affecting the processing of orthographic information. While neither Cheng (1992) nor Perfetti and Zhang (1991) found any observable effect of orthographic priming, Perfetti and Tan (1998) indeed reported some facilitation effects of orthographic priming when the SOA was 43 ms, some inhibition effects when SOA was 57ms and 85ms, and no effect when SOA was longer than 115 ms. On the other hand, Wu and his colleagues obtained a substantial effect of inhibition from orthographic priming either on lexical decision or on naming when SOA was between from 50 ms to 1000 ms. In a replication study using the same materials of Perfetti and Tan (1998), Chen and Shu (2001) re-confirmed this reliable graphic inhibition effect. Colombo (1986) also found an inhibitory effect from orthographic priming on the response to high frequency targets at a SOA of 320 ms. McClelland and Rumelhart's (1981) interactive activation model was adopted to interpret his result. Within the interactive activation framework, word units mutually inhibit each other, and the total inhibition directed toward a particular word node is a function of the activation levels of all the other active word nodes. Following the same logic the higher frequency orthographically similar primes presented prior to the stimulus word may reach a relatively high activation level and then result in an increase in inhibition of the stimulus word.

There is other research related with orthographic similarity. Glushko (1979) found consistency effects on the naming of English words and pseudo-words. Consistency refers to the degree of similarity of pronunciations among a group of different words each with the same sublexical unit. High consistency words and pseudo-words were named faster than a low consistency words and pseudo-words. In his Experiment 3, the regularity effect was taken into consideration as well, a regular word with high consistency was responded to faster than which with low consistency. This implied that it might be an analogy from orthographically similar neighbors, rather than a mapping by spelling-to-sound rules, to name English words. Fang, Horng, and Tzeng (1986) adopted this idea into the studies of Chinese and also found the consistency effect in naming characters, though Hue (1992) later showed that it was only obtained in naming characters with low frequency.

What Glushko (1979) tried to say is that the production of phonology might be a result of computation or "activation-synthesis" among orthographically similar neighbors. Grainger, O'Regan, Jacobs, and Segui (1989) further provided evidence that neighborhood frequency might be a critical factor in determining word recognition latencies. In their experiments it was shown that lexical decision latencies were adversely affected by the existence of at least one neighbor of higher frequency than the stimulus word itself (also see Grainger & Ferrand, 1994). In their study, a single word target to be processed in a trial was always presented without any preceding prime. In this kind of single-word presentation paradigm, a factor is manipulated under a between-, rather than a within-, targets design. Because words vary on a wide variety of dimensions, single-word presentation paradigms face the problem that there are always a range of possible hypotheses or confounding as to the basis of differences between performance for two different sets of words. Priming paradigms provide a potential solution to this problem and increase in internal validity because they allow estimates of the effect of a particular experimental manipulation to be derived from responses to exactly the same target items when preceded by different prime stimuli. This gave rise afterwards to Grainger's studies of orthographic priming on lexical decision.

Orthographic and phonological activation in alphabetic orthographies

Though the issue of phonology has long been focused in researches studying alphabetic orthographies, Whaley (1978) used a regression analysis and found that among many factors the occurrence frequency of word is the most influencing one affecting the performance in tasks requiring word identification. From that time on, word frequency is always treated as the major factor to be considered in the studies of word recognition and naming. Furthermore, recent literature showed that the frequency effect may be moderated by the occurrence frequency of other words which are orthographically similar (called ‘ neighborhood’) to the target word. In some studies, neighborhood words with higher frequency might inhibit the processing of the target. Andrews (1997) pointed out the reliability of this neighborhood effect is still worth being elaborated. Among many studies concerning neighborhood effect to explore the lexical decision process Jonathan Grainger and colleagues published most notable articles (in French cf. Grainger & Jacobs, 1996; in Spanish cf. Carreiras, Perea, & Grainger, 1997).

By conducting a series of studies using the lexical decision task with the priming paradigm, Grainger and colleagues attempted to find the time course of activating orthographic and phonological information. With very short exposure durations of masked non-word primes, SOA from 17 ms to 50 ms, the orthographic facilitation effect was observed. The effect size observed was largest at about 30 ms and then disappeared at 64 ms. In the meantime, the homophonic facilitation effect was also to start when the prime exposure duration was 32 ms and increase along with SOA (Ferrand & Grainger, 1992; 1993; 1994). While the prime was a word and the exposure duration longer than 64 ms, the orthographic similarity effect turned out to be inhibitory instead, no matter the homophonic effect was still facilitatory. The facilitatory homophonic effect changed to be inhibitory only when half of non-word foil targets were pseudo-homophones (Grainger & Ferrand, 1994). These results drew a picture when combined with that from a previous study (Segui & Grainger, 1990), in which only prime words with frequency higher than targets obtained orthographic inhibition effect at short SOA of 60 ms, while at long SOA of 350 ms only lower frequency words obtained the orthographic inhibition effect.

A modified version of the interactive activation model initially developed by McClelland and Rumelhart (1981) was then proposed by Ferrand and Grainger (1992) as follows. The model is characterized by a triangular structure, including a layer of sub-lexical orthographic units, a layer of sub-lexical phonological units, and a level of lexical representations (word level). On presentation of a written word, the visual input activates a set of orthographic units, which, in turn, send activation on to the word level and phonological units directly linked with. The build-up of activation at the lexical and phonological levels thus lags behind the build-up of activation at the orthographic level. This explained that at very short prime exposure of 32 ms only orthographic units will be sufficiently activated to facilitate subsequent target recognition. With longer prime exposures (e.g. 64 ms) both phonological and word units will be more activated to influence subsequent target recognition. Activated word units will inhibit target word recognition via within-level inhibition, whereas activated phonological units will provide facilitatory inputs to the target representation and hence facilitate recognition. Thus, at prime exposures of around 60 ms, facilitation effects of phonological prime-target overlap are present, but the facilitation effects of orthographic overlap are cancelled by lexical inhibition. According to this conception of the visual word recognition process, orthographic information is fed directly into the mental lexicon without any prior transformation into a phonological code. This is in conflict with the viewpoint of phonological mediation by some authors (Lukatela & Turvey, 1991; Van Orden, Pennington, & Stone, 1990), who proposed that there is no direct link between orthographic units and word units (also see Ferrand & Grainger, 1994). Nevertheless, it is obvious that phonological activation would play an important role after orthographic information has been initially activated in an alphabetic lexical identification process. This is because an alphabetic orthography was designed to a great extent to reflect the correspondence between orthography and phonology. Whereas a logographic system like Chinese, which loosens the grapheme-to-phonology correspondence, might be different.

Let's go back to the issue of orthographic inhibition effect. When SOA was also manipulated orthogonally with neighborhood frequency, Segui and Grainger (1990) obtained different effects of neighborhood frequency on lexical decision under different SOA's. When masked prime words were presented for 60 ms, only primes that are higher frequency orthographic neighbors of the target interfered with target processing relative to an unrelated condition. On the other hand, when SOA was extended to 350 ms for unmasked primes, interference was observed only with lower frequency prime words, while those with higher frequency prime words no longer produced any interference or facilitation. The results were interpreted in terms of activation and selection processes. For a short prime presentation, it was assumed that only unconscious process was performed. Only high frequency primes would obtain a higher level of activation enough to inhibit the processing of its orthographic neighbor target. For a prime presentation long enough to perform conscious processing, a selection process to account for the result was proposed as follows. If the prime is low frequency and the target a higher frequency neighbor of this word, the target representation must be inhibited for the prime to be identified. If the target is then presented for identification, it will take longer if the inhibition has not had time to dissipate. On the other hand, if the prime is high frequency and target a lower frequency one, then on prime-word identification the target representation is not a strong competitor in selection processes and does not require inhibition. This was rather a sophisticated account and was still not easy to convince others why higher frequency neighbor prime lost its inhibitory effect when SOA was extended longer. In a review article, Andrews (1997) stated that neighbors have consistently been reported in the studies on English to facilitate target naming and recognition, and thus treated Grainger's French inhibitory effect of neighbors as arising from sophisticated guessing strategies in the perceptual identification task or lexical decision strategies adopted in unusual stimulus environments.

