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Is Stroke Neighbor Priming Effect Inhibitory or Facilitatory: An Investigation Using Chinese Hanzi Characters

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ABSTRACT

Previous masked priming studies in alphabetic languages have shown that when targets are primed briefly by orthographic neighbors of higher frequency (e.g., *blue-BLUR*), the response latencies to targets become longer, compared to when the same targets are briefly primed by unrelated primes of equivalent frequency (e.g., *care-BLUR*). In comparison, the results from previous studies using single character Chinese stroke neighbors (e.g. 令-今) are mixed: orthographic neighbor priming was found to be inhibitory (Wang et al., 2014) or facilitatory (Shen & Forster, 1999) with 50 ms of prime presentation. Two experiments were conducted to test the replicability of previous studies of single Chinese Hanzi characters. In Experiment 1, following Shen and Forster's Experiment 2, we presented the simple characters and compound characters in separate blocks. Experiment 2 was an attempt to replicate Wang et al.'s Experiment 2b, in which the relative prime-target frequency of Chinese stroke neighbors was manipulated. Our results did not replicate either of the previous results. In Experiment 1, the facilitatory stroke priming effect was only observed in the compound-character condition. In Experiment 2, null stroke neighbor priming effects were observed irrespective of the relative frequency of the prime-target pairs. We discuss accounts for the discrepancies between the previous studies and our current findings.

ACKNOWLEDGEMENTS

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CHAPTER ONE:

Introduction

Visual word recognition, which plays an essential role in reading, has invited a wealth of previous studies to investigate the underlying mechanisms. Among the many proposed models of visual word recognition, the Interactive Activation model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982) has been one of the most influential models and has provided valid accounts for the empirical studies.

In the Interactive Activation model, visual information of the stimulus is assumed to flow through three processing levels: the feature level, the letter level, and the word level (see the illustration of the model in Figure 1). Within each level, there are individual units called “nodes”, which exclusively inhibit each other. For example, at the word level, visually similar nodes like *blue* and *blur* suppress each other through inhibitory connections. Between adjacent levels, there are bidirectional connections (bottom-up connections and top-down connections, in which sense this model is “interactive”). For example, through a bottom-up connection, the initial letter *b* in a stimulus would send facilitation to word nodes like *blue, blur*, but inhibition to word nodes that do not start with the letter *b* (see Rastle, 2012).

It is of particular interest for the visual word recognition that the inhibition connection within the word level gives rise to the lateral inhibition between the word nodes. One important assumption based on the Interactive Activation model and other related models (BIA model: Dijkstra et al., 1998; van Heuven et al., 1998; SOLAR model: Davis, 2001) is that the word recognition process involves lexical competition: Before a word is recognized, the representation of the word itself and the representations of orthographically similar words are activated, and then, these representations compete against each other via lateral inhibition.

In the empirical test of the Interactive Activation model's assumptions, researchers often use orthographic neighbors to examine lateral inhibition between orthographically similar words. Orthographic neighbors are defined by Coltheart et al. (1977) as words differing from each other only by one letter in the same position while keeping the letters in other positions identical (e.g., *side*, *ride*, *tile* are all orthographic neighbors of the word *tide*). An important assumption of the activation-based model is that the identification of a word must occur after the resolution of the competition among the representations of the word that is being presented and the representations of its orthographic neighbors that get co-activated.

The masked priming paradigm (Foster & Davis, 1984) has been one of the most useful tools to study the process of word recognition, including lexical competition. This paradigm has been used to study especially the automatic and early phases of various aspects of lexical processing (Kinoshita & Lupker, 2003). In this paradigm, a typical trial starts with the presentation of a forward "mask", which is followed by a stimulus called "prime" that is presented for a very short time (e.g., 50 ms). Then the prime is immediately replaced by the target. The speed and accuracy of target recognition in the "prime condition", where targets are preceded by related words, are compared with those in the "control condition". In the prime condition, primes are in some way related to the targets (e.g. orthography, phonology, semantics, etc.), and in unrelated condition, they are unrelated to the targets. The differences between the two conditions are referred to as the "priming effect". The most common task that is used in the paradigm is a lexical decision task. In this task, participants are asked to decide if the target is a word (hence "lexical") and make a response accordingly as soon and accurately as possible. When the target is a word, the participants are asked to press the "yes" button; when the target is not a word, the participants are asked to press the "no" button.

Inhibitory Neighbor Priming in Non-Logographic Languages

The inhibitory neighbor priming effect refers to a phenomenon in which lexical decisions to targets are statistically significantly delayed when primed by orthographically similar primes relative to unrelated primes. For example, for the target word *blur*, the orthographic neighbor *blue* hinders the response more than an unrelated word prime such as *case*[1] (Davis & Lupker, 2006; Nakayama et al., 2008; Segui & Grainger, 1990).

According to Davis (2003), such an effect would occur because the presentation of an orthographically similar neighbor prime causes a specific competitor of the target (i.e., the prime) to be activated stronger than the target itself at the time the target appears. Although the presentation of the neighbor prime would pre-activate the representation of the target word to some extent and this may facilitate target identification, the inhibition introduced by the neighbor prime outweighs the facilitation due to the pre-activation of the target by the neighbor prime. Control primes, on the other hand, would neither compete with nor preactivate the target representation. Therefore, recognition of the targets would be slower when targets are primed by neighborsrelat-e to when the same targets are primed by control words, and thus the inhibitory ne ighbor priming effect is shown.

Theoretically, the size of the inhibitory neighbor priming effect would be determined by how much stronger the competitive activity of the prime is than that of the target upon the presentation of the target. As the difference in the strength of activity could be calculated with the initial resting activity of the primes and targets, and that initial resting activity is a function of the word frequency of words, inhibitory priming effect should be more readily observed when the primes are of higher frequency than the targets (e.g., *blue-BLUR*) (Segui & Grainger, 1990; Davis, 2003). This pattern has been found in various alphabetic languages (e.g., English: Davis

& Lupker, 2006; French: Segui & Grainger, 1990). The slower response latencies to targets primed by high-frequency neighbors were interpreted as evidence of lexical competition, such that the activation of lexical representations of the targets is suppressed by the co-activated representations of the orthographically similar neighbors.

Besides the relative frequency of the prime-target pair, the inhibitory neighbor priming effect is also subject to other factors. In previous studies of visual word recognition, it has been found that neighborhood size affects the effect of prime-target frequency on inhibitory priming effects. For instance, using English stimuli, Nakayama et al. (2008) found that there was an interaction between the neighborhood size effect and the effect of the prime-target frequency relationship. When the neighborhood size was small, high-frequency primes but not low-frequency primes hindered the lexical decision on the word targets; when the neighborhood size was large, low-frequency primes hindered the lexical decision as much as high-frequency primes did. The inhibitory neighbor priming effect that is independent of relative prime-target frequency was also observed in the syllabic Japanese Kana script by Nakayama et al . (2011), who used words with a large number of neighbors.

The lexicality of the prime also modulates the masked neighbor priming effect. The prime lexicality effect is a key prediction of the Interactive Activation model (see Davis, 2003). It is posited that while both word neighbor primes and nonword neighbor primes activate the representations of orthographic neighbors, including the target, word neighbor primes would get activated to inhibit their targets as competitors, but nonword neighbor primes would not, as nonwords are not represented in the mental lexicon. Davis and Lupker (2006) gave support to this prediction in their Experiment 1, in which they used both English word neighbor primes and nonword neighbor primes, and observed the inhibitory neighbor priming effect from word neighbors while facilitatory priming effect from the nonword neighbor primes.

Lexical Competition in Chinese Hanzi Characters

Hanzi characters, written in a logographic script, are structurally different from the Roman script. With regard to the question of how visually similar Chinese Hanzi characters affect each other in lexical processing, several previous studies which used tools other than the masked priming paradigm have looked into the issue. One such study investigated how radicals are represented (Ding et al., 2004). Radicals, according to *Specification for Identifying Indexing Components of GB 13000.1 Chinese Characters Set* (Chen et al., 2009), are constituent units in compound characters (could be located in the left, right, upper and lower parts of a compound character). For example, in 驰 "gallop", 马 is the semantic radical, and 也 is the phonetic radical. Ding et al. used single characters that shared the same radical(s) in the same or different positions in unmasked priming experiments and found that when the prime and the target shared a radical but in different positions, there was an inhibitory priming effect. Ding et al. suggested that there could be lexical competition at the radical level in Chinese lexical processing, and the competition is modulated by positional information. Also with an unmasked priming design, Wu and Chen (2003) selected characters that shared the phonetic radical as orthographic neighbors. In this study, the inhibitory priming effect was shown when the duration of prime presentation was both as short as 50 ms and as long as 1000 ms. These studies support the idea that there is a radical level inhibition in the Chinese character processing.

