The Activation of Segmental and Tonal information in Semantic Retrieval among Chinese-English Bilingual Readers

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Abstract

Three experiments using Stroop paradigm were designed in which Chinese-English bilinguals were asked to name the ink color of Chinese characters in Chinese in Experiment 1 and in English in Experiment 2 and 3. The visual stimuli were divided into five critical conditions: color characters, homophones of the color characters (S+T+), different-tone homophones (S+T-), characters that shared the same tones but differed in segments with the color character (S-T+), and neutral character (S-T-). Experiment 1 showed significant Stroop facilitation on all congruent conditions, while Experiment 2 only showed color character Stroop effect. In Experiment 3, an ABAB mixed-block design was used in which participants were asked to read Chinese characters in block A and name the ink color of thecharacters in English in block B. Both the congruent and incongruent S+T+ conditions showed a significant Stroop interference effect. These results suggested that in Chinese naming, both tonal information and segmental information is activated, and that Chinese phonological information, including segmental and tonal information, is not activated automatically in naming in English.

Index Terms: syllable segment, tone, cross-language activation, bilingual

1. Introduction

The current study examined how phonological information of the written Chinese character, including segmental information and tonal information, contributes to its identification and meaning activation among highly proficient Chinese—English bilinguals. Mandarin Chinese syllable structure can be divided into onset (consonant or empty), rime (vowel + consonant, or vowel only) and lexical tone. Syllable segment is composed of onset and rime. There are four lexical tones in Mandarin Chinese. The first tone which is called the high-level tone is labeled as 1. The second tone is the high-rising (2); the third tone is the falling-rising (3); and the fourth tone is the high-falling (4). The same syllable segment can represent four different meanings depending on the lexical tone it carries [1]. For example, “妈” (*ma1*) means “mother”, “麻” (*ma2*) means “numb”, “马” (*ma3*) means “horse”, and “骂” (*ma4*) means “to scold”. However, neither syllable segments nor tones were explicitly represented in visual Chinese characters.

Despite the fact that phonological information is largely unavailable in written Chinese, previous research has shown that both segmental and tonal information is automatically activated during visual Chinese character recognition. In a Stroop color experiment by Spinks, Liu, Perfetti and Tan [2], the participants were asked to name the ink color of Chinese character and color patches. Their study included color characters (e.g., 红, *hong2*, red), homophones of color characters (S+T+) (e.g., 洪, *hong2*, flood), homophones that only shared the same syllable segments but differed in tone (S+T-) (e.g., 轰, *hong1*, boom), and the neutral condition (e.g., 贯, *guan4*, pass through). Both color characters and S+T+ characters produced significant facilitation effects for congruent trials in which ink color and the name of the characters were the same (e.g., 红 in red) and interference effects for incongruent trials (e.g., 红 in green). In contrast, the S+T- characters produced significant facilitation for congruent trials but did not produce significant interference for incongruent trials. One possible explanation, according to Spinks et al. [2], is that interference is a slower process compared to facilitation and that segmental activation is earlier than tonal activation. Therefore, facilitation can be a result of shared segments in the congruent condition, whereas interference would not occur via the shared segments in the incongruent condition. Overall, Spinks et al. suggested that both segmental and tonal information is activated in visual Chinese character recognition. A limitation of their study is that the Stroop effect of S-T+ condition (characters share the same tone but different segments with the color characters) has not been examined. The present study included all the four possible conditions (i.e., S+T+, S+T-, S-T+ and S+T-), to investigate whether the magnitude of segmental activation differs from that of tonal activation in Chinese.

The second goal of the present study is to investigate whether Chinese-English bilingual speakers activate phonological information in their native language (L1) when naming in their second language (L2) English. Previous research has shown that when the target language is L2, it is difficult to suppress L1. For example, Sumiya and Healy [3] conducted Stroop tasks among proficient Japanese-English bilinguals. In this study, participants were asked to name the ink color of Japanese words in Japanese or English. The Japanese words were either written in Hiragana, which were phonologically similar to the corresponding English color words, or written in Katakana, which were dissimilar from the corresponding English color words. A significant between-language Stroop effect was found for both response languages. In addition, compared with the phonologically dissimilar condition, the similar condition produced a larger between-language interference effect. Together, these findings suggested that phonological information in L1 is activated in naming in L2.

However, it remains unclear whether L1 phonology can still influence L2 naming when the phonological information is not explicitly represented in visual L1 input. Therefore, the present study conducted Stroop tasks in which Chinese–

English bilinguals were asked to name the ink color of Chinese character in English. More specifically, we examined how segmental and tonal information of Chinese influences English naming independent of each other. In sum, the present study investigated both within-language (Chinese L1) and cross-language (Chinese-English) phonological activation including segmental and tonal information.