Compatible with our research on Chinese character identification with priming paradigms, we do believe that the orthographic similarity would be a critical factor in the process of word recognition. It is without doubt that prelexical analysis of orthography is of course necessitated for the identification of a word and the retrieval of its phonological and semantic properties. For correct identification, it is natural to keep away from confusion or interference from other words. The inhibitory connections between similar forms of words are then inevitable when they are activated simultaneously. Is the picture of orthographic inhibition in lexical identification for Chinese exactly the same as or totally different from that of any alphabetic system?

The present study adopted a research strategy similar to Segui and Grainger (1990). In studies using alphabetic orthographies, an orthographic neighbor refers to a word that can be created by changing a single letter of a target word. While in the present Chinese study an orthographic neighbor is defined as a character sharing a radical with the target character. Using the aforementioned example, a target character, **他**, has many neighbor characters, **地**, **池**, and **馳**. All of these characters share the same radical, 也. It is noted that in this kind of Chinese studies the graphic similarity between a target and its neighbor is about half size of a character, while in alphabetic studies the difference between a target word and its neighbor is only a letter. Using the priming procedure in lexical decision and naming tasks, the SOA and neighbor character frequency relative to the target character were manipulated. Tasks of character lexical decision and naming were both evaluated.

Experiment 1

Because orthography does not covary with phonology in Chinese as previously stated, for correct identification it should be more necessary than other languages to keep away from confusion or interference from orthographically similar characters. Segui and Grainger (1990) obtained different effects of neighborhood frequency on lexical decision under different SOA's. When prime words were briefly presented for 60 ms, only primes that are higher frequency orthographic neighbors of the target interfered with target processing. In contrast, when SOA was extended to 350 ms, interference was observed only with lower frequency prime words. A possible alternative explanation for the fact that higher frequency primes lost their effect under SOA extended longer can be as follows. Because words they used as stimuli were in French, a shallow alphabetic orthography, phonology covaries with orthography. When SOA is long enough, the phonology would be sufficiently activated for higher frequency prime words. This might produce a facilitation effect on target processing to compensate the inhibition resulted from competition among orthographically similar neighbors. If this explanation is correct, then we would find inhibition effect from primes with higher frequency as well as with lower frequency for longer SOA in experiments using Chinese characters as stimuli. We conducted the present experiment to test this hypothesis. Two levels of SOA, 50 ms and 500 ms, were used to cover a range wider than that of Segui and Grainger (1990).

Method

Design and stimuli. Participants were randomly assigned into one of four groups representing combinations of two between-participants factors of task (lexical decision vs. naming) and SOA (50 ms vs. 500 ms). Each group of participants received the same 2 × 2 within-participants factorial consisting of two factors of prime frequency (higher vs. lower), and orthographic relatedness (similar vs. unrelated). This formed a 2 × 2 × 2 × 2 four-way factorial design.

Forty eight medium-frequency characters were selected as target stimulus set from the character database of Wu and Liu (1987). The character frequency ranged from 77 to 150 per million (with an average of 112). For each target character, four prime characters representing different combinations of 2 × 2 within-participants factorial were coupled. Two of them were orthographically similar to the target characters while the other two were unrelated. Orthogonally, half of them were with character frequency higher than the target character, ranged above 250 per million, and the other half were with relatively lower frequency, ranged below 13 per million. The number of strokes was also equated among different conditions. The complete list of target characters and prime characters is presented in the Appendix A along with the number of strokes and the character frequency. For each participant, each target character appeared just once and was preceded by only one of four different types of prime. The assignment of each target character into the different prime conditions was counter-balanced between participants. Forty eight filler trials with target character not restricted in medium-frequency and with the prime unrelated to the target were further constructed and mixed with those trials of stimulus target. This summed up with 96 trials in total for the naming task. With respect to the lexical decision task, additional 96 trials with pseudo-character targets and a different set of prime characters were constructed to sum up with 196 trials in total. A total of 20 additional characters were also selected for practice trials.

Apparatus and procedure. The experiment was controlled by an IBM PC/486 compatible microcomputer. Stimuli were presented in isolation on the center of a 17 inches VGA-adapted, 60Hz, display. A voice-activated circuit linked with a microphone was interfaced to the computer to detect the onset of the participant's pronunciation in the naming task. Reaction times (RTs) and the timing of stimulus display were both measured to the nearest millisecond and synchronized with the video raster. The software used for controlling experimental procedures and data handling was adopted from Wu (1995). Participants received 20 practice trials each with feedback. Those trials responded with error in practice were repeated until a correct response was made. No feedback was given on the subsequent experimental trials.

On each trial, the following sequence of events occurred: (a) an asterisk used as a fixation point was presented at the center of the monitor and lasted for 700 ms accompanied with a 100 Hz warning tone for 150 ms, and then disappeared to leave the screen blank for 100 ms; (b) the prime character occupying a 24 × 24 dot matrix area which subtended a visual arc of approximately 1.2 degrees, from the viewing distance of 60 cm, was then presented in isolation at the center of the screen for a period of time, depending on which SOA group the participant was assigned to; (c) the target character was then presented at the same location to replace the prime character and then remained there until the computer detected the participant's key stroke in the lexical decision task or the onset of the participant's pronunciation in the naming task, the RT timing started from the presentation of the target character until the response was made; (d) in the naming task, the phonetic symbols used in Taiwan to stand for the correct pronunciation were then presented above the stimulus character, and via a remote connection line, the experimenter seated behind the participant either pressed one of two buttons to indicate that a correct pronunciation of the character triggered the computer or the other button to indicate that an incorrect pronunciation of the character or some other sound (such as a cough) triggered the computer; and (e) the whole screen was immediately erased and there was a 1-s blank before an asterisk accompanied with a warning tone for the next trial was presented.

All the 48 experimental trials, 48 filler trials, and additional 96 pseudo-character trials in lexical decision, were evenly and randomly divided into 12 blocks. Each block was composed of four trials from different prime conditions, one for each, and four fillers, and additional eight pseudo-character target trials for lexical decision. An on-line random assignment with a block randomization shuffling procedure was performed individually so that each participant received an idiosyncratic random sequence of block-arranged stimuli.

All participants were tested individually. Upon arrival each participant was seated in a sound-deadened room and received written instructions on the screen. Both accuracy and speed were emphasized. The participant were required to take a rest after a suitable number of trials. The entire experiment took approximately 20 minutes for each participant.

Participants. One hundred participants altogether were randomly assigned to four groups, each with 25 participants, according to the manipulation of the Task (lexical decision, naming) and SOA (50, 500 ms) factors. They were recruited from the participant pool at National Taiwan University to participate in this experiment for partial fulfillment of course requirements. All were fluent readers of Mandarin with normal or corrected-to-normal vision.

