# Color Categorical Perception Effects in Bilinguals with Different Proficiency Levels: Behavioral and ERP Evidence Postprint

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## Abstract

To investigate the influence of language on perception, behavioral experiments employing a visual search paradigm were used to study the color categorical perception effect in Mongolian-Chinese bilinguals; to further examine the neural mechanisms underlying language’ s influence on perception, EEG experiments using an Oddball paradigm were employed to investigate the color categorical perception effect in Mongolian-Chinese bilinguals. Results from both behavioral and EEG experiments revealed that when distinguishing between the colors qinker and huhe in Mongolian, Mongolian-Chinese bilinguals with lower Chinese proficiency exhibited a stronger color categorical effect than those with higher Chinese proficiency; Chinese proficiency in Mongolian-Chinese bilinguals influences color categorical perception, the second language categories acquired by bilinguals can modify the categories of their native language, language can affect the pre-attentive stage of perception, and this study supports the Sapir-Whorf hypothesis.

## Full Text

## Preamble

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### Color Categorical Perception Effects in Bilinguals with Different Proficiency Levels: Evidence from Behavioral and ERP Studies

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**Abstract**

To investigate the influence of language on perception, a behavioral experiment using a visual search paradigm examined color categorical perception effects in Mongolian-Chinese bilinguals. To further explore the neural mechanisms underlying language' s impact on perception, an ERP experiment using an Oddball paradigm investigated color categorical perception effects in the same population. Both behavioral and ERP results revealed that when distinguishing between the Mongolian colors qinker and huhe, low Chinese-proficiency bilinguals exhibited stronger color categorical effects than high-proficiency bilinguals. Chinese proficiency level in Mongolian-Chinese bilinguals affects color categorical perception, and the lexical categories acquired in a second language can alter categories in the bilingual' s native language. Language can influence the pre-attentive stage of perception, providing support for the Sapir-Whorf hypothesis.

**Keywords**: color categorical perception; Mongolian; bilinguals; mismatch negativity; Sapir-Whorf hypothesis
**Classification Code**: B842

## 2.2 Materials

The experimental materials consisted of four gradually changing blue stimuli labeled A, B, C, and D. A pre-experiment naming task was conducted with 20 Mongolian-native and 20 Chinese-native university students from different majors and hometowns. The procedure involved presenting the four color blocks (ABCD) on a gray background using E-Prime, with each color block randomly presented five times for free naming. The results showed that all 20 Mongolian speakers identified A and B as qinker colors and C and D as huhe colors under all response conditions, while all 20 Chinese speakers identified all four colors as simply "blue." The RGB values for the four colors were: A = (42, 161, 218); B = (28, 139, 203); C = (4, 118, 185); D = (26, 96, 165). The distances between adjacent color pairs in CIELab values were: within-category (A, B) = (C, D) = 5.10ΔE, and between-category (B, C) = 5.07ΔE, making the distances between within-category and between-category pairs approximately equal.

For the formal experiment, the color blocks were presented on a 17-inch LCD monitor with a gray background (RGB: 192, 192, 192) using E-Prime software. Following Zhou et al. (2010), each color block was arranged in a ring of 12 squares, with 11 background color blocks and one different target color block. The target color block appeared only at the leftmost and rightmost positions in the ring, and its relationship to the background color blocks could be either within-category or between-category.

The experiment employed a 2 × 2 mixed design with two factors: Chinese proficiency (high vs. low) as a between-subjects variable, and color category (same vs. different) as a within-subjects variable. Participants were seated in a naturally lit room approximately 65 cm from the display. Following Zhou et al. (2010), the formal experiment comprised 64 trials, with BC and CB as between-category conditions (16 trials each) and AB and CD as within-category conditions (16 trials each). Each trial began with a red fixation cross "+" presented at the center of the screen for 500 ms, followed by a ring of color squares centered on a black fixation point. Participants judged the location of the target color block and responded by pressing the F key for left and the J key for right. The color ring disappeared automatically after a response or after a timeout if no key was pressed, followed by a 1000 ms gray screen before the next trial began. Participants completed 16 practice trials before the formal experiment and filled out a self-designed "Language Background Questionnaire" afterward.