Previous masked priming studies have examined lexical competition in the visual recognition of Chinese Hanzi characters at the stroke level. There are at least two published masked priming studies, the results observed from which are the focus of the present examination (Shen & Forster, 1999; Wang et al., 2014). In these studies, Hanzi characters that differed from each other by one or two strokes were defined as orthographic neighbors and termed “stroke neighbors” (Wang et al). For instance, 细 “thin”-绅 “squire”, and 兵 “soldier”-丘 “mound”, were considered as stroke neighbors, and these studies tested whether the presentation of 细 as a prime would delay the lexical decision to 绅. According to Wang et al., a Chinese Hanzi and its constituent strokes are analogous to a word and its letters in the Roman script. For example, in a similar way to the fact that the English word *pond* is comprised of the four letters *p*, *o*, *n*, and *d*, the Chinese character 下 “lower” consists of the strokes 一, 丨, and 丶. Therefore, like in the word recognition in alphabetic languages, in Chinese character recognition, lexical competition may be present between stroke neighbors (e.g., 又 “again”-叉 “cross”). If so, an inhibitory stroke neighbor priming effect – slower latencies to targets primed by stroke neighbors than by unrelated characters, should be observed.

As will be described more in detail in the following section, however, with the duration of the prime presentation being 50 ms, two previous studies reported conflicting patterns of results. Wang et al. (2014) found the stroke neighbor priming effects to be inhibitory whereas Shen and Forster (1999) found such effects to be facilitatory. Therefore, the issue of whether there is lexical competition in the visual recognition of Chinese Hanzi characters at the stroke level is yet to be resolved.

The Present Study

The goal of the present study was to investigate the mechanisms of visual recognition of Chinese characters. Specifically, we examined whether lexical competition, evidenced by the observation of inhibitory neighbor priming effects in various alphabetic languages (e.g.

English: Davis & Lupker, 2006; French: Segui & Grainger, 1990), as well as in the syllabic Japanese Kana script (Nakayama et al., 2011), also exists in the visual recognition process of single Chinese characters between stroke neighbors.[3] As previous studies have shown discrepant and even contradictory results (Shen & Forster, 1999; Wang et al., 2014), it was not clear whether lexical competition truly exists between stroke neighbors. This study, therefore, aimed to test the replicability of the previous studies.

In the present study, two experiments were conducted. Experiment 1 was a partial replication attempt of Shen and Forster (1999, Experiment 2). Following Shen and Forster, two types of single characters were selected and tested in different blocks. Experiment 2 was a replication attempt of Wang et al. (2014, Experiment 2b). Again, following Wang et al., the relative prime-target frequency was manipulated (high-low and low-high). If there is lexical competition in visual Chinese Hanzi character recognition, the presentation of the primes would significantly hinder the recognition of the targets. As a consequence, the inhibitory effect in Wang et al. would be replicated, and the replication experiment of Shen and Forster may show inhibition instead of facilitation. On the other hand, if a facilitation effect is observed, then it suggests that lexical competition does not operate at the level of stroke units, and target recognition benefits from the visual similarity between the primes and the targets.

CHAPTER TWO:

Experiment 1

Method

Participants

Forty graduate and undergraduate students at Tohoku University (Sendai, Japan), who were Chinese native speakers, participated in Experiment 1. All had normal or corrected-to-normal vision. Before the experiment, all participants had signed the consent form. Each participant received a 1,000-yen Amazon gift card for participation. Participants were naive about the goal and the mechanism of the experiment.

Stimuli

The same visually similar prime-target pairs used in Experiment 2 of Shen and Forster (1999) were used as the critical stimuli in Experiment 1. There were two types of characters to form prime-target pair conditions: simple and compound characters. Simple characters were "pictograms" (which resemble physical objects, e.g., 木 "wood") and "simple ideograms" (which are abstract symbols that stand alone, e.g., 上 "up"). Compound characters were "compound ideograms" (whose components are two or more abstract symbols that work together to indicate the meaning, e.g., 林 "forest") and "logographic-phonetic compounds" (each of which is a combination of a phonetic component that indicates the approximate pronunciation and a semantic component that indicates the meaning, e.g., 理 "rationale"). For the simple-character condition, there were 30 prime-target pairs and for the compound-character list, there were 32 prime-target pairs. Within each neighbor pair, the prime and target differed from each other by one or two strokes (e.g., 瓜 “melon” –爪 “claw” for simple-character pairs and 肝 “liver” –肚 “belly” for compound-character pairs).

Lexical characteristics of the stimuli were as follows. In the simple-character condition, for the neighbor primes, their mean number of strokes was 4.47 (range = 2–8), and their mean frequency (measured by counts per million) was 337.35 (range = 2.84–1488.97). For the targets, their mean number of strokes was 4.43 (range = 2–9), and their mean frequency was 678.20 (range = 0.17–7969.33). Thirty control primes, each of which matched with a neighbor prime for the number of strokes and word frequency, were also selected. The mean number of strokes and word frequency were 4.57 (range = 2–8) and 338.53 (range = 2.95–1489.91), respectively.

In the compound-character condition, for the primes, the mean number of strokes was 8.13 (range = 4–13), and the mean frequency was 74.00 (range = 0–599.94). For the targets, the mean number of strokes was 8.34 (range = 6–13), and the mean word frequency was 68.07 (range = 0–877.41). Thirty-two control primes, each of which matched with a neighbor prime for the number of strokes (*M* = 8.13, range = 6–13) and word frequency (*M* = 79.09, range = 0.02–590.70). The frequency data of simple- and compound characters were taken from SUBTLEX-CH (Cai & Brysbaert, 2010).

As was mentioned, the simple and compound character conditions were tested in separate blocks to follow the procedures of Shen and Forster (1999). Within each condition, prime-target pairs were divided into two counterbalancing lists in such a way that the targets primed by visually similar primes in one list would be primed by unrelated pairs in the other list. In that way, no target stimulus would be seen by a participant for more than once. The full list of neighbor character pairs can be found in Appendix A of this thesis.

To complete the design of a character decision task, a total of 62 pseudo-characters (30 simple, 32 compound) were created to serve as targets with the computer programme TrueType. Thirty simple pseudo-characters (e.g., , which was modified from 永) were created by adding or deleting one or two strokes from a real simple character whose number of strokes fell into the range of 2 to 9. Thirty-two compound pseudo-characters (whose number of strokes fell into the range of 6–13) were created by assembling real radicals (as Chen et al., 2009, indicates, “radicals”, in a broad sense, encompass any components of compound characters) that did not combine to form a real character but still presented in its “normal” position (e.g., the radical 艹 was always located in the “top” of a pseudo-character). The ways of creating pseudo-characters followed those in Shen and Forster (1999). Care was taken to make the pseudo-characters look like real characters. Sixty-two additional characters (30 in the simple character condition, 32 in the compound character condition) were randomly selected to serve as the primes that were paired with the pseudo-characters.

All target stimuli, including characters and pseudo-characters, were presented in the Songti font, whereas the prime stimuli (neighbor characters and control characters) were presented in the Kaiti font. Each single stimulus, either a character or a pseudo-character, was retrieved and stored as a BMP image file. For the target stimuli, the size of a BMP image was 80 × 80 pixels. The size of a BMP image for the prime stimuli was smaller (64 × 64 pixels). Pseudo-characters were served as targets, each of which was randomly assigned to a character prime. There was only one presentation list for non-character stimuli. The order of trials was randomized within each participant.

Apparatus and procedures

Each participant was tested individually in a quiet, bright, and disinfected room. The experiment was conducted using the computer program DMDX (Forster & Forster, 2003), in which stimuli were presented on a CRT monitor which has a refresh rate of 240 Hz. Each trial was composed of the presentation of four stimuli in the following order. First, a fixation cross (+) was presented on the center of the screen for 500 ms, followed by the forward pattern mask (“#####”), which was presented for 500 ms. Then, a prime character was presented for 50 ms and immediately replaced by a target stimulus and remained on the screen until the participant made a response or 2000 ms had been elapsed. The stimuli were presented in white against a black background.

The task was character decision. The participants were asked to judge if a target stimulus was an existing Hanzi character. They were instructed to make responses with the emphasis on both speed and accuracy. For characters (“yes” responses), they were asked to press the left arrow button on the keyboard; for pseudo-characters (“no” responses), pressing the right arrow button was required. After each trial, visual feedback was given to the participant on the screen about the correctness of the judgement (i.e., “correct”, “wrong”, “no response”) and the response time (e.g., 567.34 ms).

Before experimental trials, each participant completed 12 practice trials. The items used in practice trials were not used in the experimental trials. The participants in this experiment also carried out a naming task for a different research project. The order of the two tasks was counterbalanced.