Results and Discussion

In calculating the mean RT of correct responses for each condition within each participant, those trials with RTs less than 200 ms (possible anticipation) or 2.5 standard deviations more than the mean of the condition to which the trials belonged were treated as outliers. The percentage of outliers was 4.1%. The re-computed mean correct RTs and mean percentages of errors across participants under different conditions of prime frequency × orthographical relatedness for each Group are shown in Table 1.

Insert Table 1 about here

Table 1 shows that in general it took slightly longer for naming than for lexical decision. Furthermore, it also took longer to respond to the targets preceded by orthographically similar prime with relatively higher frequency, as compared to other conditions. The statistical significance of these effects was assessed by analyses of variance (ANOVAs) across participants, F_1, and across stimulus items, F_2.

Mean RT data obtained for all participants in Experiment 1 were submitted to a four-way ANOVA with factors of task (lexical decision, naming), SOA (50, 500 ms), prime frequency (relatively higher, lower), and orthographical relatedness (similar, control). Lexical decision was in general slightly faster than naming to be responded across items, $F_1(1,96) = 2.81$, $p > .05$, $F_2\ (1,47) = 21.44$, $p < .001$. Target preceded with an orthographically similar prime was slower to be responded as compared to its control, $F_1(1,96) = 68.08$, $p < .001$, $F_2\ (1,47) = 45.27$, $p < .001$. A significant effect of prime frequency was found, $F_1(1,96) = 31.09$, $p < .001$, $F_2\ (1,47) = 8.67$, $p < .01$. There were also some significant interaction effects obtained, including relatedness × prime frequency, $F_1(1,96) = 15.28$, $p < .001$, $F_2\ (1,47) = 6.99$, $p < .01$, task × prime frequency , $F_1(1,96) = 21.90$, $p < .001$, $F_2\ (1,47) = 9.46$, $p < .01$, and relatedness × prime frequency × Task, $F_1(1,96) = 6.24$, $p < .05$, $F_2\ (1,47) = 10.34$, $p < .01$. The three-way interaction effect suggested different result patterns obtained from different tasks. Two three-way ANOVAs were then performed separately on the RT data for lexical decision and naming.

The three-way ANOVA with factors of SOA, prime frequency, and orthographical relatedness, performed on lexical decision, showed a similar pattern as the above four-way ANOVA. The significant sources of variation were relatedness,

$F_1(1,48) = 41.14$, $p < .001$, $F_2\ (1,47) = 52.09$, $p <.001$, prime frequency, $F_1(1,48) = 36.74$, $p < .001$, $F_2\ (1,47) = 11.51$, $p <.01$, and relatedness × prime frequency, $F_1(1,48) = 17.59$, $p < .001$, $F_2\ (1,47) = 14.86$, $p <.001$. The effect of SOA was also significant across items, $F_1(1,48) < 1$, $F_2\ (1,47) = 14.29$, $p < .001$. A further analysis showed that the simple main effect of relatedness was significant under the higher prime frequency condition, $F_1(1,96) = 52.84$, $p < .001$, $F_2\ (1,94) = 53.94$, $p <.001$, while it was not significant under the lower prime frequency condition, $F_1(1,96) < 1$, $F_2\ (1,94) = 1.18$. This supports the impression from Table 1 that a preceding prime with relatively higher frequency exerted an inhibitory effect on the response of lexical decision to the target, while a prime with lower frequency exerted no effect.

A quite different result pattern was obtained from the similar three-way ANOVA performed on naming. Only the main effect of relatedness was significant, $F_1(1,48) = 27.87$, $p < .001$, $F_2\ (1,47) = 21.30$, $p <.001$. A significant main effect of SOA was found across items, $F_1(1,48) = 1.12$, $p > .2$, $F_2\ (1,47) = 13.97$, $p < .001$. It is noted that the effects concerning the factor of prime frequency were not significant in naming task, different from that in lexical decision. A similar simple effect analysis as that for lexical decision showed that the differing effects of relatedness were both significant for higher prime frequency, $F_1(1,96) = 19.97$, $p < .001$, $F_2\ (1,94) = 10.68$, $p < .01$, and for lower prime frequency, $F_1(1,96) = 8.43$, $p < .01$, $F_2\ (1,94) = 12.62$, $p < .001$.

To sum up, there were several points worthy noticing. First, the response latencies for lexical decision were slightly faster than that for naming. This confirms the general pattern from previous studies on Chinese character recognition and naming (e.g., Liu, Wu, & Chou, 1996; Wu, Chou, & Liu, 1994). Second, the prior presentations of orthographic neighbors with frequency higher than target always exerted inhibitions on the lexical decision responses to the targets, irrespective of whether the presentation of primes were brief or long. This is consistent with our prediction stated before, while is different from Segui and Grainger (1990) in which the neighbor prime of higher frequency no longer exerted inhibition on target lexical decision when SOA was long. In the present experiment we did not find any significant inhibition effect in lexical decision from the neighbor prime of lower frequency for prime presentation duration of 500 ms. Maybe it was still not long enough for activating the prime sufficiently to compete with the target. Third, whether the SOA was short or long, and whether the prime frequency was higher or lower relative to the target, the orthographic neighbors always produced inhibition on the naming response to the target. Maybe because most prime-target pairs were not homophonic, the inhibition obtained in the naming task which demands phonology was larger than in the lexical decision. It is worthy to note that according to Andrews (1997) all of the alphabetic studies using naming tasks had not found any inhibition effect except for the low-density words naming in the Spanish study of Carreiras et al. (1997). The neighborhood-size or neighborhood-density is defined as the numbers of a given word. A high-density word is a word with more neighbors. Rather, a low-density word is with few neighbors. In this experiment, not only for lexical decision the orthographic inhibition effect was obtained under higher frequency primes, for naming the orthographic inhibition effect was obtained under both higher and lower frequency primes. The orthographic inhibition effect seems to be more obvious for naming in Chinese.

Experiment 2

In Experiment 1, we obtained the same result with Segui and Grainger (1990) for short presentation of primes, while different results for long presentation of prime. According to the reason stated previously, for Chinese character recognition it should be found for neighbor primes, whether with high frequency or with low frequency, to produce inhibition on target process as long as the duration of prime presentation is sufficient. It might be still not enough for SOA of 500 ms so that we did not find any significant inhibition effect from the neighbor primes of lower frequency. For convenience, in this experiment we extended the SOA to 1000 ms while other things did not change.

Method

Design and stimuli. The same design and stimuli as Experiment 1 was adopted except that SOA was fixed at 1000 ms instead. This reduced the design into a three way factorial with the factor of Task being between-participant and the other two of prime frequency and orthographical relatedness being both within-participant.

Apparatus and procedure. The same apparatus and procedure used in Experiment 1 were adopted in this experiment.

Participants. Forty participants from the same pool as Experiment 1 were recruited in this experiment. They were randomly assigned to two groups. One group of participants received lexical decision task and the other group received naming task. There were 20 participants in each group.

Results and Discussion

The procedure for data analysis is similar as Experiment 1. The mean correct RTs and mean percentages of errors across participants under different conditions for each Group are shown in Table 1. Mean RT data obtained for all participants in this experiment were submitted to a three-way ANOVA with factors of task (lexical decision, naming), prime frequency (relatively higher, lower), and orthographical relatedness (similar, control). Lexical decision was still overall slightly faster than naming to be responded to across items, $F_1(1,38) = 1.56$, $p > .2$, $F_2\ (1,47) = 14.29$, $p < .001$. Target preceded with a orthographically similar prime was slower to be responded to as compared to its control, $F_1(1,38) = 20.55$, $p < .001$, $F_2\ (1,47) = 17.53$, $p < .001$. A marginally significant effect of prime frequency was found across participants, $F_1(1,38) = 4.24$, $p < .05$, $F_2\ (1,47) < 1$. There was no other significant effect found. Because there was not any factor interacted with task, it suggested that the same result pattern obtained for different tasks this time.