2. Experiment 1

Experiment 1 was aimed to investigate whether the magnitude of segmental activation differs from that of tonal activation in Chinese naming.

2.1. Method

2.1.1. Participants

Participants were eighteen adult native Chinese speakers with normal or corrected-to-normal vision, who were graduate students in a Mid-Atlantic university.There were 12 females and 6 males, whose ages ranged from 21 to 26 years (M = 23.6, SD = 1.24). Their length of staying in the US ranged from 1 to 3 years (M= 1.7 years), and their age of English acquisition ranged from 9 to 10 years. All participants had taken the paper-based or internet-based TOEFL (Test of English as a Foreign Language). To make the TOEFL scores comparable across participants, we calculated percentages by dividing raw scores from the total possible scores for each test. The average percentages for all the participants were 83.7% (SD = 10.0%).

2.1.2. Measures and Procedures

The Stroop experiment was conducted. Participants were asked to name the ink color of Chinese characters in Chinese. The stimuli were in four different ink colors: red, yellow, green and blue. Among all the 132 trials, 72 (6 conditions * 4 colors * 3 repetitions) were critical trials while the other 60 were fillers. The six conditions of critical trials were: congruent color characters, congruent S+T+ characters, congruent S+T- characters, congruent S-T+ characters, congruent S-T- characters and incongruent color characters.

The experiment was implemented using the DMDX software, with the following procedure. After the instruction, a 500ms fixation (“+”) appeared at the center of the screen, followed by the target character which disappeared as soon as a response was made. There was a 1,000ms interval before the next trial began. If no response was made within 3,000ms, the current trial was automatically terminated. Each stimulus was presented at the center of a computer screen in bold 48 song-ti font. Participants were required to name the color of the stimulus as quickly and accurately as possible. There were eight practice trials. During the experiment, the first author sat behind the participants and scored the accuracy of their naming. Participants received one point for each correct pronunciation and 0 point for incorrect pronunciation or no response. No half point was given.

2.2. Results

The response time (RT) data of incorrect trials and the naming latency of corrected trials that failed to trigger the voice key were deleted. RT data that were two standard deviations above or below the cell mean were excluded from data analysis. All in all, less than 8% of the original data was removed. The accuracy rates were above 95% across all conditions. The mean RT, standard deviations, and priming effect for each condition are presented in Table 1.

Table 1 *RT (SD) in each condition in Experiment 1*

Condition	RT (ms)	Stroop effect (ms)
congruent color character	719 (94)	58**
congruent S+T+	703 (100)	74***
congruent S+T-	695 (66)	82***
congruent S-T+	742 (84)	35*
incongruent color character	999 (208)	-222***
S-T- (neutral condition)	777 (102)	

*: p< .05; **: p< .01; ***: p< .001

A series of planned paired sample *t*-tests were conducted, in which RT and error rates of the five critical conditions (congruent color character, S+T+, S+T-, S-T+ and incongruent color character) were compared against the neutral condition (S-T-).

Participants showed significant facilitation in the congruent color character (t (17) =3.407, p = .007), congruent S+T+ (t(17) =5.493, p< .001), congruent S+T- (t(17) =5.738, p< .001), congruent S-T+ character conditions (t(17) =2.346, p= .031) but showed significant inhibition in the incongruent color character conditions (t (17) =5.978, p< .001). There was no significant difference in the effect sizes between the S+T+ and S+T- facilitation (t (17) = .677, p= .508). However, the effect size of the S+T- facilitation is significantly larger than that of S-T+ (t (17) = 2.205, p= .042). The analysis on error rates only showed significant inhibition for the incongruent condition (p< .001).

A further set of *t*-tests were conducted for the congruent S-T+ condition based on color groups. Since three of the four color names carry the second tone (red, blue and yellow), it is possible that the S-T+ facilitation was due to the repeated production of the second tone. Compared with the corresponding control characters, for the red S-T+ character 瓶 (*ping2*, bottle), the facilitation was marginally significant (t (48) =1.713, p= .093); for the blue color 尝 (*chang2*, taste), participants showed significant facilitation (t (47) = 2.420, p= .019); yellow S-T+ character 缠 (*chan2*, wrap around) showed a significant facilitative effect (t (47) =2.228, p=.031). However, for green S-T+ character 洞 (*dong4*, hole) which carries the fourth tone, there was no significant Stroop effect (t (45) = .430, p= .669).