Results

Table 1 shows the mean error rates and response latencies of Experiment 1 (see Table B in Appendix B for the results in Shen & Forster's (1999) Experiment 2). The data collected from one participant were replaced by the data collected from a newly recruited participant because of the high error rate. Data for simple and compound character conditions were analyzed separately, as was done in Shen and Forster. Wrong responses and responses with latencies that were outside of ± 3 standard deviations of each condition (simple-neighbor, simple-control, compound-neighbor, compound-control) mean were removed from the analysis (accounting for 0.6% and 1.2% of the correct response latencies data in the single- and compound-character conditions, respectively). Error rates and the response latencies of correct responses for character targets were analyzed. As the data were collected separately for the simple- and compound-character conditions, the data were submitted to paired t-tests respectively for each condition.

In the simple-character condition, responses were slower when the targets were primed by neighbor characters ($M = 615$, $SD = 77.47$) than by control characters ($M = 600$, $SD = 59.39$), but the difference was significant only in subject analysis, $t_s(39) = 2.06$, $SEM = 7.08$, $p < .05$; $t_i(29) = 1.12$, $p > .05$. Numerically, participants made more errors when the targets were primed by neighbor characters ($M = 6.8$, $SD = 5.94$) than by control characters ($M = 4.5$, $SD = 5.31$) neighbor but the 2.3% difference was not statistically significant, $t_s(39) = 1.90$, $p > .05$; $t_i(29) = 1.78$, $p > .05$.

In the compound-character condition, responses were faster when the targets were primed by neighbor characters ($M = 591$, $SD = 69.82$) than by control characters ($M = 607$, $SD = 63.10$). This difference was only significant in subject analysis, and marginally significant in item analysis, $t_s (39) = -3.00$, $SEM = 5.26$, $p < .05$; $t_i(31) = -1.96$, $SEM = 8.06$, $p = .06$. Participants made fewer errors when the targets were primed by neighbor characters (*M* = 9.38, *SD* = 7.35) than by control characters (*M* = 10.31, *SD* = 9.96), but the difference was not significant, both *t*s < 1.

Finally, to quantify whether the patterns of priming effects were significantly different for simple vs. compound characters, two by two Analysis of Variance (ANOVA) were conducted with Condition (Simple vs. Compound) and Prime Type (Visually similar vs. Control) as factors. In the subject analyses, both factors were within-subject factors, and in the item analyses, Condition was a between-item factor and Prime Type was a within-subject factor. Results showed that, for the response latency data, the interaction was significant, F_s (1, 39) = 12.87, $p < .05$, *MSE* = 717.25, $\eta_p^2 = 0.25$; F_i (1, 60) = 4.20, *MSE* = 1628.33, $p < .05$, $\eta_p^2 = 0.07$, but for the error rate data, the interaction was nonsignificant, F_s (1, 39) = 2.82, $p = .10$; F_i (1, 60) = 1.76, $p = .19$. There was a significant difference between the pattern of priming effects for simple and compound characters, but only in response latency.

Findings of this experiment showed that the neighbor priming effect was facilitatory in the compound-character condition, which was consistent with Shen and Forster (1999). However, in the simple-character condition, the neighbor priming effect was nonsignificant (and the trend was inhibitory). In sum, the results of Experiment 1 successfully replicated only for the compound-character condition.

Discussion

In Experiment 1, the facilitatory stroke neighbor priming effect observed in Shen and Forster (1999) was replicated in the compound-character condition. This indicated that, at least for compound characters, a target could be recognized more quickly when it followed a visually similar prime (in this experiment, a “stroke neighbor”). The facilitation might originate from the orthographic overlap between the prime and the target. It was suggested that, when a compound-character prime is presented, the lexical representations of its orthographic neighbors are pre-activated based on visual similarity. Therefore, the judgement would be quicker upon the appearance of the target.

On the other hand, an overall null effect was observed in the simple character condition, which was neither consistent with the results in Shen and Forster (1999) nor with those in Wang et al. (2014). Since there was a trend for inhibition, the null effect could be considered as a result of the inhibition produced by the lexical competition between the representations of the single character target and its orthographic neighbors being canceled out by the orthographic facilitation (which originated from the pre-activation of the representation of the target).

A critical issue to consider, then, is why there was a discrepancy between the observations in the compound-character condition and the simple-character condition (there was a significant between Condition and Prime Type). One possibility is that the difference in priming effect is related to the fact that simple characters had fewer strokes than compound characters. To examine whether the number of strokes modulates the priming effect, a combined (simple and compound character conditions) correlation analysis between the number of strokes and the priming effect was conducted. As the correlation coefficient ($r = 0.26$, $p < .05$) indicated, the influence of the number of strokes on the priming effect was significant, the characters with more strokes are more likely to receive facilitation. Indeed, the difference in the number of strokes might lead to the difference in the priming effect. Since the relationship between a Chinese character and its constituent strokes is in a way similar to that between a word in alphabetic languages and its constituent letters–although, unlike an alphabetic word, a Chinese character is assembled in a rectilinear structure instead of a horizontal string–the number of strokes in Chinese characters may affect the pattern of priming effect similarly to the number of letters in alphabetic words. Forster et al. (1987) shed some light on the mechanism. In their study, a word-length dependent masked neighbor priming effect in the lexical decision task was found: the priming effect was significantly facilitatory for eight-letter words and null for four-letter words). Forster et al. interpreted such effects as a function of the neighborhood density (size). It is possible that characters with a larger number of strokes also have a smaller number of neighbors. As Marian et al. (2012) showed, longer words in alphabetic languages tend to have fewer orthographic neighbors. We could expect the same pattern to be found in Chinese characters, and thus similar influence of the number of strokes could be observed in the visual recognition of Chinese characters.

In addition to Forster et al. (1987), the effect of neighborhood size has been observed in previous studies of alphabetic languages (e.g., Nakayama et al., 2008). In the present study, compared to compound characters, simple characters had fewer strokes and simpler structures, and it is indeed possible that neighborhood sizes of simple characters and compound characters were different. For example, whereas 田 "farmland" could have more stroke neighbors like 电 "electricity", 由 "reason", 申 "applicate", etc. because of its simple structure, 细 only has 绅 "squire" and 紬 "silk" (which is a rare Chinese character), because establishing neighborhood is more constricting for visually more complex characters. However, since there is not yet a study in which the stroke neighborhood sizes of single Chinese characters are systematically investigated, it is unclear how exactly this variable would affectthe priming effect.

These possibilities explain why differential priming patterns were observed for simple and compound characters. They, however, do not account for why we have observed different patterns of priming effects in the present study than those in Shen and Forster's (1999) Experiment 2, as in the present Experiment 1 the same target characters were used in the character decision task and the procedures were largely identical. Whereas in Shen and Forster's Experiment 2, significant facilitatory priming effects were found in both the simple-character condition and the compound-character condition, in the present study, such facilitation was observed only in the compound-character condition. One explanation could be that, although we tried to follow Shen and Forster's way of creating pseudo-characters in the simple-character condition (i.e., adding or deleting one or two strokes from a real simple character), discriminating the pseudo-characters and the real characters could still have been more difficult in the present study.

The findings in Experiment 1 have shown that, when simple characters and compound characters were presented in separate blocks, different patterns of stroke neighbor priming effects could be yielded. However, in real-world reading, simple characters and compound characters are rarely separated, and compound characters are more prevalent (According to Li et al., 2011, more than 80% of Chinese characters are compound). Besides, the frequencies of the primes and the targets were not subject to manipulation in Experiment 1, which means this could be a confounding factor. To investigate whether different results would be produced in a more ecologically valid and better-controlled experimental design, we attempted to replicate Wang et al. (2014, Experiment 2b), in which simple and compound characters were in the same block and relative frequencies of prime-target pairs were manipulated.

CHAPTER THREE:

Experiment 2

Method

Participants

Fifty-two graduate and undergraduate students at Tohoku University (Sendai, Japan), who were Chinese native speakers, participated in Experiment 2. Fifteen of the participants had also participated in Experiment 1, which was conducted 5 months earlier. All participants had normal or corrected-to-normal vision. Before the experiment, all participants had signed the consent form. Each participant received a 1,000-yen Amazon gift card for participation. Participants were naive about the goal and the mechanism of the experiment.

Stimuli

In Wang et al.'s Experiment 2b, 56 stroke neighbor character pairs were selected from *A Dictionary of Chinese Character Information* (Li & Liu, 1988) as critical stimuli, among which 39 pairs were listed in Appendix A of Wang et al. (2014). Each pair consisted of a low-frequency character and a high-frequency character (e.g., 肋 "rib", and 助 "help"). Since a new database of character information, SUBTLEX-CH (Cai & Brysbaert, 2010), was used in the present study, the character frequency data of all the 39 pairs of characters were recollected from the new database. Of the 39 pairs, 14 pairs were not used and replaced by other stimuli because they did not form salient low and high frequency contrast. Thirty-one neighbor pairs were newly selected from SUBTLEX-CH to match the total number of prime-target pairs to that used in Wang et al. (2014, Experiment 2b). In the final stimuli list, the frequency of the high-frequency member of the pair was on average 1119.52 (range: 105.57–7594.4). The low-frequency member of the neighbor pairs had a mean frequency of 15.5 (range: 0.02–78.8).

