Lateralized Stroop Interference Effect With Chinese Characters

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Abstract: Previous studies show Stroop effect is stronger in the right visual field. However, (1) whether the lateralization patterns of two aspects of Stroop effects, facilitation and inhibition, for native Chinese speakers are similar to each other, and (2) whether secondary interference tasks modulate Stroop effect as in the studies about the lateralized Whorf effect, are remaining open questions. We show in the present study visual field asymmetry of Stroop interference was caused mainly by the lateralized facilitation effect, but not by the bilateral inhibition effect. Moreover, contrary to the robustness of verbal interference task in studies on the lateralized Whorf effect, the magnitude of the visual field asymmetry was not modulated by the secondary verbal interference task. This study further consolidates the idea that language information and color naming interact more strongly in the left hemisphere, which sheds light on the debate of the Sapir-Whorf hypothesis based on Chinese characters.
Keywords: Stroop effect; Whorf hypothesis; lateralized Whorf effect; Visual fields; Chinese character.

0. Introduction

Writing systems and reading are such important inventions after spoken language has evolved in the history of human evolution that they alter the intellectual evolution of our species, as well as shaping our brain. In general, there are two important traditions of writing systems—the alphabetic system (phoneme based script) and the Chinese logo syllabic system (non-phoneme based script). In contrast to the alphabetic writing system, the single Chinese character presents semantic and phonetic information simultaneously, albeit neither very precisely; thus the single Chinese character allows the brain to search the word along both dimensions simultaneously while the alphabetic system enables only the phonetic dimension (Wang & Tsai 2011). A lot of studies, especially based on scientific methods, have been conducted on the alphabetic writing systems, whereas the nature of Chinese writing system and its uniqueness are still waiting for elaboration. Moreover, the Chinese character system has suffered numerous doubts and criticism in history, even today, most of which are apparently due to lack of knowledge about the processing mechanisms of Chinese characters and its impact on shaping our brain.

Another closely related topic is whether and how the language we speak shapes the way we perceive and think about the world, which is commonly referred to as the Whorf hypothesis or also called Sapir-Whorf hypothesis to acknowledge the role of Whorf's mentor. Although these questions and ideas are intriguing and seem to be not far from our daily experience, they are nevertheless not easily amenable to experimental test (Carroll 2007), especially in early days. In Chinese linguistics, studies on Sapir-Whorf hypothesis have also been mostly constrained with theoretical discussion rather than providing empirical evidence based on Chinese characters. However, with persistent efforts and especially significantly growing knowledge about human brain, several recent experimental studies provide supportive evidence for the Sapir-Whorf hypothesis and offer proposal to reformulate the hypothesis (such as Boroditsky, Fuhrman & McCormick 2011; Kay, Regier, Gilbert & Ivry 2009). Given the background about Sapir-Whorf hypothesis and that a writing system is largely if not completely corresponding to a spoken language, we speculate that different writing systems may also induce different impact on our readers' brain and thus shape the way we perceive the world. The experiment reported in this paper is thus constructed within this context and is trying to shed light on Sapir-Whorf hypothesis based on Chinese characters.

It has been generally accepted that left hemisphere (LH) is more functionally specialized for language than the right hemisphere (RH) for most people, especially for the right-handed monolinguals or later bilinguals (Damasio, Grabowski, Tranel & Hichwa 1996; Gazzaniga 1970; Hellige 1993; Hull & Vaid 2007; Kandel, Schwartz &

Jessell 2000; Leehey & Cahn 1979; MacLeod & MacDonald 2000; Searleman 1977; Soares & Grosjean 1981; Wada, Clarke & Hamm 1975). Given the crossing of neural projections in the visual system, the stimuli presented in the right visual field (RVF) is primarily and directly projected to the LH, and the stimuli presented in the left visual field (LVF) to the RH (Gazzaniga, Ivry & Mangun 2009). Therefore, the language-relevant stimuli are believed to be processed more efficiently when presented in the RVF than in the LVF. In other words, the language involvement is thought to be stronger when the language-relevant stimuli are presented in the RVF. This idea has gained support from two lines of research: 1) the LH lateralized Whorf effect: across-category discrimination can be achieved faster by the LH (Drivonikou, Kay, Regier, Ivry, Gilbert, Franklin & Davies 2007; Franklin, Drivonikou & Bevis 2008; Gilbert, Regier, Kay & Ivry 2006、2008; Kay & Kempton 1984; Kay, et al., 2009; Regier & Kay 2009; Siok, Kay, Wang, Chan, Chen, Luke & Tan 2009; Tan, Chan, Kay, Khong, Yip & Luke 2008), and 2) the LH lateralized Stroop effect: Stroop effects are stronger with words presented to RVF (Brown, Gore & Pearson 1998; MacLeod 1991). Both of these two effects are actually consistent with the broad formulation of Sapir-Whorf hypothesis that the languages we speak affect our perception of the world and even shape our innermost thoughts, and in particular, these "Whorfian" effects are largely restricted to the right visual field, which is known to project to the left cerebral hemisphere (Kay, et al., 2009).