## 2.1 Participants

Sixty-eight Mongolian-Chinese bilingual university students participated, all with normal or corrected-to-normal vision and right-handed, with Mongolian as their native language and Chinese as their second language. Based on a language background survey administered before the experiment, participants were divided into high Chinese proficiency and low Chinese proficiency groups. Considering that smaller mean differences between Mongolian and Chinese proficiency scores indicate more balanced language abilities, participants were assigned to groups based on the difference between their self-rated Mongolian proficiency scores and Chinese proficiency scores across listening, speaking, reading, and writing. Those with a mean difference score 1 were classified as high Chinese proficiency, while those with a mean difference > 1 were classified as low Chinese proficiency. The demographic and language background characteristics of the participants are presented in Table 1 .

## 2.4 Results

All participants achieved accuracy rates above 90%, with no speed-accuracy trade-off. After removing error trials, response time data beyond two standard deviations were excluded, resulting in the removal of approximately 9% of the data. The descriptive statistics for response times after data exclusion are shown in Table 2 . ANOVA results revealed a significant main effect of color category, $F(1, 66) = 34.78$, $p < 0.001$, $^2 = 0.34$, while the main effect of participant group was not significant, $F(1, 66) = 2.75$, $p > 0.05$. The interaction between participant group and color category was significant, $F(1, 66) = 18.90$, $p < 0.001$, $^2 = 0.22$. Simple effects analysis showed that the color categorical perception effect was not significant for high Chinese proficiency bilinguals, whereas it was significant for low Chinese proficiency bilinguals, $p < 0.001$, $^2 = 0.54$.

## 2.5 Discussion

Previous research has reported that Mongolian speakers show significant categorical effects when distinguishing dark blue from light blue, whereas Chinese speakers do not exhibit this effect (He et al., 2016). The present study differentiated Chinese proficiency levels among Mongolian-Chinese bilinguals and found that high Chinese proficiency bilinguals, similar to Chinese speakers, showed no significant categorical perception effect when distinguishing dark blue from light blue. In contrast, low Chinese proficiency bilinguals, similar to Mongolian speakers, exhibited significant color categorical perception effects. These findings suggest that differences in second language proficiency lead to variations in color categorical perception effects among bilinguals, providing support for the Sapir-Whorf hypothesis at a more refined level of language proficiency differentiation. Given these results and to further explore the neural mechanisms underlying language' s influence on color perception, Experiment 2 employed event-related potential (ERP) technology to examine whether differences in color categorical perception effects exist during early perceptual processing stages among Mongolian-Chinese bilinguals with different proficiency levels.

## 3.1 Participants

Twenty-nine Mongolian-Chinese bilingual university students participated in the ERP experiment. The screening and grouping criteria were identical to those used in the visual search experiment, with participant characteristics presented in Table 3 .

## 3.2 Materials

Four colors were selected: H1 (RGB: 26, 96, 165), Q1 (RGB: 28, 139, 203), G1 (RGB: 0, 254, 84), and G2 (RGB: 0, 175, 52). The pre-experiment naming task showed that H1 and Q1 were both considered "blue"in Chinese but corresponded to huhe and qinker in Mongolian, respectively, while G1 and G2 were identified as "green" in both Chinese and Mongolian.

## 3.3.1 EEG Data Recording

Brain electrical activity was recorded continuously using a Brain Product system with an actiCAP64 electrode cap, with FCz as the reference electrode and AFz as the ground. Vertical electrooculogram (VEOG) was recorded from an electrode placed below the right eye. The sampling rate was 500 Hz, with a filter bandwidth of 0.01–70 Hz and a notch filter at 50 Hz. Impedance between scalp and electrodes was maintained below 7 kΩ (Thierry et al., 2009).