Within each prime-target pair, low- and high-frequency characters were matched on number of strokes (high-frequency characters: mean= 3–13, range = 6.64; low-frequency characters: mean = 2–12, range = 6.71). The phonological similarity (in terms of segments) between the prime and target in each pair was minimized. Besides, there was no obvious semantic similarity or associative connection between the two stimuli within each prime-target pair.

Each of the low- and high-frequency characters served as the prime or target once in neighbor priming conditions. That is, for example, in each of the two neighbor priming conditions, for the high-frequency-low-frequency neighbor pairs 助 “help”–肋 “rib”, the low-frequency character 肋 was primed by the high-frequency character 助, and the high-frequency character 助 was also primed by the low-frequency character 肋.

To serve as control primes for the neighbor pairs, unrelated characters were selected from SUBTLEX-CH. Frequencies and number of strokes were matched with those in the neighbor pairs (e.g., for high-frequency-target condition, 羽 “feather”/助 “help”; for low-frequency-target condition, 近 “near”/肋 “rib”). For the high-frequency control primes, the mean frequency was 1108.86 (range = 104.76–7792.81), and the mean number of strokes was 6.64 (range = 3–13). For the low-frequency control primes, the mean frequency was 15.5 (range = 0.02–78.8) and the mean number of strokes was 6.73. The full list of neighbor and control character pairs can be found in Appendix C of this thesis.

To complete the design of a character decision task, 56 pseudo-characters were created in an identical way to Experiment 1. Fifty-six more characters were selected from SUBTLEX-CH to prime the pseudo-characters. The newly selected primes were matched on the number of strokes with the other two groups of primes (*M* = 6.73, range = 2–12), but not for the frequency.

The characters of medium frequency were instead selected for primes paired with pseudowords (*M* = 563.62, range = 59.69–3473.98).

All stimuli, including characters and pseudo-characters, were presented in the same Songti font, following Wang et al. (2014). Each stimulus, either a character or a pseudo-character, was retrieved and stored as a BMP image file (67 × 67 pixels). For character targets, there were four counterbalancing lists for the assignment of groups to different conditions so that each participant was tested in all four conditions and saw no stimulus for more than once. For example, for the neighbor pair 兵 "soldier"–丘 "mound", four different prime-target pairs were assigned to four different conditions, namely: high-frequency target preceded by a low-frequency prime (丘 "mound"–兵 "soldier"); high-frequency target preceded by a low-frequency control prime (匆 "hasty"–兵 "soldier"); low-frequency target preceded by a high-frequency prime (兵 "soldier"–丘"mound"); high-frequency target preceded by a high-frequency control prime (抢 "rob"–丘 "mound"). Pseudo-characters were served as targets for "no" responses in a character decision task, each of which was randomly assigned to a character prime. For each participant, there were 56 characters and 56 pseudo-characters to respond to. The order of trials was randomized for each participant.

Apparatus and Procedures

The apparatus and procedures were the same as in Experiment 1, except that the stimuli were presented in a single session (instead of two separate blocks, and that the primes and the targets were in the same font and size, following Wang et al., 2014).

Results

Table 2 shows the mean error rates and response latencies of Experiment 2 (check Table D in Appendix D of this thesis for the results in Wang et al. (2014, Experiment 2b)). Wrong responses and responses whose latencies were outside of ± 3 standard deviations of each condition (neighbor LF target; control LF target; neighbor HF target; control HF target) mean were removed from the analysis (accounting for 1.5% of the correct response latencies data). Error rates and the response latencies of correct responses for character targets were analyzed. The data were submitted to a 2 (Target Frequency: high and low frequency) × 2 (Prime Type: neighbor prime and unrelated prime) analysis. In the subject analysis (*F*s), both factors Target Frequency and Prime Type were within-subject factors; in the item analysis (*F*i), Target Frequency was a between-item factor, and Prime Type was a within-item factor.

For response latencies, a main effect of target frequency was significant [$F_s(1, 51) = 160.73$, $MSE = 646.64$, $\eta_p^2 = 0.76$, $p < .0001$; $F_i(1,110) = 43.52$, $MSE = 3179.85$, $\eta_p^2 = 0.28$, $p < .0001$]. Participants produced quicker responses in the judgement of high-frequency targets. The main effect of prime type was not statistically significant [$F_s(1, 51) = 2.09$, $p > .05$; $F_i(1,110) = 3.49$, $p > .05$]. The interaction between target frequency and prime type was also not significant [both $Fs < 1$].

For error rates, a main effect of target frequency was significant [$F_s(1, 51) = 26.63$, $MSE = 66.54$, $\eta_p^2 = 0.34$, $p < .0001$; $F_i(1, 110) = 11.81$, $MSE = 161.58$, $\eta_p^2 = 0.10$, $p < .0001$]. Mirroring the response latency analyses, participants were more accurate when judging high-frequency than low-frequency targets. The main effect of prime type was not statistically significant [$F_s(1, 51) = 3.39$, $p > .05$; $F_i(1,110) = 2.77$, $p > .05$], although a paired t-test showed that in the high-frequency target condition, neighbor primes induced significantly more errors ($t_s(51) = 2.79$, *SEM* = 0.97, $p < .05$; $t_i(55) = 2.23$, *SEM* = 1.21, $p < .05$). The interaction between target frequency and prime type was also not significant [$F_s(1, 51) = 1.41$, $p > .05$; $F_i(1,110) = 1.00$, $p > .05$].

The analyses showed that high-frequency targets were responded to more quickly and more accurately than to low-frequency targets, demonstrating a standard word frequency effect. Critically, however, neighbor primes did not interfere with the responses to targets relative to control primes. The lack of inhibition effect was also not modulated by the relative frequency of the prime-target pairs. Results of this experiment were therefore inconsistent with those of Wang et al. (2014, Experiment 2b), in which significant inhibitory effects were shown both in response latencies and error rates using a 50 ms prime duration.

Discussion

In Experiment 2, an attempt to replicate the results of Wang et al. (2014, Experiment 2b) was not successful. The significant inhibitory stroke neighbor priming effect, which was observed irrespective of relative prime-target frequency in Wang et al. was not observed in the present experiment. In fact, although it was not statistically significant, the trends were facilitatory both for low-frequency and high-frequency targets. These results were rather surprising considering that in Wang et al., robust inhibition effects were produced by stroke neighbors, and such priming patterns were observed consistently across various prime durations (SOA = 33ms, 50 ms, 67ms) and different displays of prime-target pairs (primes and targets were in the same size and Songti font in Experiment 1 and Experiment 2a-b; slightly different sizes for the primes and the targets were chosen in Experiment 2c). The null stroke neighbor priming effect observed in Experiment 2 suggested either that there was no lexical competition between the representations of the stroke neighbors, or that the inhibition originating from the lexical competition was not strong enough to overcome the potential facilitation produced by the form overlap.

One possibility that might lead to the discrepancies between the results in the current experiment and those in the Experiment 2b in Wang et al. (2014) was that, although the aim was to make a replication, the stimuli used in the current experiment were not identical to those in the original study. As was discussed in the Discussion section of Experiment 1, the neighborhood size of stroke neighbors, as well as the difficulty in discriminating the characters and the pseudo-characters, may alter the patterns of priming effects. The same might hold for Experiment 2. That is to say, the difference in stimulus characteristics between Wang et al. and our Experiment 2 might lead to the difference in priming effects.[3]

It is also possible that the difference in the priming effects came from the different experiences of the participants in the current experiment and the participants in Wang et al. (2014). While the participants in Wang et al. were Chinese students at a Chinese mainland university and were likely to be immersed in a monolingual environment, participants in the current experiment were Chinese students at a Japanese university. Most of them enrolled in Japanese-taught programs, thus had to deal with materials in Japanese text in their daily life. As Bijeljac-Babic, Biardeau, and Grainger (1997) found in French-English bilinguals, orthographic neighbor primes inhibit target recognition across languages (i.e., joie-JOIN), suggesting that in the visual word recognition, both languages of the bilinguals are activated. Likewise, it was possible that in the character decision task, both the Chinese lexicon and the Japanese lexicon were activated. Since the participants in the current experiment had much experience in reading both Chinese hanzi characters and Japanese kanji characters, it is possible that when Chinese primes are presented, Japanese Kanji neighbors are also activated, and this might have influenced their performance in a character decision task with Chinese characters. However, as Foster et al. (1987) showed, it is the presence of fewer neighbors (covaried with word length) that is associated with more facilitation, our bilingual participants, assumingly collectively know more neighbors than the participants in Wang et al., would produce more inhibition effects. Therefore, it is not likely that this difference in the participant population is the reason for the discrepancy.