The precondition for both LH lateralized Whorf effect and LH lateralized Stroop effect is based on that language-relevant stimuli are processed more efficiently when presented in the RVF. Unlike the alphabetic writing system such as English, the logosyllabic writing system of Chinese does not provide any direct segmental information on phonetic segments (Wang 1973; Wang & Tsai 2011).

The "Stroop Effect" is named after John Ridley Stroop who discovered this phenomenon in the 1930s. In Stroop's classic paper (Stroop 1935), he combined word and color, creating a conflict situation. In his original works, he conducted three experiments, but it was the Experiment 2 that introduced the task that now goes by his name. The contrast in Experiment 2 was calculated between the time used to name the colors of colored rectangles (e.g., for the green rectangle, say "green": the control condition) and the time to name the colors of incongruent color-word combinations (e.g., the word "red" written in green, say "green": the experimental condition). Color naming was dramatically slower for the incompatible color words, and the Stroop effect was born. Nowadays, the Stroop effect in the incongruent condition is also often named more specifically as "Stroop interference effect", and the Stroop task is now one of the best known and widely used paradigms in cognitive psychology. Since Stroop's classic article (Stroop 1935), research on this well-known effect has developed into a very rich area, including follow-up intensive studies on Stroop interference effect, as well as investigations on Stroop facilitation effect (FE) and their underlying mechanisms (for a more comprehensive review about Stroop effect see MacLeod 1991、2005; MacLeod & MacDonald 2000).

In a review of the Stroop literature, MacLeod (1991) described several early investigations which examined the laterality in the Stroop task and observed greater interference in the left hemisphere. MacLeod (1991) also suggested that most models of Stroop interference would predict greater interference effects in the LH relative to the RH due to the LH's preferential role in language-related processes. Later Brown, et al. (1998) summarized the foregoing studies on the lateralization of Stroop effect, and reported their own results. Their results illustrated the stronger Stroop effect when words were presented to RVF, supporting the hypothesis that more efficient processing of words in the LH will enhance their tendency to produce the Stroop interference.

Given that language functions are dominated in the LH, and the visual field asymmetry effect can be disrupted by taxing verbal working memory through a secondary verbal interference task (Gilbert, et al., 2006; Gilbert, et al., 2008), we test three hypotheses in the present study. First, as it has been evidenced in previous studies (MacLeod 1991), Stroop effect should be stronger when stimuli are presented in the RVF than in the LVF since the dominant language processing in the LH will tend to produce greater interference. Second, lateralization patterns of the FE and inhibition effect (IE) should be similar to each other. Third, similar to earlier studies (Gilbert, et al., 2006; Gilbert, et al., 2008), the visual field asymmetry effects should be modulated when language resources are taxed by the demands of a secondary verbal interference task.

1．Materials and Methods

1.1 Participants

Twelve native Mandarin participants (mean age = 24.4 years, SD = 2.8), who finished pre-university education in Mainland China, and studied in the Chinese University of Hong Kong when the experiment was performed, were paid to participate in this study. The participants were right-handed, and had normal or corrected-to-normal vision, and normal color vision. No participant has successfully acquired his/her second language, English here, before 6 years old.

1.2 Stimuli

红 (/hong2/, red), 绿 (/lü4/, green), 黄 (/huang2/, yellow), 蓝 (/lan2/, blue) were the four color words used in this study, served as the experimental condition. Three neutral words, 笔 (/bi3/, pen), 表 (/biao3/, watch), and 球 (/qiu2/, ball), and four color patches were as filler materials, served as the control condition. The three neutral words shared no orthographical, phonological or semantic relationship with the above four color words. Each word was represented in four colors, resulting in (7 × 4 + 4 color patches) × 2 VFs = 64 stimuli. The radius of the stimuli was approximately 4.25°, and the width and height of the colored words and color patches were approximately 1.6°, with a viewing distance of 80 cm.