## 3.3.2 EEG Data Analysis

Offline analysis of raw data was performed using Brain Product' s Vision Analyzer Software (Version 2.0). The analysis proceeded as follows: data were re-referenced to the average of TP9 and TP10; ocular artifacts were removed; a low-pass filter of 20 Hz was applied; epochs were segmented from 100 ms before stimulus presentation to 700 ms after stimulus onset, with the 100 ms pre-stimulus interval serving as baseline. Posterior electrodes O1, O2, Oz, POz, PO3, PO4, PO7, and PO8 were pooled into a single region of interest. Following Mo, Xu, Kay, and Tan (2011), the N2 component was measured as the mean amplitude in the 160–240 ms time window after stimulus presentation. Data were averaged for each participant under different stimulus conditions, and difference waves were computed by subtracting standard stimulus waveforms from deviant stimulus waveforms. The peak in the 180–260 ms range of these difference waves was identified as the visual mismatch negativity (vMMN), after which waveforms were grand-averaged across all participants (Thierry et al., 2009).

### 3.3.3 Experimental Procedure

The experimental materials were presented as circular or square color blocks. In the Oddball paradigm, circular color blocks served as standard or deviant stimuli (differing in color), while square blocks served as target stimuli. Stimuli were presented on a Lenovo LCD monitor with a gray background (RGB: 192, 192, 192). Each color block was displayed for 800 ms with an inter-stimulus interval of 200 ms. The experiment consisted of four blocks: two blocks used green materials (G1 and G2 alternated as standard and deviant) and two blocks used blue materials (H1 and Q1 alternated as standard and deviant). Each block contained 640 color blocks, with presentation probabilities of 70% for standard stimuli, 20% for deviant stimuli, and 10% for target stimuli. Each block comprised 64 sequences of 10 blocks, with 7 standard stimuli, 2 deviant stimuli (never presented consecutively), and 1 target stimulus pseudo-randomly presented within each sequence. The order of the 64 sequences was randomized.

Participants were seated individually in a dimly lit laboratory approximately 60 cm from the gray-background display. After 180 practice trials, a red fixation point was presented for 800 ms to begin the experiment. Participants were instructed to press the K key when they detected a target stimulus and to refrain from responding to all other stimuli. Target, deviant, and standard stimuli were presented pseudo-randomly throughout the experiment.

### 3.4.1 Target Stimuli

The average hit rate for target stimuli was 98.65%, with a mean reaction time of 517 ms and an average of fewer than 3 false alarms. Following Mo et al. (2011), the mean amplitude of N2 was measured in the 160–240 ms time window. Results showed that target stimuli elicited a larger N2 than standard stimuli, F(1, 28) = 23.53, $p < 0.001$, $^2 = 0.17$, as shown in Figure 1 [Figure 1: see original paper]. Topographic maps were constructed using ERP mean values from the corresponding time windows. Both behavioral and ERP data indicated that participants achieved high recognition rates for target stimuli and allocated substantial attention to them, confirming that the response pattern to deviant stimuli in the Oddball paradigm satisfied the conditions for eliciting vMMN (Gábor et al., 2014).

### 3.4.2 Deviant Stimuli

Within the 180–260 ms time window, separate 2 (color: blue, green) × 2 (stimulus type: standard, deviant) repeated-measures ANOVAs were conducted on peak amplitudes and latencies of the original occipital waveforms for each bilingual group. For low Chinese proficiency bilinguals, the main effect of stimulus type on peak amplitude was significant, $F(1, 13) = 10.26$, $p < 0.001$, $^2 = 0.42$, while the main effect of color type was not significant, but the two-way interaction was significant, $F(1, 13) = 24.68$, $p < 0.001$, $^2 = 0.63$. For high Chinese proficiency bilinguals, the main effect of stimulus type was significant, $F(1, 14) = 89.56$, $p < 0.001$, $^2 = 0.85$, as was the main effect of color type, $F(1, 14) = 60.45$, $p < 0.001$, $^2 = 0.80$, but the interaction was not significant, $F(1, 13) = 1.32$, $p > 0.05$. Latency analyses revealed no significant main effects or interactions for either group, $p > 0.05$, $^2 < 0.06$, with all latencies around 200 ms.