What was successfully replicated, though, was the nonsignificant interaction effect between target frequency and prime type. Wang et al. (2014) found inhibitory effects for both high-frequency targets and low-frequency targets. In Experiment 2 also, prime-target frequency did not affect the pattern of the stroke neighbor priming effect, although the effect was null (and the trends were facilitatory) rather than inhibitory. This result was not consistent with what researchers have observed in multiple previous studies involving alphabetic languages (e.g., Segui & Grainger, 1990; Davis & Lupker, 2006), that is, the inhibitory neighbor priming effect and the significant interaction between target frequency and prime type. Nevertheless, a few previous studies investigating the effect of the relative frequency of the prime-target pair (e.g., Nakayama et al.,2008, Nakayama et al., 2011) have found that when the prime has many neighbors, participants have comparable performance in the lexical decision task regardless of the relative frequency of the prime-target pairs. However, unlike the previous studies, the present experiment did not yield a significant inhibitory neighbor priming effect. At present, it is unclear whether the size of the stroke neighborhood contributes to the null priming effect.

CHAPTER FOUR:

General Discussion

The present study explored the mechanism of visual recognition in Chinese at the character level. We were particularly interested in whether lexical competition truly exists in the visual recognition of Chinese characters at the stroke level. Evidence in support of lexical competition has been suggested in the previous studies on various alphabetic languages (e.g., English: Davis & Lupker, 2006; French: Segui & Grainger, 1990), and the syllabic Japanese Katakana (Nakayama et al., 2011).

The two masked priming studies using stroke neighbors in single Chinese Hanzi characters so far (Shen & Forster, 1999; Wang et al., 2014) have yielded discrepant results. While Shen and Forster (1999) observed a facilitatory stroke neighbor priming effect, Wang et al. (2014) found such effect to be inhibitory. If the presentation of an orthographic neighbor of a Chinese character interferes with the visual recognition of that character, then we can infer that the lexical competition indeed exists in the visual recognition of a single Chinese character between stroke neighbors. If facilitation occurs, it indicates that there is little or no lexical competition between stroke neighbors. Thus, the empirical discrepancy makes it difficult to draw any conclusion about the existence of lexical competition in single Chinese characters. The research goal of the present study was to figure out which of the previous studies would be more replicable.

To achieve this research goal and identify the factors lead to the discrepancies in the previous masked priming studies using single Chinese characters (Shen & Forster, 1999; Wang et al., 2014), two replication attempts of the previous experiments were made. In Experiment 1, we tried to replicate the results of the character decision task in Shen and Forster's experiment. However, unlike the original study, where the facilitation produced by stroke neighbors was found both in the simple-character condition and the compound-character condition, in the present study, the facilitatory stroke neighbor priming effect was significant in one of the two conditions–the effect was significant only when the targets were compound characters. This indicates that the brief presentation (50 ms) of the orthographic neighbor of a Chinese character pre-activates the orthographic representation of that character, and thus speeds up the visual recognition. However, this was not true for the simple characters (“pictograms” and “simple ideograms”). The neighbor primes neither facilitate nor inhibit target processing for simple characters.

In Experiment 2, we attempted to replicate the results of Wang et al. (2014), a study that used a more stringent experimental design than Shen and Forster (1999) (Shen & Forster’s study was not specifically designed for the investigation of the stroke neighbor priming effect). In Experiment 2, the relative frequency of prime-target pairs was included as an additional independent variable. The stroke neighbor priming effect in this experiment was found to be null. That is, targets primed by neighbors were not facilitated or inhibited relative to unrelated primes, and this was the case for lower-frequency targets primed by higher frequency words and vice versa. Such results suggested that brief exposure (duration = 50 ms) of the orthographic neighbor of a Chinese character was unable to produce significant interference on the visual recognition of that character, irrespective of the relative frequency of the prime-target pair. At the same time, targets were not significantly facilitated by the orthographic similarity of the neighbor primes, indicating that the orthographic facilitation could be canceled out by the inhibition due to lexical competition. Importantly, the findings of Experiment 2 were not only different from those in Wang et al., but also those in Shen and Forster.

Priming Effects as a Function of Overall Responding Speed

On the surface, it is difficult to reconcile the results in the two attempts of replication and those in the original studies. Different patterns of results were found not only between the experiments with different experimental designs (separate blocks vs. a single block) but also between the original experiments and the replication attempts in the present study. However, the comparison among the mean response latencies (when a target was primed by its stroke neighbor) may shed some light on this apparent inconsistency. In the character decision task of Shen and Forster (1999, Experiment 2), where the stroke neighbor priming effect was facilitatory, the mean response latencies were 541 ms and 521 ms in the simple-character condition and the compound-character condition, respectively. In Experiment 1 of the current study, in which the facilitatory effects in Shen and Forster’s study were replicated in the compound-character condition, the mean response latencies were 615 ms and 591 ms in the simple-character condition and the compound-character condition, respectively. In Wang et al. (2014, Experiment 2b), where the stroke neighbor priming effect was inhibitory irrespective of relative prime-target frequency, the mean response latencies were 615 ms and 669 ms in the high-frequency target condition and the low-frequency target condition, respectively. In Experiment 2 of the current study, null stroke priming effects were found in both the high-frequency and the low-frequency conditions, the mean response latency was 554 ms and 598 ms, respectively. Here, we can get the general idea that the direction of the priming effect might be a function of the overall response latency. The priming effect tends to be facilitatory with shorter response latency and inhibitory with longer latency.

As the patterns of priming effects suggest, it is possible that the size of the priming effect is negatively correlated with the response latency of the target that is primed by a stroke neighbor (this possibility was also discussed in the Discussion section of Experiment 2). To examine this possibility, a correlation analysis between the size of the priming effect and the response latency of the target, using the combined data from Experiment 1 and Experiment 2, was conducted (see Figure 2 for a scatterplot depicting the relationship between the two variables). The Pearson's correlation coefficient (r) returned to be -0.55 ($p < .0001$), which according to Cohen (1988), is considered as a large effect.

The longer response latency might reflect a higher difficulty of the character decision task, and as a consequence, the higher tendency to depend on the activation level of character units to decide on the lexicality of the target (De Moor et al., 2005; Grainger & Jacobs, 1996; Kinoshita, 1987). In such situations, character identification was more likely to be achieved by the lexical competition between the representations of the targets and their stroke neighbors, leading to an overall inhibitory stroke neighbor priming effect. In contrast, when the difficulty level is low, which can be indicated by faster overall response latencies, the participant is more likely to make use of the global activation level of representations of the prime and the target to decide whether the target is a character or a pseudo-character. As a result, the response to the target might benefit more from the visual similarity between the prime and the target, leading to facilitatory stroke neighbor priming effects.

Thus, one possibility that can account for differential results in the previous studies and the present study regarding the priming effect is that inhibition tends to appear when the response latency is longer, which indicates a higher difficulty of the lexical decision task. On the contrary, when the response latency is short, it is likely that participant rely more on the overall familiarity to make lexical decisions, therefore the facilitatory priming effect would be shown. There is one caveat that should be taken into consideration, though. The correlation analysis between the size of the priming effect and the response latency of the target that is primed by a stroke neighbor, although quite strong, is a post hoc analysis. Whether there is indeed a causal effect of the longer response latencies and the stronger inhibitory stroke neighbor priming effects is left to be tested in future research.

Ways to Understand the Discrepancies in Response Latencies

Another issue that arise from the comparison among the response latency data of the present study and those in Shen & Forster (1999) and Wang et al. (2014) is that why the mean response latencies were different across different experiments, although the procedures were quite similar and the stimuli were largely the same single Chinese characters. There are several approaches to explain the differences.

First, there could be confounding familiarity effects in Shen and Forster's experiment. . As suggested by Wu and Chen (2003), in addition to the orthographic related primes, there were two other types of primes that primed the same set of targets for the compound characters– phonologically related primes, and both orthographically and phonologically related primes (which were not included in the present study since the phonological priming effect was not the focus of our investigation). The repeated presentation of a target probably increased the global familiarity, which in turn could give rise to greater facilitation (De Moor et al., 2005; Grainger & Jacobs, 1996; Kinoshita, 1987). Also, the lexical decision experiment was not the only experiment in Shen and Forster. In Experiment 1 of their study, Shen and Forster conducted a naming task using largely the same stimuli. It was not pointed out whether there was overlap between the participants in the two experiments (and if so, the proportion). If many participants were in both experiments, it was likely that the participants became familiar with the target characters (which were the same in the two experiments) and the procedures of the experiments. Therefore, they were able to make quicker responses to the targets due to the familiarity, and the facilitatory effect was produced.