1.3 Procedure

Figure 1 illustrates the procedure for the trial presentation. Each trial began with a central fixation '+' for 500 ms. Then, the fixation was replaced by a 500 ms interference display: with an animal name for the verbal-interference task, a spatial grid for the spatial-interference task, and blank screen for no-interference. The fixation then reappeared for another 1,000 ms, followed by the stimulus screen for 150 ms, an interval selected to discourage eye movements. Participants were instructed to press one of the four color-patch (not color word) labeled buttons (each button corresponding to one designated color) on a PST Serial Response Box (supplied by Psychology Software Tools, Inc., Pittsburgh, PA, USA) to indicate the color of the just appeared stimuli, and to respond as quickly and as accurately as possible. After the response to the primary Stroop task, another interference display was presented for 1,500 ms, and the participants were instructed to respond to the second interference display by pressing two different buttons to indicate whether the two interference displays were the same or not. No feedback was provided during the whole experiment. Then the screen went blank for 250 ms before the fixation '+' appeared to indicate the start of the next trial. Although participants were instructed to maintain fixation, we did not monitor eye movements.

For the no-interference blocks, a blank screen was presented in lieu of an interference display. For the verbal-interference blocks, the interference display consisted of a single animal word drawn from the set: ‘‘猫’’(cat), ‘‘狗’’(dog), ‘‘蛇’’(snake), ‘‘猪’’(pig), ‘‘牛’’(ox), ‘‘兔’’(rabbit), ‘‘鸡’’(hen), ‘‘马’’(horse), ‘‘鼠’’(rat), and ‘‘羊’’(sheep).

For the spatial-interference task (non-verbal interference task), the displays consisted of a spatial grid in which 11 of the 25 squares were black and 14 were white. A set of 10 none-character-like grids was created. The overall size of the animal words and spatial grids was the same as the color words or color patches used as above.

Each participant completed two sessions for each interference type, with each session including three 64-trial blocks of the same interference type. The session types were interleaved and the order of the session types was counterbalanced across participants.

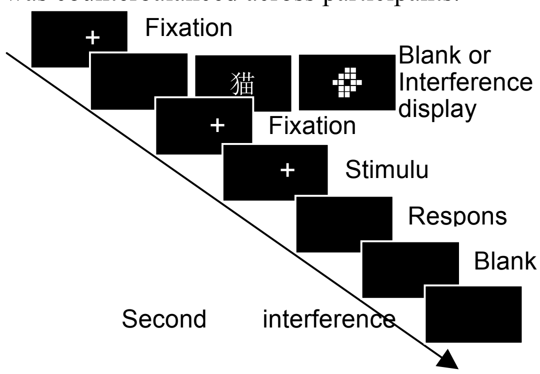

Figure1. Illustration of the trial presentation procedure.

The Stroop stimulus displays were interleaved with blank displays (for the task with no secondary interference), displays containing an animal word, or a spatial grid (for the task with verbal or nonverbal secondary interference respectively). The last slide labeled as ‘Second interference display’ only appeared in the tasks with secondary interference.

2．Results

In our design, there were two interference displays in each trial. In addition to the vocal response to the primary task, participants were instructed to respond to the interference task: Whether the two interference displays were the same or not, by pressing two different buttons. The percentage of the same interference displays was set to about 50% of trials.

The color identification accuracy was very high, with 97% correct responses. Only reaction time (RT) data were analyzed here. Trials in which the participant made wrong responses, or in which the RT fell outside of two standard deviations from the participant's mean were not included in the analysis of the data. Regarding the performance of the secondary interference tasks, participants correctly made 93% and 88% correct responses in the verbal and spatial conditions, respectively, which were similar to the scores (92% for the verbal task, and 89% for the spatial task) for the secondary interference tasks in Gilbert, et al., 2008, where they conducted experiment to verify that the two types of interference tasks were demanding and of equal difficulty.