Both groups showed significantly larger negative waves for deviant stimuli compared to standard stimuli. Difference waves were computed by subtracting standard stimulus waveforms from deviant stimulus waveforms at occipital sites, with the resulting difference wave in the 180–260 ms window identified as visual vMMN, as shown in Figure 2 [Figure 2: see original paper]. Topographic maps were constructed using mean vMMN values from the corresponding time windows. A 2 (Chinese proficiency: high, low) × 2 (color type: blue, green) mixed-design ANOVA on mean vMMN amplitudes revealed no significant main effects for Chinese proficiency or color, $p > 0.05$, $^2 < 0.06$, but the interaction was significant, $F(1, 28) = 25.08$, $p < 0.001$, $^2 = 0.46$. Simple effects analysis showed no significant difference between blue and green vMMN amplitudes for high proficiency bilinguals, $p > 0.05$, $^2 = 0.16$, whereas low proficiency bilinguals showed significantly larger vMMN amplitudes for blue stimuli compared to high proficiency bilinguals, $p < 0.05$, $^2 = 0.12$, and significantly larger vMMN amplitudes for blue than for green stimuli, $p < 0.001$, $^2 = 0.46$.

## 3.5 Discussion

The ERP data demonstrate that Chinese proficiency level affects color perception in Mongolian-Chinese bilinguals. Low Chinese proficiency bilinguals exhibited stronger vMMN when distinguishing qinker and huhe colors compared to green colors, indicating that weaker influence from Chinese color terms allowed their native Mongolian color categories to produce categorical perception effects and elicit stronger vMMN. In contrast, high Chinese proficiency bilinguals showed no categorical effect in the blue region, suggesting that second language lexical categories interfered with native language labels. The latency and characteristics of vMMN indicate that Chinese language learning influenced pre-attentive stages of color perception in an automatic fashion. These findings align with Athanasopoulos, Dering, Wiggett, Kuipers, and Thierry (2010), who found that English learning interfered with language labels in Greek-English bilinguals, affecting their color categorical perception. The results demonstrate that language influences early cognitive processing stages, with different color terms in bilinguals' two languages interfering with each other, and that this influence occurs at pre-attentive, automatic processing levels.

## 4 General Discussion

Color perception involves the detection of physical light wavelength properties. Given the consistency of spectral properties in natural environments and the universality of human visual physiology, linguistic universalism posits that color perception is a bottom-up process independent of language and culture, and that color categorical effects are similarly language-independent (Liu et al., 2008; Yang et al., 2016; Berlin & Kay, 1969). In recent decades, however, the Sapir-Whorf hypothesis has garnered increasing empirical support, suggesting that even basic cognitive processes like color perception are shaped by language. Developmental psychology and artificial concept learning studies indicate that language learning transforms color categorical effects from perceptual phenomena into language-mediated effects (Kwok et al., 2011; Zhou et al., 2010; Franklin et al., 2008). Research on bilinguals has further confirmed language' s influence on perception, demonstrating that interference between two languages can shift color categorical effects from language-based to perceptual effects (Athanasopoulos et al., 2010). The present study extends these findings by showing that Chinese, a language substantially different from English, also influences native color categorical perception when learned as a second language, thereby expanding the external validity of previous research while enhancing internal validity through reaction time and ERP methodologies.

Previous cross-linguistic research on color categorical perception has primarily employed between-subjects designs, which are susceptible to large individual differences. The present ERP experiment used a within-subjects design comparing color regions with different numbers of lexical labels within the same language, revealing stronger categorical effects in regions with more color terms. This provides clearer evidence that language influences perception, consistent with findings from artificial concept learning studies (Zhong et al., 2015; Kwok et al., 2011; Zhou et al., 2010) while extending these laboratory-based conclusions to natural language learning contexts, thereby enhancing ecological validity.

The vMMN color categorical effect exhibited left-hemisphere dominance, consistent with Liu et al. (2009), who found right visual field-left hemisphere lateralization of N2pc in visual search tasks due to language' s influence on color categorical perception. Using an Oddball paradigm, the present study identified vMMN with a latency of approximately 200 ms, converging with previous research to demonstrate that language affects early perceptual processing. Combined with existing studies, these findings indicate that language influences not only higher-level cognitive processes like memory and thinking but also primary perceptual processes, affecting both conscious and pre-attentive early processing stages. This suggests that human perception is highly flexible and plastic, with language playing a shaping role.