Second, while it was possible to make sure that the lexical characteristics of words (such as word frequencies and the number of strokes) were matched between the attempts of replication and the original experiments, it was challenging to achieve this in the creation of pseudo-characters because there is virtually no effective way of quantifying how difficult it is to discriminate a character from a pseudo-character. As a result, it was quite likely that the difficulty of making the correct judgement on the lexicality of a target was different across experiments. When the discrimination between character and pseudo-characters is difficult, the participants are less likely to make use of the global familiarity with the targets but rely more on the activation of target representations which may become more susceptible to lexical competition (De Moor et al., 2005; Grainger & Jacobs, 1996; Kinoshita, 1987). As a result, less facilitation would be generated. Therefore, the use of pseudoword targets, which were different among the three studies, could have resulted in discrepancies in the overall response latency data.

Third, the differences in the response latencies might also result from the differences in the instructions and the way of giving trial-by-trial online feedback. Whereas the emphasis was on both speed and accuracy of responses in the present study, as well as in Shen and Forster (1999), no such description could be found in Wang et al. (2014). It is possible that in Wang et al.'s Experiment 2b, the participants focused more on the accuracy instead of the speed of the responses because the mean response latency was slower and the mean error rate was quite low (range = 4.2%–4.6% for the low-frequency targets; range = 0.9%–1.6% for the high-frequency targets). Feedback on response speed can also alter the way participants respond to the targets. For instance, investigating a masked neighbor priming effect in Dutch, De Moor et al. (2005, Experiment 2) found that, if participants are told to respond to targets as fast as possible and are given trial-by-trial online speed feedback, they make significantly faster responses in the lexical decision task. In that situation, the word neighbor primes produced a significant facilitation effect. Although the demand in De Moor et al. was different from the present study (i.e., in De Moor et al., the participants were encouraged to make lexical decisions within 600 ms and the feedback of "too slow" was presented when the response was slower than 600 ms), we could get the idea that the trial-by-trial speed feedback on the screen may press the participants to make response to the targets more quickly. In the present study and Shen and Forster, both trial-by-trial speed feedback and trial-by-trial error feedback were given to the participants on the screen when a response was made. In contrast, it was only mentioned in Wang et al. that the feedback of errors was given to the participants. If the participants focus more on being correct, it would be more possible that they make the decisions based on the activation of individual representation units, which could lead to inhibitory neighbor priming effect (De Moor, et al., 2005; Grainger & Jacobs, 1996; Kinoshita, 1987）.

To summarize, from the comparison among Shen and Forster (1999, Experiment 2), Wang et al. (2014, Experiment 2b), and the present study, it was found that a visually similar prime does not always produce an inhibitory priming effect. Inhibitory priming effects seem to be observed when the the response latencies were long and/or when the target recognition is made on the basis of the activation of the targets instead of the global familiarity.

Different Patterns of Orthographic Neighbor Priming Effects in Logographic and Non-logographic Languages

It is of particular interest to us, then, what may lead to the discrepancies in the patterns of orthographic neighbor priming effects in the logographic Chinese Hanzi and non-logographic languages (alphabetic languages and Japanese Katakana). That is, why would the inhibitory priming effect be less likely to be observed in single Chinese Hanzi characters. One potentially critical issue in the comparison would be how "orthographic neighbor" in Chinese Hanzi characters should be defined. Whereas it is relatively easy to find prime-target pairs in which the prime and the target only differ from each other only by one letter/character in the same position in non-logographic languages (e.g., *ride–RUDE* in English; *char–CHAT* in French センター "center"–セーター "sweater" in Japanese Katakana), two Chinese Hanzi characters with the same number of strokes would rarely be different only in one stroke (e.g., 申 "apply"–电 "electricity"). Probably due to this reason, in Shen and Forster (1999) and Wang et al. (2014), the definition of stroke neighbors was extended to include "characters that could be formed by substituting, adding, or deleting one or more character strokes".

Since Experiment 1 and Experiment 2 in the present study were partial replications of the previous two studies, the same definition was adopted. This made many of the stroke neighbor pairs in Shen and Forster (1999), Wang et al. (2014), and the present study essentially deletion or addition neighbors, instead of substitution neighbors (which are what is typically defined as "neighbors"). Therefore, the priming effects produced by stroke neighbors could be different from what researchers have observed in the previous studies of non-logographic languages in that the overall stroke neighbor priming effect could be a combination of the addition neighbor priming effect, the deletion neighbor priming effect, and the substitution neighbor priming effect.

As a result, since the replacement of some of the prime-target pairs might make the proportions of deletion, addition, and substitution neighbors significantly different from those reported in Wang et al., the pattern of the stroke neighbor priming effect might also be changed (such that the inhibitory orthographic neighbor priming effect in non-logographic languages would not be replicated). Although previous studies of alphabetic languages (e.g., see Davis & Taft, 2005; and Davis, Perea, & Acha, 2009) showed deletion neighbors (e.g., *rail-TRAIL*) and addition neighbors (e.g., *crown-CROW*) in alphabetic languages also evoke inhibitory effects– could lead to the hypothesis that, the stroke neighbor priming effect is likely to be inhibitory, regardless of the proportions of deletion, addition, and substitution neighbors. There, however, is not yet a study in which the specific effects of deletion and addition neighbors of Chinese Hanzi characters are manipulated and examined. Further empirical studies are required to determine whether the proportions of deletion, addition, and substitution neighbors really played a role in altering the stroke neighbor priming effect in the present study.

The differences in the linguistic features between the Chinese Hanzi stroke neighbors and letter neighbors in non-logographic languages may also result in different patterns of orthographic neighbor priming effects. It has been supported by previous studies that the different characteristics of the orthographic neighborhood could at least partially account for the differences in the priming effect. For example, Nakayama et al. (2014) observed that inhibitory neighbor priming effects could be found in the visual recognition of two-character Kanji compound words, however, compared to the effects in alphabetic languages, they were smaller. Such discrepancy occurred probably due to the fact that the shared Kanji character brought about morphological overlap, which led to additional facilitation.

Specifically, we would like to hypothesize that Chinese Hanzi characters have a limited number of stroke neighbors. In a casual examination of the stimuli list in Experiment 2 of the present study, it was found that for many characters in the list, I could only come up with one or two stroke neighbors (e.g., 细 “thin” only has the stroke neighbor 绅 “squire”, 因 “factor” only has two stroke neighbors, 困 “trap” and 囚 “prisoner”). This contrasts the ranges of the number of orthographic neighbors in non-logographic languages. For example, for a four-letter word in alphabetic languages, the number of orthographic neighbors would be around 6– 12 (see Marian et al., 2012). Since the number of stroke neighbors is limited, the inhibitory effect from orthographic neighbors is likely to be much smaller in Chinese Hanzi characters than in words in non-logographic languages because it is suggested by previous studies that the neighbor priming effect can be smaller when the prime-target pair has few neighbors. For instance, Davis and Lupker (2006) used the stimuli that had a small neighborhood size (*M* = 3.5). In this study, when the prime-target pairs had no shared neighbors (a shared neighbor is a neighbor of both the prime and the target, for example, *tale* is a shared neighbor of *take-TAME*), a nonsignificant orthographic priming effect was observed. Because the likelihood of the prime-target pair having a shared neighbor is largely dependent on the neighborhood size of these pairs (words with more neighbors have greater chances to share neighbors), the prime-target pairs in Chinese Hanzi characters may have few shared stroke neighbors, which could reduce the stroke neighbor priming effect to nonsignificant. A systematic follow-up exploration about the stroke neighborhood size in Chinese Hanzi characters is needed to confirm this hypothesis.

Lexical Competition in Single Chinese Hanzi Characters Takes Longer to Show Inhibition

We also would like to argue that, although in the present study the stroke neighbor priming effect was not observed, the null priming effect does not necessarily indicate that there is no lexical competition between the representations of the prime and the target. In our study, the prime was presented for 50 ms. It could just be that the processing of the prime requires more time to reach a deep enough level to produce the inhibitory effect. Using Japanese Kanji, whose script is almost identical to that of Chinese Hanzi, Deng et al. (2020) found that, when the duration of prime presentation was extended from 50 ms to 67 ms, the stroke neighbor priming effect shifted from being nonsignificant to being significantly inhibitory. This result provided some support to the idea that the longer processing of the prime might turn the initially null stroke neighbor priming effect into an inhibitory effect. The present study, combined with the previous studies using single Chinese Hanzi characters (or Japanese Kanji characters), corroborates the idea that when the duration of prime presentation becomes longer, or when the response to the target is slower, the stroke neighbor priming effect has the tendency of shifting from being facilitatory to being inhibitory.