The two-way ANOVA with factors of prime frequency, and orthographical relatedness, performed on lexical decision, showed a slight different pattern as compared to Experiment 1. The main effect of relatedness was significant, $F_1(1,19) = 14.09$, $p < .01$, $F_2\ (1,47) = 30.05$, $p <.001$. The effect of prime frequency was significant marginally only across participants, $F_1(1,19) = 4.53$, $F_2\ (1,47) = 2.83$. The interaction effect of relatedness × prime frequency was no longer significant, $F_1(1,19) < 1$, $F_2\ (1,47) < 1$. A similar simple effect analysis as Experiment 1 showed that the differing effect of relatedness was significant for both conditions of higher prime frequency, $F_1(1,38) = 8.81$, $p < .01$, $F_2\ (1,94) = 23.34$, $p <.001$, and lower prime frequency, $F_1(1,38) = 6.54$, $p < .05$, $F_2\ (1,94) = 13.05$, $p <.001$. This indicated that a preceding orthographically similar prime exerted an inhibitory effect on the lexical decision of the preceded target regardless of higher and lower prime frequency. Nevertheless, when inspecting Table 1 the prime with higher frequency seemed still to produce more inhibition than that with lower frequency. This was harmonious with that of Experiment 1.

Moreover, the two-way ANOVA performed on naming showed a pattern which was still consistent with Experiment 1. Only the main effect of relatedness was significant marginally, $F_1(1,19) = 6.82$, $p < .05$, $F_2\ (1,47) = 4.75$, $p <.05$. All other effects were not significant.

When Experiment 2 extended the SOA to 1000 ms, the result pattern agreed with the tendency of experiment 1. Both for lexical decision and naming, we obtained a significant effect of inhibition on target recognition for neighbor prime with lower frequency. Because the inhibition effect from neighbor prime with higher frequency is still significant and no longer decreasing, comparing with Grainger' s result, it seems that the orthographic inhibition in Chinese is more robust than that in French or other alphabetic systems.

Experiment 3

Experiments 1 and 2 showed that orthographic similar character primes with frequency higher than target character manifests strong inhibition effects on either lexical decision or naming. Unlike the result from alphabetic orthography by Segui and Grainger (1990), the strong inhibition effect exerted from higher frequency orthographic neighbor characters on the target characters did not decrease along with SOA increasing. In contrast, prime character with frequency lower than target always shows smaller orthographic inhibition. Along with this dimension, it might be predicted that pseudo-character primes orthographically similar to target characters would not exert any inhibition on target processing, because a pseudo-character could not possess any lexical status to compete with the target. This experiment was an attempt to test this implication and to replicate the above two experiments with a larger set of stimulus materials. An additional prime condition with pseudo-characters was thus designed in this experiment. Ferrand and Grainger (1992) had ever used a masked prime paradigm to examine the effects of pseudo-homophonic prime and its orthographic control on target lexical decision. Both pseudo-homophonic prime and its orthographic control showed facilitation effects under SOA was 32 ms, while only pseudo-homophonic facilitation exhibited under 64 ms SOA. They had not evaluated non-word primes under any SOA longer than 64 ms.

Method

Design and stimuli. Participants were evenly assigned into one of four groups representing combinations of two between-participants factors of task (lexical decision vs. naming) and SOA (50 ms vs. 500 ms). Each group of participants received the same 3 × 2 within-participants factorial arranged materials according to the manipulation of two factors of prime type (frequency higher than target, lower than target, and pseudo-character), and orthographical relatedness (similar vs. unrelated). The design is the same as Experiment 1 except that a new level of pseudo-character was added into the factor of prime type.

Besides the original stimulus set of forty eight characters used as targets in Experiment 1 and 2, more 24 target characters with similar features were selected and added. For each target character, six primes representing different combinations of 3 × 2 within-participants factorial were coupled. Four of them were the same as in Experiment 1 and 2, otherwise two were pseudo-character conditions, one with orthographic similarity and the other unrelated control. The complete list of target characters and their corresponding different conditions of prime is presented in the Appendix B along with the character frequency. For each participant, each target character appeared just once and was preceded by only one of six different types of prime. The assignment of each target character into the different prime conditions was counter-balanced between participants. Seventy two filler trials with target character not restricted in medium-frequency and with the prime unrelated to the target were further constructed and mixed with those trials of stimulus target. This summed up with 144 trials in total for the naming task. With respect to the lexical decision task, additional 144 trials with pseudo-character targets and a different set of prime characters were constructed to sum up with 288 trials in total. A total of 20 additional characters were also selected for practice trials.

Apparatus and procedure. The same apparatus and similar procedure as Experiment 1 was adopted in this experiment.

All the 72 experimental trials, 72 filler trials, and additional 144 pseudo-character trials in lexical decision, were evenly and randomly divided into 12 blocks. Each block was composed of six trials from different prime conditions, one for each, and six fillers, and additional twelve pseudo-character target trials for lexical decision. Other things were the same as Experiment 1.

Participants. One hundred and fifty eight participants altogether were randomly assigned to four groups according to the manipulation of the Task and SOA factors. Two groups of participants (45 and 43) received a lexical decision task with 50 or 500 ms SOA, while the other two groups (each with 36 participants) received a naming task with each SOA. They were recruited from the participant pool at National Taiwan University to participate in this experiment for partial fulfillment of course requirements. All were fluent readers of Mandarin with normal or corrected-to-normal vision.

Results and Discussion

The procedure for data analysis is similar as Experiment 1. In calculating the mean RT of correct responses for each condition within each participant, those trials with RTs less than 200 ms (possible anticipation) or 2.5 standard deviations more than the mean of the condition to which the trials belonged were treated as outliers. The percentage of outliers was 3.8 %. The re-computed mean correct RTs and mean percentages of errors across participants under different conditions of prime type × orthographical relatedness for each Group are shown in Table 2.

Insert Table 2 about here

For abbreviation, two three-way ANOVAs with factors of SOA (50, 500 ms), prime type (frequency higher, lower, pseudo-character), and orthographical relatedness (similar, control) were performed separately on the RT data for lexical decision and naming.

From the ANOVA performed on lexical decision, it showed that the significant sources of variation were relatedness, $F_1(1,86) = 30.15$, $p < .001$, $F_2\ (1,71) = 21.28$, $p < .001$, prime type, $F_1(2,172) = 35.26$, $p < .001$, $F_2\ (2,142) = 34.39$, $p < .001$, and relatedness ×prime, $F_1(2,172) = 20.17$, $p < .001$, $F_2\ (2,142) = 21.18$, $p < .001$. The effect of SOA was also significant across items, $F_1(1,86) < 1$, $F_2\ (1,71) = 35.31$, $p < .001$. The further analysis showed that the simple simple-main effect of relatedness is strongly significant under the prime with higher frequency in 50 ms SOA, $F_1(1,258) = 47.31$, $p < .001$, $F_2\ (1,426) = 35.05$, $p < .001$; and in 500 ms SOA, $F_1(1,258) = 17.06$, $p < .001$, $F_2\ (1,426) = 14.00$, $p < .001$, marginally significant under the prime with lower frequency in 50 ms SOA, $F_1(1,258) = 5.47$, $p < .05$, $F_2\ (1,426) = 3.64$, $p > .05$; and in 500 ms SOA, $F_1(1,258) = 4.19$, $p < .05$, $F_2\ (1,426) = 4.58$, $p < .05$, not significant under the prime with pseudo-character in 50 ms SOA, $F_1(1,258) < 1$, $F_2\ (1,426) < 1$, and in 500 ms SOA, $F_1(1,258) = 1.37$, $F_2\ (1,426) < 1$.