From the perspective of language’ s shaping effect on perception, linguistic universalism and the linguistic relativity hypothesis are not necessarily contradictory. Yang et al. (2016) and Franklin et al. (2008) demonstrated both universal aspects of color perception and how language can shape innate perceptual abilities during development, leading to language-perception associations. Zhong et al. (2015), Kwok et al. (2011), and Zhou et al. (2010) used artificial concept learning to establish causally that language shapes color perception. Bilingual research reveals that different language learning experiences or cultural exposure can influence color perception. In summary, while perceptual processing has universal aspects independent of language, it is also susceptible to linguistic influence, lending validity to the Sapir-Whorf hypothesis, at least in its weaker form.

Differences in second language proficiency among bilinguals correspond to differences in conceptual connections. High-proficiency language users exhibit shared conceptual representations, whereas low-proficiency users maintain separate conceptual systems (Jiang et al., 2015; Boroditsky, 2001). The present findings suggest that high-proficiency Mongolian-Chinese bilinguals’ blue categories approach a shared or gradually merged concept, while low-proficiency bilinguals remain more influenced by their native language and tend to categorize using familiar native language labels. This indicates that language learning can alter categorical perception effects, with the magnitude of change varying by proficiency level.

Regarding the cognitive mechanisms underlying language’ s influence on color perception, Hu, Hanley, Zhang, Liu, and Roberson (2014) proposed the Category Label Comparison Model, which posits that color categorical effects arise from cognitive conflict during automatic comparison between language labels and perceptual information. When identifying colors within the same category (e.g., dark blue and light blue), the language label is identical ( “blue” ) but perceptual information differs ( “dark” vs. “light” ), creating inconsistency between label and percept that produces cognitive conflict and longer processing times. When identifying colors from different categories (e.g., blue and green), both language labels ( “blue” vs. “green” ) and perceptual information differ, resulting in consistent label-percept comparisons, no cognitive conflict, and shorter processing times. This difference between within-category and between-category processing produces categorical effects. In the present study, low Chinese proficiency Mongolian-Chinese bilinguals showed stronger categorical effects when identifying qinker and huhe than when identifying green colors, confirming the Category Label Comparison Model.

While the present study employed relatively objective language assessment methods to manipulate proficiency, more precise distinctions in language proficiency require novel measurement approaches. Additionally, the experimental paradigm' s impact on the signal-to-noise ratio of the vMMN component warrants consideration, and future research should employ alternative paradigms for replication. In conclusion, this study demonstrates from both behavioral and electrophysiological perspectives that second language learning in bilinguals influences color perception, providing evidence for the Sapir-Whorf hypothesis and extending previous findings through the lens of language' s shaping effect and dynamic changes in categorical perception.

Beyond color perception, research has documented language' s influence on time perception (Boroditsky, 2001), motion and spatial perception (Athanasopoulos & Bylund, 2013; Bylund & Athanasopoulos, 2013), face perception (Fugate, 2013), categorization (Athanasopoulos & Kasai, 2007; Zhang, He, & Zhang, 2007), and shape perception (Gilbert et al., 2008). These findings contribute to a clearer understanding of the language-perception (cognition) relationship. To further elucidate the neural mechanisms of language' s influence on cognition, several issues require systematic investigation: How does language differentially affect early versus late stages of perceptual processing? Are there alternative models beyond the Category Label Comparison Model that can explain categorical perception? Can congenitally blind children without color experience establish color categorical perception effects through language alone? As an essential cultural marker, language embodies differences in natural environment, society, and culture across groups. Cultural and ethnic psychologists have identified language as a breakthrough point for cultural psychology research (Zhang, Morris, Cheng, & Yap, 2013; Xiao & Zhang, 2013). Integrating linguistic and cultural psychology through examining language labels' impact on human psychology may provide new perspectives for cultural psychology research.