It is quite possible that, either through a longer duration of prime presentation or longer response latency, a prime gets more time to be processed. Some researchers using the masked priming paradigm as a tool have considered the processing of the prime to discontinue after the appearance of the target (see Forster, 2006). However, as Perea and Rosa (2000) suggested, we should not assume that the processing of the prime would halt as soon as the appearance of the target, although the duration of prime presentation is very brief. Nakayama, Lupker, and Itaguchi (2018) had a detailed discussion and argued that the prime processing, at least at the “conceptual level”, might still go on after the presentation of the target (also see Grainger et al., 2012). This idea has received support from several ERP/MEG studies (e.g., Hauk et al., 2006; Pylkkänen & Marantz, 2003), in which it was shown that even the clearly visible item took longer than 50–60 ms to be fully processed. In comparison, the duration of prime presentation in the present study was 50 ms. Therefore, it is reasonable to think that the prime processing is not finished when the prime is replaced by the target. It is possible that the longer response latency of the target makes it more likely for the processing of the prime to reach a deeper level, and the more thoroughly processed prime would increase the competitive strength of the prime stimulus but not that of the target stimulus (Davis, 2003), causing stronger lexical competition that could overwhelm the facilitation produced by the initial sublexical activation. If that would be the case, we can reasonably posit that the prime could be processed more fully with a longer response latency in a similar way to how the processing of the prime may benefit from a longer duration of prime presentation. As a result of the longer processing time, the inhibitory orthographic neighbor priming effect can be more readily observed.

To sum up, lexical competition does likely exist in the visual recognition of single Chinese Hanzi characters, but it may take longer to become strong enough to induce significant inhibition on the target recognition. In this way, the lexical competition between the representation of the prime and the target would be stronger than when the response latency is short, which leads to an inhibitory stroke neighbor priming effect.

It is worth mentioning there is another possibility that cannot be completely ruled out by the results in the present study, though, that the phonological activation emerging at a later stage in the lexical processing also contributes to the interference with the response to the target. Wang and Yan (2006) studied the orthographic priming effect in Chinese reading with three different durations of prime presentation (35 ms, 43 ms, 57 ms). The results show that the orthographic priming effect was facilitatory at the shortest duration of prime presentation (35 ms), but shifted to null effect when the duration became longer (43 ms) and showed an inhibitory trend at the longest duration (57 ms). It is argued that at the duration of 57 ms, when the prime and the target were visually similar, the discrepancies in the later activated phonological information produced interference in the process of Chinese character recognition (but also see Nakayama et al., 2014, in which it is found that the phonological influence was immaterial in the Kanji compound word recognition). Nevertheless, whether the inhibitory priming effect could be attributed to the phonological interference is out of the scope of the present study.

A Proposed Model in the Visual Character Recognition in Chinese

Last but not least, the findings in the present study shed some light on what the psychological model is like in the visual recognition of Chinese characters. Note that the semantic activation of a Chinese character will not be touched on in the following discussion of models, because the present study did not investigate the semantic effect. All of the prime-target pairs bear no obvious semantic similarity with each other. Besides, how subcharacters–i.e., phonetic components and semantic radicals–are processed is beyond the scope of this thesis. It is not unreasonable to assume that the semantic information plays a relatively limited role in the visual recognition of Chinese characters, though, since the majority (73.6%) of the Chinese words are two-character compound words (The Chinese Lexicon Project, Tse et al., 2017), a native Chinese speaker may be less inclined to get the meaning out of a single character.`

In general, although the inhibitory stroke priming effect (which would indicate the lexical competition between the representations of the stroke neighbors) was not constantly observed in the present study when the duration of prime presentation was 50 ms, the findings in the present study can be fittingly accommodated by the Interactive Activation (IA) model (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982), which features the within-level inhibition and the between-level (could either be top-down or bottom-up) interaction. Our data collected from Experiment 1 and Experiment 2, combined with the results in the previous masked priming studies using stroke neighbors (Deng et al., 2020; Shen & Forster, 1999; Wang et al., 2014), provided support to the idea that upon the visual presentation of the Chinese character, starting from the stroke analysis, the orthographic information would be analyzed rapidly first and then probably fed forwardly to the phonological activation. Within each level, the orthographic or phonological representations inhibit each other as they are among the candidates to be chosen; between levels, a level at a later stage receives activation from (and probably provide feedback to) the previous level, and the lexical decision is achieved through the integration of elements at different levels. Figure 3 shows our proposed model in the visual character recognition in Chinese.

Conclusion

In summary, in the present study, we attempted to replicate two experiments in the previous studies (Shen & Forster, 1999, Experiment 2; Wang et al., 2014, Experiment 2b). Despite the limitations in the present study (e.g., a reliable database about stroke neighbors in Chinese character is lacking for the investigation of the neighborhood size or frequency effect; a follow-up experiment manipulating the duration of processing–a common method is to control the duration of prime presentation–would help to tease out the time course of the visual character recognition), there are some ideas we can generalize from the findings of the present study about the visual character recognition at the moment: in the visual recognition of single Chinese characters, it may take more time for the processing to reach the lexical level and show inhibitory stroke neighbor priming effects (either with longer duration of prime presentation or longer response latency); the inhibitory orthographic neighbor priming effect in single Chinese characters is more elusive than that in words in alphabetic languages, probably due to the smaller neighborhood size of single Chinese characters and the fact that in the previous studies, different definitions of orthographic neighbors were adopted (many of the orthographic neighbors in the previous experiments were actually deletion or addition neighbors).

Footnotes

1 Unrelated words are better than blank words and meaningless words in setting up the control condition in that they also preactivate the word codes (e.g., De Moor, Van der Herten, & Verguts, 2007).

2 We contacted the author in an effort to obtain the complete stimuli list but unfortunately, we did not receive a response.

3 Inhibitory neighbor priming effects were also found in Nakayama et al. (2014), in which two-character Kanji compound words (written in a logographic script) were used.

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Table 1

Latencies and Error Rates for Word Targets as a Function of Prime Type and Target Character Frequency in Experiment 1

	Response latencies				Error rates			
Prime Type	SN	SC	CN	CC	SN	SC	CN	CC
	615	600	591	607	6.8	4.5	9.4	10.3
PE	-15		16		-2.3		0.9	

Note. Time in ms; error rates in percentages. SN = simple-neighbor; SC = simple-control; CN = compound-neighbor; CC = compound-control; and PE= priming effect.

Table 2

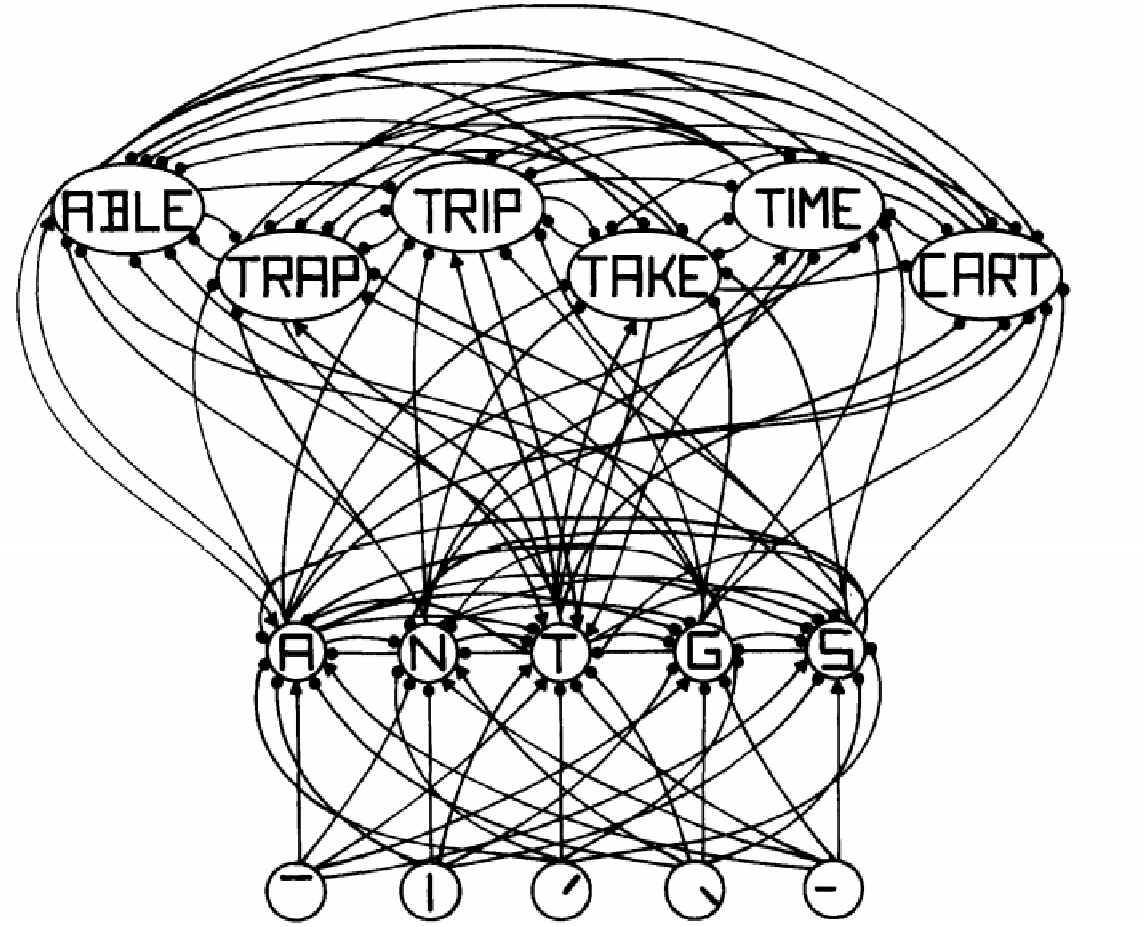
Latencies and Error Rates for Word Targets as a Function of Prime Type and Target Character Frequency in Experiment 2

	Response latencies				Error rates			
Prime type	Neighbor HF	Control LF	Neighbor HF	Control HF	Neighbor LF	Control LF	Neighbor HF	Control HF
	598	607	554	560	9.3	8.7	4.5	1.8
PE	9		6		-0.7		-2.7	

Note: Time in ms; error rates in percentages. LF= low character frequency; HF= high character frequency; and PE= priming effect.