From the ANOVA performed on naming, it showed that the significant sources of variation were relatedness, $F_1(1,70) = 67.67$, $p < .001$, $F_2\ (1,71) = 25.56$, $p < .001$, prime type, $F_1(2,140) = 5.39$, $p < .01$, F_2 $(2,142) = 4.07$, $p < .05$, SOA, $F_1(1,70) = 7.55$, $p < .01$, F_2 $(1,70) = 348.18$, $p < .001$. The further analysis showed that the simple simple-main effect of relatedness is significant under the prime with higher frequency in 50 ms SOA, $F_1(1,210) = 8.97$, $p < .01$, F_2 $(1,426) = 4.72$, $p <.05$; and in 500 ms SOA, $F_1(1,210) = 12.55$, $p < .001$, F_2 $(1,426) = 9.52$, $p <.01$, significant under the prime with lower frequency in 50 ms SOA, $F_1(1,210) = 16.04$, $p < .001$, F_2 $(1,426) = 9.78$, $p <.01$; and in 500 ms SOA, $F_1(1,210) = 17.63$, $p < .001$, F_2 $(1,426) = 11.80$, $p <.01$, significant under the prime with pseudo-character only in 500 ms SOA, $F_1(1,210) < 7.71$, $p < .01$, F_2 $(1,426) = 5.90$, $p < .05$. In contrast with that of lexical decision, the orthographic inhibition effect is easier to be obtained in naming under prime with lower frequency character or pseudo-character.

It is obvious that the prior presentations of orthographic neighbors with frequency higher than target always exerted inhibitions on the lexical decision responses to the targets, whether the presentation of primes were brief or long. In addition to lexical decision, whether the SOA was 50 ms or 500 ms, and whether the prime frequency was higher or lower relative to the target, the orthographic neighbors always produced inhibition on the naming response to the target. It seems that naming task demonstrated even more robust inhibition effect from orthographic neighbors in Chinese. The same result pattern of Experiment 1 and 2 was thus well replicated in this experiment. It also showed that prime with pseudo-character did not affect target recognition while exert a marginally significant inhibition effect on target naming under longer prime exposure duration of 500 ms.

Experiment 4

In the studies using very short SOA durations of masked non-word priming procedures, Ferrand and Grainger (1992; 1993; 1994) observed the orthographic and phonological facilitation effects to depict the picture about the activation process of sub-lexical orthographic information and pre-lexical phonology. While in our Experiment 3 we did not observe any orthographic facilitation effect when the prime was pseudo-character. It may imply that as short as 50 ms Chinese participants have passed the stage of radical process and entered into an upper level of process to reject the identification of the target as a lexical unit. To evaluate the inference of Ferrand and Grainger in Chinese, it is needed to explore an experimental condition under which the embedded radical of a target character is explicitly processed and kept not entering into an upper stage of lexical level process. If the free radical prime facilitates the response of the target, then the interactive activation network proposal could be confirmed. We then straightforwardly included in Experiment 4 a prime condition in which a free radical, which is embedded in the target character or not, was presented in isolation. In the context of a further replication of previous experiments, it is also interesting to find what will be if participants are demanded to explicitly process the embedded radical of a character.

It is also noted that sublexical processing, in English, means pre-lexical analysis of substring of a word for the purpose of converting its graphemes into phonology and then mapping to a lexical level unit. But for Chinese, how it will be to define pre-lexically sub-lexical process when we have known it is without any orthographically pre-defined phonology to mediate lexical process? A radical is usually a constituent unit of a character, when stands alone in isolation with size adjusted as a normal character, also could play a role as a character with specific semantic and pronunciation. The pronunciation of a radical standing as a character is usually unrelated with those pronunciations of characters embedding that particular radical. The consistency among pronunciations of different characters embedding the same radical is in general low (Liu, Chen, & Su, 2001). It suggests that a too much pre-lexical process of embedded radical would be harmful to the process of target character processing. Pre-lexical process of a radical will be logically restricted within a very shallow level of orthographic analysis. It should not enter into a higher level of linguistic transformation. If the radical has been well processed to an extent that its phonological information could be possible to be activated, then conflict results inevitably. This means that it may be hard to observe a reliable facilitation effect of embedded radical on character naming.

Method

Design and stimuli. Participants were evenly assigned into one of four groups representing combinations of two between-participants factors of task (lexical decision vs. naming) and SOA (50 ms vs. 500 ms). Each group of participants received the same 4×2 within-participants factorial arranged materials according to the manipulation of two factors of prime type (frequency higher than target, lower than target, pseudo-character, and isolated radical), and orthographical relatedness (similar vs. unrelated). The design is the same as Experiment 3 except that a new level of isolated radical was added into the factor of prime type.

The stimulus set of 72 characters as targets used in Experiment 3 was adopted in this experiment. For each target character, eight primes representing different combinations of 4 × 2 within-participants factorial were coupled. Six of them were the same as in Experiment 3, otherwise two were isolated radical conditions, one with orthographic similarity (right half part radical of the target character) and the other unrelated radical control. For each participant, each target character appeared just once and was preceded by only one of eight different types of prime. The assignment of each target character into the different prime conditions was counter-balanced between participants. The same seventy two filler trials used in Experiment 3 were also adopted to mix with experimental stimulus trials. This ended up with 144 trials in total for the naming task. With respect to the lexical decision task, the same 144 trials with pseudo-character targets used in Experiment 3 were also adopted to end up with 288 trials in total. Twenty additional characters were also selected for practice trials.

Apparatus and procedure. The same apparatus and similar procedure as Experiment 3 was adopted in this experiment. For the prime condition with isolated radical, the isolated radical was displayed in its own normal size (radical size) as that embedded in a character, instead of in character size.

All the 72 experimental trials, 72 filler trials, and additional 144 pseudo-character trials in lexical decision, were evenly and randomly divided into 9 blocks. Each block was composed of eight trials from different prime conditions, one for each, and eight fillers, and additional 16 pseudo-character target trials for lexical decision.

Participants. One hundred and seventeen participants altogether were randomly assigned to four groups according to the manipulation of the Task and SOA factors. Two groups of participants (30 and 28) received a lexical decision task with 50 or 500 ms SOA, while the other two groups of participants (31 and 28) received a naming task with 50 or 500 ms SOA. They were recruited from the same participant pool as Experiment 3. All were fluent readers of Mandarin with normal or corrected-to-normal vision.

Results and Discussion

The procedure for data analysis is similar as Experiment 3. The computed mean correct RTs and mean percentages of errors across participants under different conditions of prime type × orthographical relatedness for each group are shown in Table 2.

Insert Table 2 about here

Two three-way ANOVAs with factors of SOA (50, 500 ms), prime type (frequency higher, lower, pseudo-character, isolated radical), and orthographical relatedness (similar, control) were performed separately on the RT data for lexical decision and naming.