Table 1 shows the results of RT for the effect of congruency across visual fields, LVF and RVF. The RT data were analyzed by using a 3 (interference type: no interference, spatial interference, and verbal interference) × 2 (visual field: left vs. right) × 3 (congruency: congruent, incongruent, and neutral) within-subject repeated

measures ANOVA. There was a highly significant main effect of congruency, with congruent condition fastest, and incongruent condition slowest [$F(1.13, 12.44) = 56.3$, $p < 0.001$]. There were no effect of interference type [$F(1.42, 15.58) = 1.06$, $p = 0.35$], and visual field [$F(1, 11) = 1.9$, $P = 0.20$]. The interaction between visual field and congruency was significant [$F(1.63, 17.91) = 8.3$, $p < 0.01$], indicating stronger interference in the RVF.

	No interference			Spatial interference			Verbal interference	
Congruency	LVF	RVF		LVF	RVF		LVF	RVF
Neutral	579(28)	579(30)		583(32)	585(32)		597(33)	595(34)
Congruent	548(29)	537(29)		556(30)	550(30)		568(34)	546(31)
Incongruent	650(36)	648(36)		665(41)	668(39)		669(41)	675(42)
TSE	102(15)	111(17)		109(16)	118(14)		101(16)	129(17)
FE	-31 (7)	-42(12)		-27 (7)	-35 (6)		-29 (6)	-49 (7)
IE	71 (13)	69 (11)		82 (12)	83 (10)		72 (13)	80 (13)

Table 1. Mean RT, total Stroop effect (TSE), FE, and IE in millisecond for the effects of congruency across visual fields.

Note: The RT here did not include the 150 ms of stimulus presentation time. TSE is the difference score computed as the RT difference between incongruent and congruent conditions, which reflects the overall language interference effect. FE is the difference score computed as the RT difference between congruent and neutral conditions. IE is the difference score computed as the RT difference between incongruent and neutral conditions. The numbers in parenthesis were the SEMs (standard error of the mean).

The individual TSE data were analyzed by using a 3 (interference type: no interference, spatial interference, and verbal interference) × 2 (visual field: left vs. right) within-subject repeated measures ANOVA. There was a significant effect of visual field [$F(1, 11) = 10.24$, $P < 0.01$], with RVF producing a larger TSE [$t(11) = 3.2$, $p < 0.01$]. There were no effect of interference type [$F(1.29, 14.2) = .36$, $p = .62$], and no interaction effect between interference type and visual field [$F(1.95, 21.5) = 1.95$, $p = .17$].

The RT under the same congruency condition increased generally from no interference, to spatial interference, and further to verbal interference, indicating that the addition of the secondary tasks was demanding. The visual field asymmetry on TSE was larger for verbal interference (129 - 101 = 28 ms), than for no interference (111 – 102 = 9 ms) and for spatial interference (118 – 109 = 9 ms), but this difference did not reach significance level.

Table 1 also presents the FE and IE. Both of these two effects were analyzed by using a 3 (interference type: no interference, spatial interference, and verbal interference) × 2 (visual field: left vs. right) within-subject repeated measures ANOVA separately. For FE, there was a significant effect of visual field [F

(1,11) = 9.48, $p < 0.05$], with RVF producing a larger facilitation [t (11) = -6.76, $p < 0.01$]. There were no significant effect of interference type [F (1.56, 17.11) = 0.34, p = 0.66], and no interaction effect between interference type and visual field [F (1.61, 17.7) = 0.77, p = 0.45]. For IE, there was no significant effect of visual field [F (1, 11) = 0.93, p = 0.36], of interference type [F (1.86, 20.4) = 1.74, p = 0.20] and no interaction effect between interference type and visual field [F (1.93, 21.2) = 1.45, p = 0.26].

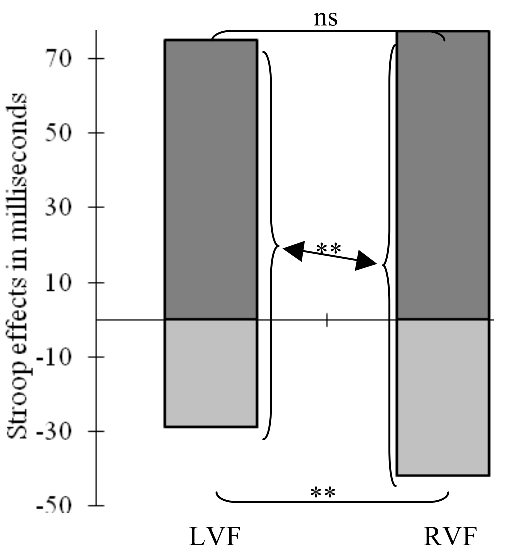

Figure 2. The positive part shows IE across visual fields, while the negative part shows FE across visual fields. The overall effects are TSE across visual fields.