Figure 1

An Illustration of the Classic Interactive Activation Model.



Note. It is assumed by the Interactive Activation model that, in the visual word recognition, the visual input flows through three processing levels: the feature level, the letter level, and the word level. There are between-level bidirectional connections and within-level lateral inhibition. The original figure was in McClelland and Rumelhart (1981, Figure 3).

Figure 2

The Scatterplot Showing the Correlation Between the Size of the Priming Effect and the Response Latency of the Target that is Primed by a Stroke Neighbor

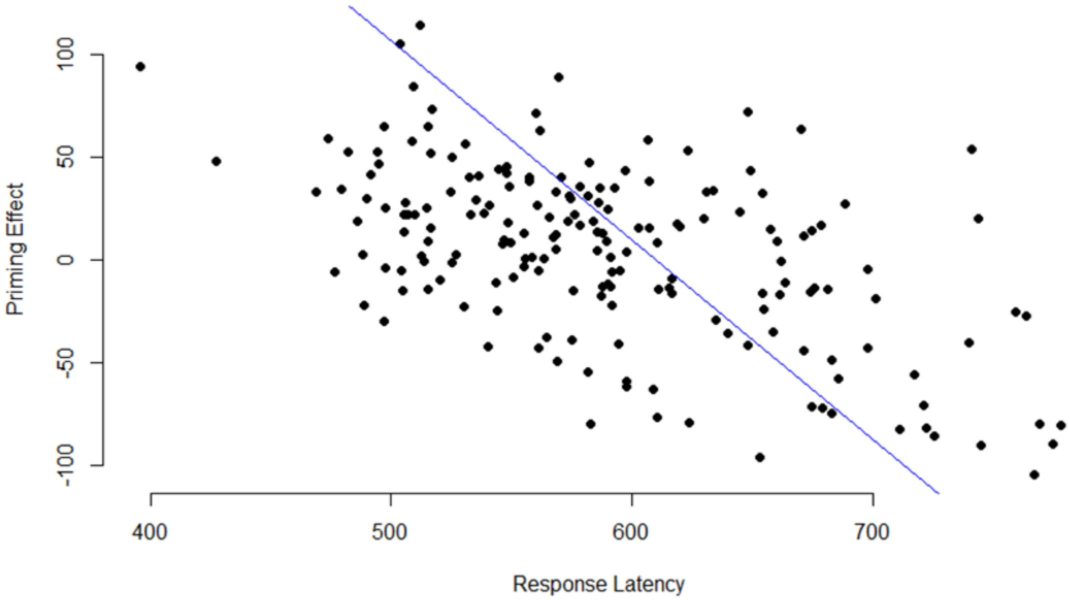
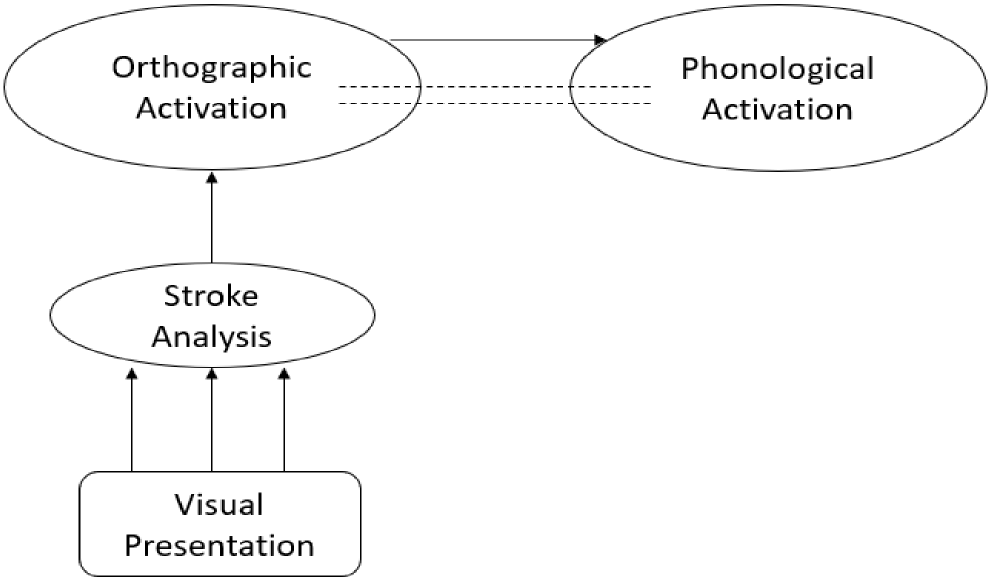


Figure 3

The Proposed Model of the Visual Recognition of a Single Character in Chinese



Note. The essential assumption of the model is that orthographic activation rapidly emerges after the initial stroke analysis, of which the information would be sent to the phonological activation.

Appendix A

Primes and Targets Used in Experiments 1.

Simple-character condition		Compound-character condition	
Prime	Target	Prime	Target
令	今	埋	理
夫	天	肚	肝
习	刁	村	材
刀	刃	忌	忘
中	申	饮	饭
田	由	栏	柱
本	木	铬	铭
史	吏	佯	伴
牛	午	伸	仲
未	末	待	侍
非	韭	枯	估
亚	业	扯	址
土	士	抽	柚
免	兔	沽	沾
臣	巨	泽	译
爪	瓜	钿	铀
入	人	冰	泳
户	尸	洗	洗
予	矛	缓	绶
方	万	驮	驶
丸	九	述	迷
丢	去	性	牲
又	叉	缉	楫
且	旦	扰	忧
民	良	针	钉
日	目	栎	栋
龙	尤	坤	绅
毋	母	酩	酪
乐	牙	扔	扬
鸟	乌	纹	绞
		圩	坪
		托	扦

Appendix B

Table B. Latencies and Error Rates for Word Targets as a Function of Prime Type and Target Character Frequency in Shen and Forster (1999, Experiment 2)

	Response latencies				Error rates			
Prime type	*SN*	*SC*	*CN*	*CC*	*SN*	*SC*	*CN*	*CC*
	541	576	521	541	5.0	3.3	6.3	6.3
PE	35		20		-1.7		0	

Note: Time in ms; error rates in percentages. SN = simple-neighbor; SC = simple-control; CN = compound-neighbor; CC = compound-control; and PE= priming effect.

Appendix C

Neighbor Pairs Used as Prime and Target Characters in Experiment 2.

HF	LF
细	绅
选	迭
王	玉
感	惑
兵	丘
苦	苫
助	肋
户	尺
下	卜
早	旱
再	冉
任	仕
史	吏
参	叁
白	臼
过	迂
未	禾
待	侍
印	卯
开	卉
它	宅
家	冢
习	勺
厌	庆
准	淮
闭	闲
究	穷
义	叉
耍	要
会	云
非	韭
博	傅
如	妲
马	乌
否	杏
手	士
己	巳
者	昔
任	佳
响	晌
血	皿
差	着
复	夏
子	孑
击	缶
快	炔
官	宫
因	囚
之	乏
治	冶
坏	坯
注	汪
查	杳
理	埋
活	沽
太	犬

Appendix D

Table D. Latencies and Error Rates for Word Targets as a Function of Prime Type and Target Character Frequency in Wang et al. (2014, Experiment 2b)

	Response latencies				Error rates			
Prime type	Neighbor HF	Control HF	Neighbor LF	Control LF	Neighbor HF	Control HF	Neighbor LF	Control LF
	669	658	610	603	4.2	3.9	2.1	1.2
PE	-11		-7		-0.3		-0.9	

Note: Time in ms; error rates in percentages. LF= low character frequency; HF= high character frequency; and PE= priming effect.