In summary, Mongolian-Chinese bilinguals with different Chinese proficiency levels exhibit differential color categorical perception effects, with language' s influence manifesting at early pre-attentive processing stages. The Sapir-Whorf hypothesis holds even during early perceptual processing.

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## References

Athanasopoulos, P., & Bylund, E. (2013). Does grammatical aspect affect motion event cognition? A cross-linguistic comparison of English and Swedish speakers. *Cognitive Science*, 37(2), 286–309.

Athanasopoulos, P., Damjanovic, L., Krajciova, A., & Sasaki, M. (2011). Representation of colour concepts in bilingual cognition: The case of Japanese blues. *Bilingualism: Language and Cognition*, 14(1), 9–17.

Athanasopoulos, P., Dering, B., Wiggett, A., Kuipers, J-R., & Thierry, G. (2010). Perceptual shift in bilingualism: Brain potentials reveal plasticity in pre-attentive colour perception. *Cognition*, 116(3), 437-443.

Athanasopoulos, P., & Kasai, C. (2007). Language and thought in bilinguals: The case of grammatical number and nonverbal classification preferences. *Applied Psycholinguistics*, 29(1), 105-123.

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution.* Berkeley and Los Angeles: University of California Press.

Boroditsky, L. (2001). Does language shape thought? Mandarin and English speakers' conceptions of time. *Cognitive Psychology*, 43(1), 1-22.

Bylund, E., & Athanasopoulos, P. (2013). Language and thought in a multilingual context: The case of isiXhosa. *Bilingualism: Language and Cognition*, 17(2), 431-441.

Chris, M. B., Samuel, C. B., Aidan, J. H., & Franklin, A. (2014). Categorical encoding of color in the brain. *Proceedings of the National Academy of Sciences of the United States of America*, 111(12), 4590-4595.

Drivonikou, G. V., Kay, P., Regier, T., Ivry, R. B., Gilbert, A. L., Franklin, A., & Davies, I. R. (2007). Further evidence that Whorfian effects are stronger in the right visual field than the left. *Proceedings of the National Academy of Sciences of the United States of America*, 104(3), 1097-1102.

Franklin, A., Drivonikou, G. V., Bevis, L., Davies, I. R., Kay, P., & Regier, T. (2008). Categorical perception of color is lateralized to the right hemisphere in infants, but to the left hemisphere in adults. *Proceedings of the National Academy of Sciences of the United States of America*, 105(9), 3221-3225.

Franklin, A., Drivonikou, G. V., Clifford, A., Kay, P., Regier, T., & Davies, I. R. (2008). Lateralization of categorical perception of color changes with color term acquisition. *Proceedings of the National Academy of Sciences of the United States of America*, 105(47), 18221-18225.

Fugate, J. M. B. (2013). Categorical Perception for Emotional Faces. *Emotion Review*, 5(1), 84-89.

Gábor, S., Jan, K., & István, C. (2014). Visual mismatch negativity: A predictive coding view. *Frontiers in Human Neuroscience*, 8(3), 666.

Gilbert, A. L., Regier, T., Kay, P., & Ivry, R. B. (2006). Whorf hypothesis is supported in the right visual field but not the left. *Proceedings of the National Academy of Sciences of the United States of America*, 103(2), 489-494.

Gilbert, A. L., Regier, T., Kay, P., & Ivry, R. B. (2008). Support for lateralization of the Whorf effect beyond the realm of color discrimination. *Brain and Language*, 105(2), 91-98.

He, J., Li, J., Zhang, Y., & Zhang, S. (2016). Language affects Perception: Evidence from Mongolian. Paper presented at the meeting of the 16th International Conference on the Processing of East Asian Languages, Guangzhou, China.

Hu, Z., Hanley, J. R., Zhang, R., Liu, Q., & Roberson, D. (2014). A conflict-based model of color categorical perception: Evidence from a priming study. *Psychonomic Bulletin & Review*, 21(5), 1214-1223.

Jameson, K. A., & Alvarado, N. (2003). Differences in color naming and color salience in Vietnamese and English. *Color Research and Application*, 28(2), 113-138.