2.3. Discussion

The findings were generally consistent with the results reported in Spinks et al. [2]. Most importantly, the congruent S-T+ condition also showed significant facilitation, suggesting that tonal information may be activated during Chinese visual word recognition. However, since the effect size for the S+T- facilitation is greater than that for the S-T+ facilitation, it appears that segmental information has a greater influence than tonal information in visual word recognition. Further comparisons showed that the S-T+ facilitation is probably due to the fact that three of the four color names (红, *hong2*, red, 黄, *huang2*, yellow and 蓝, *lang2*, blue) used in the current experiment carry the second tone. Since the participants repeatedly produced the second tone, this repeated activation may have elevated the resting level of the second tone, resulting in faster production time of the second tone compared to the fourth tone (in the color name of 绿, *lv4*, green). It is likely that if more color names with the first, the third or the fourth tone were included in the stimuli, or if the task does not require production so that the participants cannot repeat in the second tone, the S-T+ facilitation may disappear.

3. Experiment 2

Experiment 2 was aimed to investigate whether Chinese-English bilingual speakers activate phonological information in Chinese (L1) when naming in English (L2).

3.1. Method

3.1.1. Participants

Participants were same as those in Experiment 1.

3.1.2. Measures and Procedures

Measures and Procedures were same as those in Experiment 1, except that the response language in Experiment 2 was English. The order of Experiment 1 and 2 was counterbalanced.

3.2. Results

Data cleaning procedure was the same as that in Experiment 1. The mean RT, standard deviations, and priming effect for each condition are presented in Table 2. The average accuracy rate was above 92% across all the conditions.

Table 2 *RT (SD) in each condition in Experiment 2*

Condition	RT (ms)	Stroop effect (ms)
congruent color character	757 (96)	38*
congruent S+T+	804 (119)	-8
congruent S+T-	804 (119)	9
congruent S-T+	786 (101)	9
incongruent color character	1030 (301)	-234***
S-T- (neutral condition)	787 (90)	

*: $p< .05$; ***: $p< .001$

Planned paired sample t-tests showed a significant 38ms facilitation in the congruent color character condition (t (17) =2.430, p= .026) and a significant 234ms inhibitory effect in the incongruent color character condition (t (17) =4.111, p< .001). There was no significant Stroop effect in any other conditions (all ps > .1). The analysis of error rates did not show any significant Stroop effect. We conducted a correlation test between participants' TOEFL score and their between-language Stroop effect, and found no significant correlation (r= .089, p= .733 for Stroop interference effect, r= .115, p = .661 for Stroop facilitation effect).

3.3. Discussion

No Stroop effect was found except the classic facilitation of the congruent color characters and interference of the incongruent color characters. If the phonological information of L1 is activated, at least the congruent S+T+ characters should have shown significant facilitation, considering the pronunciation of the characters is the same as the pronunciation of the ink color which would in turn activate the concept of the color, resulting in faster naming time of that color in English. A possible explanation is that the phonological information of L1 is inhibited when the target language is L2. The significant Stroop effects observed in the color characters may be due to the activation of the shared conceptual representation between L1 and L2.

Another possible explanation is that the phonological information of the Chinese characters is activated; however, this activation cannot aid L2 naming because the phonological information of L1 and L2 is very different (e.g., hong2 and red). We conducted Experiment 3 to test these possibilities.

4. Experiment 3

4.1. Method

4.1.1. Participants

Twenty-five graduate students at a mid-Atlantic university participated in the current study. None of the students have participated in Experiments 1 and 2. The demographic information of these participants is similar to that of the participants in Experiments 1 and 2.

4.1.2. Measures and Procedures

The stimuli for the critical trials were same as those in Experiments 1 and 2. The differences were that instead of fillers we added an incongruent S+T+ condition and there were only 56 critical trials (7 conditions*4 colors*2 repetitions) in Experiment 3. The 56 trials were pseudo-randomly divided into two blocks, 28 trials for each, with a character-naming block before each color-naming block. In each color-naming block, there were at least 2 characters from each of the seven conditions and 4 repetitions for each of the four color characters. The stimuli in each block were pseudo-randomized so that the same color or character did not appear consecutively. The character naming block consisted of 28 trials, the characters were written in black ink and same as those in the following color-naming block.

All participants received four blocks of stimuli—Character naming 1 (Ch1), Color naming 1 (C1), Character naming 2 (Ch2), and Color naming 2 (C2). Half of the participants received the order 1: Ch1→C1→Ch2→ C2, and the other half received the order 2: Ch2→C2→Ch1→ C1. The experiment was implemented using the DMDX software, with the same procedure as that in Experiment 1 and 2. Participants were asked to read the character in Chinese as quickly and accurately as possible in the character reading block, and name the color of the visual stimulus as quickly and accurately as possible in English in the Stroop block. There were 8 practice character reading trials followed by 8 practice Stroop trials before the experiment. Instructions were presented when the task was switched. The scoring procedure was the same as that in Experiment 1 and 2.