As shown in Figure 2, the experimental results were consistent with the hypothesis that the Stroop effects were more prominent when the stimuli were presented in the RVF than in the LVF, providing evidence for the first hypothesis. However, the FE effect showed a LH lateralized pattern, but the IE showed a bilateral pattern. Therefore, the second hypothesis was rejected. Furthermore, these results showed no evidence to support that different types of secondary interference task modulated Stroop effect. Thus, the third hypothesis was rejected.

3. Discussion

Our experimental data showed that the Stroop effect was stronger when the stimuli were presented in the RVF. However, the significant main effect of visual field only was found on TSE and FE, not on IE, indicating that the main effect of visual field on TSE data mainly came from the FE. In other words, comparing with neutral condition, the congruent stimuli were processed more quickly in the RVF than in the LVF, whereas the incongruent stimuli were processed with very similar speeds in both visual fields. On one hand, although the FE in the present study shows obvious lateralization pattern, with much quicker speed to name the congruent character in the RVF than the LVF, the absolute value for FE is smaller than the corresponding IE, which is consistent with previous studies in English in standard Stroop paradigm without considering the factor of visual fields (MacLeod & MacDonald 2000). In the congruent stimuli, the responses to both word and color are identical. Under such circumstance, it is possible that reading congruent words occurs during the color naming process. Since there are well-established findings that reading is faster than naming, it is possible that the “undetectable reading errors” will be included in calculating the overall RTs in congruent conditions, thus producing obvious facilitation, which was proposed by MacLeod & MacDonald (2000) as an “inadvertent reading hypothesis”. Moreover, given that the word presented in the RVF is transmitted to the left hemisphere, which is more functionally specialized for language, it is reasonable to observe that the magnitude of FE is much stronger in the RVF. The result of facilitation pattern is consistent with our expectation that the language-relevant stimuli are believed to be processed more efficiently when presented in the RVF than in the LVF.

On the other hand, another related issue is whether color processing is lateralized (Pennal 1977). The RTs under neutral condition may shed some light on this issue. Examining the numbers in Table 1, the average RTs under neutral condition for the LVF and RVF are (579+583+597)/3 = 586.3 ms and (579+585+595)/3 = 586.3 ms, respectively, providing no evidence for lateralization in color perception.

Assuming the color is equally processed in the two hemispheres, and words are more efficiently processed in the LH as documented, then more Stroop IE should appear when the stimuli are projected directly to the LH than to the RH. However, as Table 1 shows, there was no significant main effect of visual field on IE. The possible explanation for the almost equal interference effects in both visual fields may be related to the brain mechanism in processing conflict or competing situation in the incongruent condition of Stroop task. In the review of MacLeod and MacDonald (2000), fMRI imaging studies finds that the anterior cingulated cortex (ACC) shows greatest activation in the incongruent Stroop task, suggesting that it mediates processes involved in Stroop interference. Anterior cingulate cortex is a part of the brain's limbic system (Bush, Luu & Posner 2000; Gazzaniga, et al., 2002, p. 82; Gazzaniga, et al., 2009), resembling a "collar" form extending above the corpus callosum in the anterior-posterior direction.The less left lateralized location of this area in the brain may be one reason that causes the main effect of visual field not significant on inhibition data. However, because the precise role of the anterior cingulate cortex has still been a matter of considerable debate, the above explanation is tentative and waiting for more experimental and brain imaging studies to disclose and clarify. Furthermore, another intriguing question is whether color words written in English alphabets or other writing systems also show the same pattern of IE and FE in the two visual fields as Chinese characters show in the present study, which will shed light on the issue about how different writing systems are processed in human brain and how these differences shape the brain and our view of the world.