Jiang, S. X., Li, J., Liu, X. Y., Qi, S. S., & Yang, Y. S. (2015). An ERP study of advantage effect differences on task switching in proficient and non-proficient bilinguals. *Acta Psychologica Sinica*, 47(6), 746-756. [姜淞秀, 李杰, 刘兴宇, 七十三, 杨伊生. (2015). 不同熟练度双语者非语言任务转换的差异——来自 ERP 证据. 心理学报, 47(6), 746-756.]

Kwok, V., Niu, Z., Kay, P., Zhou, K., Mo, L., Jin, Z., ···Tan, L. (2011). Learning new color names produces rapid increase in gray matter in the intact adult human cortex. *Proceedings of the National Academy of Sciences of the United States of America*, 108(16), 6686-6688.

Liu, Q., Chen, A., Wang, Q., Zhou, L., & Sun, H. (2008). An evidence for the effect of categorical perception on color perception. *Acta Psychologica Sinica*, 40(1), 8-13. [刘强, 陈安涛, 王琪, 周柳, 孙弘进. (2008). 知觉加工中存在颜色类别知觉效应的证据. 心理学报, 40(1), 8-13.]

Liu, Q., Li, H., Campos, J. L., Wang, Q., Zhang, Y., Qiu, J., ···Sun, H-J. (2009). The N2pc component in ERP and the lateralization effect of language on color perception. *Neuroscience Letters*, 454(1), 58-61.

Mo, L., Xu, G., Kay, P., & Tan, L. (2011). Electrophysiological evidence for the left-lateralized effect of language on preattentive categorical perception of color. *Proceedings of the National Academy of Sciences of the United States of America*, 108(34), 14026-14030.

Regier, T., & Kay, P. (2009). Language, thought, and color: Whorf was half right. *Trends in Cognitive Sciences*, 13(10), 439-446.

Roberson, D., Pak, H., & Hanley, J. R. (2008). Categorical perception of colour in the left and right visual field is verbally mediated: Evidence from Korean. *Cognition*, 107(2), 752-762.

Thierry, G., Athanasopoulos, P., Wiggett, A., Dering, B., & Kuipers, J. R. (2009). Unconscious effects of language-specific terminology on preattentive color perception. *Proceedings of the National Academy of Sciences of the United States of America*, 106(11), 4567-4570.

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Pro-*

*ceedings of the National Academy of Sciences of the United States of America*, 104(19), 7780-7785.

Xiao, E-P., & Zhang, J-J. (2012). National language influences national psychology: Evidence from classifying kinship words. *Advances in Psychological Science*, 20(8), 1189-1200. [肖二平, 张积家. (2012). 从亲属词分类看民族语言对民族心理的影响. 心理科学进展, 20(8), 1189-1200.]

Yang, J., Kanazawa, S., Yamaguchi, M. K., & Kuriki, I. (2016). Cortical response to categorical color perception in infants investigated by near-infrared spectroscopy. *Proceedings of the National Academy of Sciences of the United States of America*, 113(9), 2370-2375.

Zhang, J.-J., & Zhang, F.-L. (2010). The asymmetric effect of bilingualism and diglossia on picture naming and picture classification. *Acta Psychologica Sinica*, 42(4), 452-466. [张积家, 张凤玲. (2010). 双语和双言对图片命名和分类的不对称影响. 心理学报, 42(4), 452-466.]

Zhang, Q. R., He, X. M., & Zhang, J. J. (2007). A comparative study on the classification of basic color terms by undergraduates from Yi nationality, Bai nationality and Naxi nationality. *Acta Psychologica Sinica*, 39(1), 18-26. [张启睿, 和秀梅, 张积家. (2007). 彝族、白族和纳西族大学生的基本颜色词分类. 心理学报, 39(1), 18-26.]

Zhang, S., Morris, M. W., Cheng, C-Y., & Yap, A. J. (2013). Heritage-culture images disrupt immigrants' second-language processing through triggering first-language interference. *Proceedings of the National Academy of Sciences of the United States of America*, 110(28), 11272-11277.