4.2. Results

Two participants (1 male and 1 female) were removed because of their high error rates in Chinese character reading block (above 20%). The high error rates may be due to the fact that they acquired Mandarin and Cantonese simultaneously. The procedure of data cleaning was same as that in Experiments 1 and 2. Overall, less than 5% of the original reaction time data was removed. The mean reaction times and standard deviations for each condition in block C1 and C2 were presented in Table 3. The accuracy rates were above 99% across all the conditions.

Table 3 *RT (SD) in block C1 and C2 in Experiment 3*

Condition	RT (ms)	Stroop effect(ms)
congruent color character	735 (66)	9***
congruent S+T+	828 (83)	-44**
congruent S+T-	798 (86)	-14
congruent S-T+	798 (74)	-14
incongruent color character	877 (301)	-93***
incongruent S+T+	816 (79)	-32*
S-T- (neutral condition)	784 (74)	

*: p< .05; **: p< .01; ***: p< .001

Planned paired sample t-tests revealed classic Stroop facilitation and interference effects (for congruent color characters, t (22) =4.448, p < .001; for incongruent color characters, t (22) =6.184, p < .001). There was a significant interference effect in the congruent S+T+ condition (t (22) =3.484, p= .002) as well as the incongruent S+T+ condition (t (22) =2.651, p= .015). The effects on all other conditions were not significant.

4.3. Discussion

In Experiment 2, there was no significant Stroop effect on S+T+ condition. However, in Experiment 3, both congruent and incongruent S+T+ conditions showed significant interference effects. It suggested that the addition of the character-naming block was effective in activating L1 phonological information. In addition, the fact that there was no S+T- or S-T+ Stroop effect suggested that neither segmental information nor tonal information in Chinese alone can affect English L2 naming.

However, an unexpected finding was that the congruent S+T+ condition showed an interference effect instead of the expected facilitation. In the control condition, neither the phonology nor orthography provided information related to color names, whereas S+T+ provided helpful phonological information but unhelpful orthographic and semantic information. As the task was a color naming task, information related to color names will influence participants' response latency. As a result, for the S+T+ condition, the previously activated phonology helped activate consistent color meaning (e.g., 洪, *hong2* activated the meaning of "red"). However, the orthographic information suggested that the meaning of the character was not about color (e.g., 洪 activated the meaning of "flood"). According to traditional dual-route model of reading aloud [4], two routes are involved in visual Chinese character recognition: the lexical route — from orthography to meaning (OM route), and the non-lexical route — from orthography to phonology to meaning (OPM route). These two pathways are parallel. As a result, for the S+T+ condition (e.g., 洪, *hong2*, flood), the meaning activated by phonology (e.g., hong2 activates meaning *red*) was competing with the meaning activated by orthography (e.g., 洪 activates meaning *flood*). It could be this competition that delayed participants' response. In addition, the participants had to inhibit the helpful phonological information because they must respond in L2 instead of L1. Therefore, congruent S+T+ showed interference instead of facilitation.

5. General Discussion

Experiment 1 showed that both segmental and tonal information is activated during visual Chinese character recognition, although neither of them is represented explicitly. However, tonal activation may occur at a different stage from the segment activation. Experiments 2 and 3 showed that Chinese phonology is not activated automatically during English (L2) naming.

One may ask why the congruent S+T+ condition showed significant facilitation in Experiment 1 but significant interference in Experiment 3. In our within-language Stroop task (Exp.1), participants might have only activated orthography and phonology in the OPM route simply because it was a naming task. However, in the between-language Stroop task (Exp.2), the bilinguals did not activate this route because the task is a L2 naming task. If L1 phonology was forced to be activated (Exp.3), participants did not stop at the phonology stage in the OPM route, instead, they proceeded to the meaning stage. In Experiment 3, as the task was a color naming task, L1 phonology not only activated the meaning of the character (e.g., 洪, *hong2*, meaning *flood*), but also the meaning of its homophone character (i.e., the target color, e.g., 红, *hong2*, meaning *red),*). As a result, competition occurred between the meaning activated by the character (e.g., 洪, *hong2*, flood) and the meaning of the homophone character (e.g., 红, *hong2*, red).

6. Conclusions

The present experiments replicated Spinks et al. [2] and further showed that 1) segmental information plays a more important role than tonal information during visual Chinese character recognition; 2) for Chinese—English bilinguals, when the target language is English L2, Chinese L1 phonology, including segmental and tonal information, is suppressed. However, if Chinese L1 phonological activation is demanded, the meanings of the character and its homophone character are both activated (based on the requirement of the tasks) and compete with each other, resulting in cross-language interference.

7. References

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