From the ANOVA performed on lexical decision, it showed that the significant sources of variation were prime type, $F_1(3,168) = 14.16$, $p < .001$, $F_2\ (3,213) = 12.91$, $p <.001$, and relatedness × prime, $F_1(3,168) = 6.15$, $p < .001$, $F_2\ (3,213) = 6.33$, $p <.001$. The effect of SOA was also significant across items, $F_1(1,56) < 1$, $F_2\ (1,71) = 7.90$, $p <.01$. The further analysis showed that the simple simple-main effect of relatedness is significant under the prime with higher frequency in 50 ms SOA, $F_1(1,224) = 9.84$, $p < .01$, $F_2\ (1,568) = 10.15$, $p <.01$; and in 500 ms SOA, $F_1(1,224) = 5.98$, $p < .05$, $F_2\ (1,568) = 7.00$, $p <.01$, and significant under prime with radical in isolation, indicating an orthographic facilitation effect with an effect size far weaker than that of the inhibition effect from under the prime with higher frequency, at 50 ms SOA only marginally by participants, $F_1(1,224) = 3.55$, $p = .05$, $F_2\ (1,426) < 1$, and at 500 ms SOA only by items, $F_1(1,224) = 2.85$, $p < .1$, $F_2\ (1,426) = 8.51$, $p <.01$.

From the ANOVA performed on naming, it showed that the significant souces of variation were relatedness, $F_1(1,57) = 27.86$, $p < .001$, $F_2\ (1,71) = 13.61$, $p < .001$, prime type, $F_1(3,171) = 4.30$, $p < .01$, $F_2\ (3,213) = 2.77$, $p < .05$, and relatedness × prime, $F_1(3,171) = 5.40$, $p < .01$, $F_2\ (3,213) = 2.47$, $p <.1$. The effect of SOA was also significant across items, $F_1(1,57) < 1$, $F_2\ (1,71) = 8.47$, $p < .01$. The further analysis showed that the simple simple-main effect of relatedness is significant under the prime with higher frequency in 50 ms SOA, $F_1(1,228) = 16.56$, $p < .001$, $F_2\ (1,568) = 4.59$, $p <.05$; and in 500 ms SOA, $F_1(1,228) = 13.91$, $p < .001$, $F_2\ (1,568) = 4.87$, $p <.05$, marginally significant under the prime with lower frequency in 50 ms SOA across participants, $F_1(1,228) = 4.12$, $p < .05$, and significant in 500 ms SOA, $F_1(1,228) = 11.22$, $p < .01$, $F_2\ (1,568) = 4.51$, $p <.01$.

It is obvious that the prior presentation of orthographic neighbors with frequency higher than targets always exerts inhibitions on the lexical decision responses to the target, whether the presentation of primes were short or long. In addition to lexical decision, whether the SOA was 50 ms or 500 ms, and whether the prime frequency was higher or lower relative to the target, the orthographic neighbors always produced inhibition on the naming response to the target. It seems that naming task demonstrated even more robust inhibition effects from orthographic neighbors in Chinese. The experiment replicated the same result pattern of Experiment 1, 2, and 3. The prime with pseudo-character exerted no effect at all as expected. It also showed that prime with component radical in isolation did facilitate the recognition of target characters, while exerted no effect on character naming at all. It is compatible with the aforementioned argument that it's hard to observe a reliable facilitation effect of radicals on the naming of embedding characters. There still remains further study to solve why the radical facilitation could be observed only on lexical decision instead of naming. A possible explanation is that naming task demands phonology that participants have to quit the process of radical earlier to prevent conflict between pronunciation activated from the embedded radical and that from the whole character. The result that the phonetic radical facilitation effect could not be observed on naming is in contradiction to that of Flores d' Arcais, et al. (1995). They found that earlier exposure of the phonetic radical produced facilitation of the Kanji naming response, which was stronger at the 180-ms SOA than at the 60-ms SOA. This facilitation effect is difficult to be evaluated because the prime in the control condition they used was a configuration of fragments composed of pieces of the strokes randomly selected from the target character. Nevertheless, it also remains possible in the present experiment that lexical decision may involve more than naming in analyzing a character into components and inducing the facilitation effect from radical components. This question will be aimed in the near future.

General Discussion

According to the above four experiments, we demonstrated that orthographic neighbor primes stably exerted inhibitory effects on the responses of lexical decision and naming to the character target. Moreover, the relative frequency of the prime to the target also played an important role to affect the time-course of inhibition. When the SOA was as short as 50 ms, only higher frequency orthographic neighbor primes produced inhibitory effects on the target processing. While when the SOA was long enough, both higher frequency orthographic neighbor primes and lower frequency ones produced inhibition on the target processing. This is different from what was observed by Segui and Grainger (1990) using French. In their study, only higher frequency orthographic primes exhibited inhibition effects at 60 ms SOA, while when the SOA was extended long this higher frequency orthographic inhibition effect disappeared and the lower frequency orthographic inhibition effect was manifested. In short, for a deep orthography like Chinese, higher frequency orthographic neighbor primes produced stable inhibition along with the SOA extended long, while in a shallow orthography like French, higher frequency orthographic neighbor prime lost its inhibitory effect when the SOA was long.

A possible interpretation is proposed as follows. For a short prime presentation, only higher frequency primes would produce a level of activation high enough to inhibit the processing of the orthographic neighbor target. For a prime presentation long enough, both higher frequency primes and lower frequency primes would obtain activation levels high enough to inhibit the processing of their orthographic neighbor targets. This is applicable for any orthography except that in a shallow alphabetic orthography phonology will play an important role as well. Because in shallow orthographies, phonology covariates with orthography to a great extent. When a SOA was long enough, the phonology of primes would be sufficiently activated for words of higher frequency, thus produces on the processing of the orthographic neighbor target a facilitatory effect which compensates the inhibition resulted from orthographic similarity. In Chinese, phonology does not covariate with orthography. Some neighbor countries had ever imported thousands of characters into their own writing systems. More than two thousands of characters had been adopted by Korea around the sixth century, and about three thousands by Japan around the 8th century. But none had pronounced the imported characters in exactly the same way as Chinese. They use their own ways. Even within mainland China or Taiwan, people with different dialects pronounce the same characters with exactly the same meaning in different ways. In normal reading of the traditional Chinese with Mandarin, there are even more than 900 characters each with more than two different pronunciations depending on different semantic situations encountered. It is also noted that a total amount of characters known by a college student is around five thousands in general while the total amount of different pronunciations with tone is only around 1400. It is thus obvious that Chinese orthography does not bind phonology. There exists no obligatory phonological process in lexical identification to produce any facilitation from phonological priming. Phonology for some people reading Chinese orthography might even be semantically mediated. For instance, the character 行 is pronounced as /hang2/ when it combines with the character 列 to form a compound word 行列 (means ‘row and column’), and pronounced as /hsin2/ when it combines with the character 進 to form another word 進行 (means ‘progression’).

Both the prime condition of pseudo-characters included in Experiment 3 and the prime condition of free radicals presentation in isolation included in Experiment 4 played important roles in supporting the above explanations and screened from the possible confounding variables. In Experiment 3, without pseudo-character primes exerting no interference the notion of within-level inhibition among lexical units would encounter difficulties. Because a pseudo-character possesses no lexical status the phenomenon of interference might be classified to be within a perceptual rather than a linguistic domain. In Experiment 4, with free radical primes exerting facilitation effects the notion of inter-level facilitations to support an interactive activation model is then confirmed. According to the notion of an interactive activation model a bottom-up (a facilitation link drew from the radical level to the character level) process and a top-down (also a facilitation link came from a holistic level down to a feature level) process are both required. Moreover, there were few studies before to seriously evaluate the role of radical priming on lexical decision and naming.