Zhong, W. F., Li, Y., Li, P. X., Xu, G. P., & Mo, L. (2015). Short-term trained lexical categories produce preattentive categorical perception of color: Evidence from ERPs. *Psychophysiology*, 52(1), 98-106.

Zhou, K., Mo, L., Kay, P., Kwok, V. P., Ip, T. N., & Tan, L. H. (2010). Newly trained lexical categories produce lateralized categorical perception of color. *Proceedings of the National Academy of Sciences of the United States of America*, 107(22), 9974-9978.

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## Tables

**Table 1**

Demographic and Language Background Characteristics of Mongolian-Chinese Bilingual Participants [M (SD)]

| Variable | High Chinese Proficiency | Low Chinese Proficiency |
|---|---|---|
| Sample size (gender) | 35 (17M, 18F) | 33 (15M, 18F) |
| Mean age (years) | 20.85 (1.14) | 21.10 (1.16) |
| Mongolian listening | 5.24 (0.95) | 5.66 (1.08) |

| Variable | High Chinese Proficiency | Low Chinese Proficiency |
|---|---|---|
| Mongolian speaking | 5.23 (0.99) | 5.49 (1.03) |
| Mongolian reading | 5.09 (1.02) | 5.12 (0.99) |
| Mongolian writing | 5.10 (1.01) | 5.18 (1.02) |
| Chinese listening** | 4.89 (1.23) | 4.04 (1.29) |
| Chinese speaking** | 4.97 (1.34) | 4.08 (1.19) |
| Chinese reading*** | 4.86 (1.29) | 3.80 (0.99) |
| Chinese writing*** | 4.66 (1.19) | 3.79 (0.98) |
| Mongolian usage frequency (%)*** | 74.45 (9.90) | 89.38 (10.02) |
| Chinese usage frequency (%)*** | 45.54 (6.60) | 28.97 (5.79) |
| Age of L2 acquisition (years)** | 8.96 (1.86) | 10.02 (0.96) |
| Age of Chinese fluency (years)*** | 10.23 (2.09) | 14.36 (3.96) |

Note: **$p < 0.01$,** *$p < 0.001$

**Table 2**

Response Times in Visual Search Task for Mongolian-Chinese Bilinguals with Different Chinese Proficiency Levels [M (SD), ms]

| Condition | High Chinese Proficiency | Low Chinese Proficiency |
|---|---|---|
| Within-category | 893 (193) | 923 (187) |
| Between-category | 910 (194) | 1064 (201) |

**Table 3**

Demographic Characteristics of ERP Experiment Participants with Different Chinese Proficiency Levels [M (SD)]

| Variable | High Chinese Proficiency | Low Chinese Proficiency |
|---|---|---|
| Sample size (gender) | 15 (8M, 7F) | 14 (7M, 7F) |
| Mean age (years) | 21.25 (1.10) | 21.20 (1.17) |
| Mongolian listening | 5.34 (0.96) | 5.76 (1.09) |
| Mongolian speaking | 5.28 (1.09) | 5.39 (1.01) |
| Mongolian reading | 5.19 (1.01) | 5.22 (1.00) |
| Mongolian writing | 5.15 (1.01) | 5.16 (1.02) |
| Chinese listening** | 4.99 (1.23) | 4.17 (1.29) |
| Chinese speaking** | 4.97 (1.21) | 3.98 (1.09) |
| Chinese reading*** | 4.93 (1.19) | 3.90 (1.00) |
| Chinese writing*** | 4.86 (1.09) | 3.76 (0.98) |
| Mongolian usage frequency (%)*** | 78.65 (9.95) | 91.68 (11.01) |
| Chinese usage frequency (%)*** | 43.54 (6.45) | 24.42 (5.43) |
| Age of L2 acquisition (years)** | 8.46 (1.96) | 11.08 (2.99) |
| Age of Chinese fluency (years)*** | 9.73 (1.97) | 14.86 (4.26) |

Note: **$p < 0.01$,** *$p < 0.001$

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv —Machine translation. Verify with original.*