However, since the total Stroop effect (TSE), which is the difference score computed as the RT difference between incongruent and congruent conditions, reflects the overall language interference effect, and a highly significant main effect of visual field and significant interaction between visual field and congruency were found on the TSE data, the results of the present study are still consistent with the expectation that more Stroop interference effect should appear when the stimuli are projected directly to the LH than to the RH.

Tzeng, Hung, Cotton, and Wang (1979) reported a LVF–RH advantage for commonly-used Chinese single characters, and argued that the RH advantage was due to the holistic processing of the overall form of Chinese characters. Similarly, Tsao and Wu (1981) found a larger Stroop interference when color words were presented to the LVF. The studies (Tsao et al., 1981; Tzeng et al., 1979) were carried out in USA. Therefore, their participants were possibly early Chinese–English bilinguals, while our participants are Chinese monolinguals or at most late Chinese–English bilinguals (Hull & Vaid 2007). It is likely that such controversies over the lateralization patterns of Chinese single-character word processing are due to the bilingual status of the participants (Peng & Wang 2011).

According to Gilbert, et al.(2006、2008), the secondary verbal interference task attenuated the RVF advantage for detecting across-category targets, but non-verbal (spatial) interference task did not. Similarly, the verbal interference task was assumed to reduce the Stroop interference in the RVF, but the spatial interference task would not. However, our data showed that the secondary interference tasks did not modulate the visual field asymmetry patterns for TSE at all, whatever the nature of the secondary interference tasks was. The core controversy here is why the secondary verbal interference disrupted the lateralization pattern in Gilbert, et al.(2006、2008), but did not in our experiment.

There are several differences of course between previous studies (Gilbert, et al., 2006、2008) and the current study. The interference task in Gilbert, et al. (2006、2008) was one-back match (whether the secondary task stimulus was the same as that shown in the previous trial), while ours was within-trial match. As for the one-back match design, the participants know the answers to the interference task before they respond to the primary task. Therefore, the trials following an overt response on the secondary task have to be discarded for analysis because RTs on the subsequent primary task might be slower due to a post-response refractory period. However, in our study, the participants did not know the answers to the interference task when they responded to the primary task. In other words, the subjects had to hold on the working memory for the interference stimuli throughout the primary task. Therefore, within-trial match verbal interference task would be equally effective with one-back match one. Moreover, we need not discard any trials due to a post-response refractory reason. Thus it is less likely that the no effect for verbal interference task in the current study was due to the within-trial match design.

However, it is more likely that no effect for verbal interference task in the current study was due to the nature of Stroop task, and/or the nature of stimuli for the interference task. The primary tasks in previous studies were color discrimination (Gilbert, et al., 2006) and shape discrimination (Gilbert, et al., 2008) where the lexical information of the stimuli were implicitly embedded in the stimuli, whereas the primary task in the current study was color identification (naming the color), where the lexical information explicitly appeared simultaneously with the color information in the character orthography. Reading is a highly practiced process for literate adults and to some extent is an automatic process. Consequently, the LH language advantage might not be easily taxed out by a secondary verbal task, still producing larger TSE when the stimuli were presented in the RVF/LH.

Furthermore, the stimuli for the verbal interference task in Gilbert (2006、2008) were alphabetic while ours were Chinese characters, with native Chinese subjects. The phonological information is usually automatically activated when memorizing an alphabetic word, whereas any part of a Chinese character, or as a whole, does not directly correspond to any phonological form. As for Chinese character mapping, like the verbal interference task in the current study, memorizing the spatial information of the character is sufficient to achieve high mapping accuracy, especially for a small close set of words. Therefore, it is possible that the effect of the verbal interference task with stimuli written in Chinese is similar to that of the spatial interference task. This is an interesting topic that merits further studies.

4. Conclusion

To sum up, the findings presented in this paper illustrate two results. First, stronger Stroop effect has been shown when the Stroop-like stimuli written in Chinese characters were presented in the RVF than in the LVF due to the dominant language processing in the LH. More specifically, visual field asymmetry of Stroop interference was caused mainly by the lateralized FE, but not by the bilateral IE. Second, the lateralization pattern was not modulated by a secondary interference task no matter what the nature of the interference task was, contrary to the studies about the lateralized Whorf effect (Gilbert, et al., 2006、 2008). Further work will be required to detail the temporal process of the interaction between language processing and color naming, in order to arrive at a clearer picture of the neural mechanism underlying this interaction in the Chinese brain.

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