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Table 1

Mean correct latencies in milliseconds as a function of task, graphemic similarity, prime type, and SOA for Experiment 1 and 2

Task	SOA	Higher Frequency		Lower Frequency	
		GS	Control	GS	Control
Experiment 1					
LDT					
	50 ms	504 (9.3)	435 (3.0)	442 (3.3)	435 (2.0)
	500 ms	516 (8.7)	470 (2.7)	463 (1.7)	458 (3.0)
Naming					
	50 ms	517 (1.3)	479 (1.0)	508 (2.3)	490 (1.3)
	500 ms	498 (1.0)	469 (4.0)	490 (3.3)	464 (0.3)
Experiment 2					
LDT					
	1000 ms	525 (4.6)	478 (4.2)	509 (0.8)	470 (0.8)
Naming					
	1000 ms	551 (1.3)	522 (2.1)	546 (1.7)	519 (0.8)

Note: Percentages of errors are given in parentheses.
SOA = Stimulus Onset Asynchrony,
GS = Graphemically Similar.

Table 2

Mean correct latencies in milliseconds as a function of task, graphemic similarity, prime type, and SOA for Experiment 3 and 4

Task	SOA	Higher Frequency		Lower Frequency		Pseudo-character		free radical	
		GS	Control	GS	Control	GS	Control	GS	Control
Experiment 3									
LDT									
	50 ms	535	481	482	463	486	489		
		(11.3)	(3.0)	(4.4)	(3.0)	(4.3)	(5.2)		
	500 ms	506	473	474	457	456	465		
		(7.0)	(2.9)	(2.7)	(1.7)	(4.8)	(2.5)		
Naming									
	50 ms	536	517	528	502	518	510		
		(3.2)	(2.1)	(1.4)	(1.4)	(1.6)	(1.6)		
	500 ms	475	452	475	448	465	447		
		(2.8)	(2.8)	(2.6)	(2.6)	(1.9)	(3.7)		
Experiment 4									
LDT									
	50 ms	503	463	457	440	469	472	433	457
		(12.6)	(1.9)	(4.1)	(1.9)	(6.3)	(4.8)	(2.4)	(4.1)
	500 ms	490	458	441	443	462	449	439	461
		(6.7)	(2.4)	(3.2)	(2.0)	(7.5)	(6.8)	(2.8)	(3.6)
Naming									
	50 ms	489	458	471	455	467	455	453	455
		(2.5)	(1.8)	(2.9)	(1.4)	(1.4)	(0.7)	(1.1)	(0.7)
	500 ms	487	458	482	455	482	472	464	459
		(2.0)	(2.0)	(1.2)	(0.8)	(0.8)	(0.8)	(0.4)	(0.8)

Note: Percentages of errors are given in parentheses. SOA = Stimulus Onset Asynchrony, GS = Graphemically Similar.

Appendix A
Experimental Materials in Experiment 1 and 2

Target			Higher Frequency Prime Neighbor			Higher Frequency Prime Control			Lower Frequency Prime Neighbor			Lower Frequency Prime Control		
C	NS	CF	C	NS	CF	C	NS	CF	C	NS	CF	C	NS	CF
儀	15	105	議	20	398	歡	22	392	蟻	19	13	蹦	18	13
奶	5	107	仍	4	381	依	8	379	扔	5	12	妃	6	12
顏	18	121	領	14	317	較	13	314	頒	13	11	滄	13	11
刺	8	131	制	8	469	拉	8	473	剖	10	11	畔	10	11
刊	5	89	利	7	837	何	7	841	划	6	11	仕	5	11
硬	12	102	便	9	1105	相	9	1045	哽	10	10	栩	10	10
攻	7	120	改	7	435	球	11	432	孜	7	10	灶	7	10
牠	7	133	地	6	2613	你	7	2717	弛	6	10	朴	6	10
稅	12	127	說	14	3061	得	11	3140	蛻	13	9	貂	12	9
封	9	129	對	14	2092	裡	13	2101	吋	6	9	汝	6	9
訂	9	89	打	5	885	物	8	879	汀	5	9	札	5	9
核	10	140	孩	9	468	科	9	461	骸	16	8	諫	16	8
仔	5	81	好	6	1863	所	8	1943	籽	9	8	趴	9	8
股	8	87	設	11	373	跟	13	373	骰	14	7	滷	14	7
堆	11	96	推	11	270	項	12	268	椎	12	7	琢	12	7
猜	11	77	清	11	638	接	11	635	倩	10	7	捆	10	7
佔	7	80	點	17	1086	間	12	1104	玷	9	7	炳	9	7
悄	10	84	消	10	394	統	11	387	俏	9	7	拷	9	7
乾	11	148	吃	6	493	即	7	501	屹	6	7	旭	6	7
勤	13	95	動	11	1383	現	11	1372	勳	16	6	擄	16	6
織	18	112	識	19	344	隨	16	344	幟	15	6	嫻	15	6
朗	10	105	明	8	1000	位	7	992	朔	10	6	畝	10	6
悟	10	99	語	14	344	派	9	341	唔	10	6	栓	10	6
恨	9	89	很	9	1126	將	11	1178	垠	9	6	恤	9	6
抬	8	85	治	8	369	料	10	371	冶	7	6	吠	7	6
幼	5	91	功	5	403	呢	8	387	肋	6	6	佣	7	6
殘	12	133	錢	16	361	據	16	361	棧	12	5	鈍	12	5
帳	11	95	張	11	606	結	12	605	悵	11	5	酗	11	5
雪	11	145	電	13	806	感	13	801	霏	16	4	壑	17	4
狗	8	89	夠	11	251	停	11	252	駒	15	4	諛	15	4
略	11	150	路	13	762	像	14	780	酪	13	4	睦	13	4
彼	8	112	被	11	692	師	10	698	跛	12	4	湄	12	4
吹	7	109	次	6	794	許	11	787	炊	8	4	歿	8	4
煩	13	118	須	12	334	備	12	336	頏	12	2	脛	11	2
坦	8	111	但	7	1529	法	8	1452	靼	14	2	膈	14	2
輪	15	115	論	15	551	數	15	558	綸	14	2	滬	14	2
週	12	113	調	15	438	輕	14	436	碉	13	2	蜈	13	2
括	9	103	活	9	739	別	7	735	蛞	12	2	軼	12	2
吧	7	139	把	7	1260	從	11	1233	粑	10	2	陝	10	2
抵	8	88	低	7	302	般	10	306	祗	10	2	悌	10	2
妙	7	134	沙	7	251	供	8	247	眇	9	2	埂	10	2
拍	8	145	怕	8	290	投	7	289	珀	9	2	洵	9	2
洛	9	90	格	10	375	紅	9	375	恪	9	2	邵	8	2
折	7	136	新	13	892	加	5	906	昕	8	2	杵	8	2
揮	12	136	運	13	514	強	11	531	諢	16	1	觭	15	1
衝	15	139	術	11	404	程	12	411	衕	12	1	愫	13	1
借	10	111	錯	16	254	衛	15	257	腊	12	1	嵋	12	1
探	11	146	深	11	487	該	13	485	琛	12	0	稈	12	0

Note: C = character, NS = number of strokes, CF = character frequency per million.

Appendix B
Experimental Materials in Experiment 3 and 4

Target		Higher Freq. Prime				Lower Freq, Prime				Pseudo-Character	
		Neighbor		Control		Neighbor		Control		Neighbor	Control
C	CF	C	CF	C	CF	C	CF	C	CF	C	C
儀	105	議	398	戰	363	蟻	13	蹦	13	[得儀]	[鋅淬]
奶	107	仍	381	化	715	扔	12	朴	10	[坡奶]	[狼研]
顏	121	領	317	隨	344	頒	11	滄	11	[彩顏]	[鋅徑]
刺	131	制	469	拉	473	剖	11	嫺	6	[彩刺]	[狼岳]
刊	89	利	837	何	841	划	11	畔	11	[襟刊]	[幅汗]
硬	102	便	1105	相	1045	哽	10	仕	11	[好硬]	[町怡]
攻	120	改	435	依	379	孜	10	栩	10	[恸攻]	[吠拴]
牠	133	地	2613	你	2717	弛	10	趴	8	[稻牠]	[得作]
稅	127	說	3061	得	3140	蛻	9	貂	9	[襟稅]	[說祕]
封	129	對	2092	知	1328	吋	9	捆	7	[耕封]	[說犹]
訂	89	打	885	卻	959	汀	9	峙	6	[轍訂]	[吠詰]
核	140	孩	468	料	371	骸	8	畝	6	[歧核]	[碑作]
仔	81	好	1863	此	1395	籽	8	札	9	[棵仔]	[仁犯]
股	87	設	373	即	501	骰	7	拷	7	[轍股]	[好泠]
堆	96	推	270	項	268	椎	7	琢	7	[映堆]	[狼溫]
猜	77	清	638	接	635	倩	7	滷	7	[豹猜]	[襟桐]
佔	80	點	1086	如	1809	玷	7	忡	2	[好佔]	[燃扔]
悄	84	消	394	取	564	俏	7	祛	0	[好悄]	[河誌]
乾	148	吃	493	記	419	屹	7	揹	0	[斛乾]	[彩村]
勸	91	動	1383	間	1104	勳	6	擢	2	[鼬勸]	[飯噹]
織	112	識	344	邊	534	幟	6	躐	1	[鞈織]	[敲鴿]
朗	105	明	1000	個	4028	朔	6	舫	4	[豹朗]	[鋅仙]
悟	99	語	344	師	698	唔	6	埂	2	[旗悟]	[豬犹]
恨	89	很	1126	理	1269	垠	6	倔	7	[稻恨]	[狼稀]
抬	85	治	369	呢	387	冶	6	邵	2	[坡抬]	[襟犽]
幼	91	功	403	加	906	肋	6	叱	9	[綿幼]	[即取]
殘	133	錢	361	跟	373	棧	5	鈍	5	[碑殘]	[詢甜]
帳	95	張	606	這	4972	悵	5	緋	4	[河帳]	[得種]
楊	144	場	669	結	605	煬	5	嵋	1	[好楊]	[晴姬]
狗	89	夠	251	停	252	駒	4	酗	5	[殤狗]	[虞磨]
略	150	路	762	部	855	酪	4	琨	4	[犢略]	[睛蛹]
彼	112	被	692	特	673	跛	4	杵	2	[竣彼]	[陳柚]
吹	109	次	794	位	992	炊	4	佣	6	[怡吹]	[殆缸]
煩	118	須	334	備	336	頊	2	湄	4	[好煩]	[動郵]
坦	111	但	1529	所	1943	靼	2	炳	7	[礪坦]	[珠沌]
輪	115	論	551	數	558	綸	2	膘	2	[襟輪]	[飯理]

Note: C = character, CF = character frequency per million.
A pseudo-character was constructed from a pair of two characters in square brackets with the left radical from the left character and the right radical from the right character.

Appendix B
Experimental Materials in Experiment 3 and 4 (Continues).

Target		Higher Freq. Prime				Lower Freq, Prime				Pseudo-Character	
		Neighbor		Control		Neighbor		Control		Neighbor	Control
C	CF	C	CF	C	CF	C	CF	C	CF	C	C
週	113	調	438	程	411	碉	2	睦	4	[建週]	[豬詢]
括	103	活	739	物	879	蛞	2	恤	6	[綴括]	[呵指]
吧	139	把	1260	法	1452	耙	2	歿	4	[礪吧]	[種行]
抵	88	低	302	紅	375	祗	2	洵	2	[耕抵]	[河蛭]
妙	134	沙	251	供	247	眇	2	吠	6	[知妙]	[河桅]
拍	145	怕	290	般	306	珀	2	陜	0	[眼拍]	[碑缺]
洛	90	格	375	球	432	恪	2	栓	6	[疏洛]	[級報]
折	136	新	892	信	858	昕	2	妃	12	[行折]	[填統]
揮	136	運	514	強	531	諢	1	觭	1	[襟揮]	[俞煎]
徑	94	經	1603	從	1233	脛	2	愫	1	[狼徑]	[喝浹]
借	111	錯	254	統	387	腊	1	螟	2	[河借]	[喝誌]
探	146	深	487	該	485	琛	0	稈	0	[碑探]	[軀師]
幅	99	福	277	群	233	蝠	2	戢	3	[隔幅]	[豬狐]
敬	118	教	1178	就	2668	赦	11	鄆	0	[轍敬]	[飯銀]
敦	76	政	913	認	615	孜	0	塚	2	[暢敦]	[桶煤]
脈	72	派	341	規	311	掁	0	拭	12	[賺脈]	[稻狗]
扮	71	份	253	投	289	枌	0	汝	9	[襟扮]	[晴戰]
釣	98	的	26642	裡	2101	趵	0	悌	2	[弘釣]	[詢餌]
伸	151	神	784	任	605	砷	2	旭	7	[牧伸]	[狂往]
析	76	近	561	保	591	伒	0	帙	0	[牧析]	[珠貶]
杜	73	社	536	則	560	牡	5	阮	14	[疏杜]	[順怡]
雞	94	難	678	機	942	錐	8	黠	2	[陳雞]	[彩模]
坡	74	破	290	連	442	詖	0	祀	7	[牧坡]	[好拴]
鄰	90	都	2048	影	586	鄔	3	礦	2	[就鄰]	[軀諫]
孔	81	亂	265	比	739	軋	10	仆	4	[鞈孔]	[呆卉]
副	126	到	3513	現	1372	劃	6	貶	10	[訊副]	[豬桐]
頗	75	類	378	滿	544	頦	1	榛	2	[轍頗]	[彩浣]
額	129	顯	324	雖	474	顱	5	螞	0	[舒額]	[駝詢]
淨	104	靜	269	輕	436	崢	3	婢	10	[糠淨]	[晴徨]
梅	73	海	754	許	787	誨	5	綵	2	[鐵梅]	[蟻修]
欲	93	歡	392	較	314	歙	25	悖	4	[糠欲]	[轍吱]
斜	85	科	461	根	424	蚪	5	皎	2	[郵斜]	[豬詰]
姓	125	性	980	非	582	甦	6	炕	2	[蚊姓]	[種佃]
勤	95	助	279	隊	306	勦	2	諛	4	[致勤]	[碑緬]
惱	82	腦	268	衛	257	瑙	10	豌	2	[碑惱]	[襟錘]
柯	68	河	252	待	287	蚵	2	沱	2	[町柯]	[幅洋]

Note: C = character, CF = character frequency per million.
A pseudo-character was constructed from a pair of two characters in square brackets with the left radical from the left character and the right radical from the right character.