A delayed discrimination task yields categorical perception of color not only in the right but also in the left visual field

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Abstract

Whether categorical perception of color is lateralized in the left cerebral hemisphere (e.g., Gilbert, Regier, Kay, & Ivry, 2006) or not (e.g., Witzel & Gegenfurtner, 2011) is still controversial. This ongoing debate, however, has been studied with visual search tasks, which seemed to produce residual laterality effects. The present study assessed whether a delayed discrimination task with divided visual field method, rather than visual search tasks, yields lateralized or bilateral categorical perception of color. The results showed an advantage for between-category discrimination relative to within-category discrimination. Such an advantage, importantly, was obtained in the left visual field as well as in the right visual field. These results suggest categorical perception of color is bilateral and not lateralized. Combining recent studies with visual search tasks (e.g., Witzel & Gegenfurtner, 2011), our results would provide further evidence for bilateral categorical perception, and thus throw doubt on the laterality effects of categorical perception.

Keywords: categorical perception; color perception; delayed discrimination task

Introduction

A growing number of studies have shown that categorical perception (better discrimination of the stimuli from adjacent categories than those from the same category) of color (e.g., Roberson & Davidoff, 2000; Suegami & Michimata, 2010; Wiggett & Davis, 2008; Winawer et al., 2007). In a seminal study, Gilbert, Regier, Kay, and Ivry (2006) employed a visual search task, where a colored target was detected faster when the target and distracters belonged to different color categories than when the target was in the same color category as the distracters (i.e., categorical perception). However, such a categorical perception of color was observed only when the target appeared in the right visual field (RVF) but not in the left visual field (LVF). Some successive studies, either behavioral studies (e.g., Drivonikou, et al., 2007) or imaging study with fMRI (Siok et al., 2009), obtained a stronger categorical perception in the RVF relative to LVF. Since the RVF is projected to the left cerebral hemisphere (LH), which is thought to be a center of verbal processing, the results would apparently reflect the fact that categorical perception is verbally mediated.

Meanwhile, some other studies suggested that lateralized categorical perception in the RVF could be interpreted in terms of other general cognitive mechanisms supported by the LH, rather than simply verbal or language-related processing. Holmes and Wolff (2012), for instance, showed that not only labeled objects but also unlabeled objects produced categorical perception in the RVF on a visual search task. They attributed such a categorical perception in the RVF to an LH's advantage in qualitative or "categorical" processing (cf, Hellige & Michimata, 1989; Kosslyn et al., 1989; Laeng, Chabris, & Kosslyn, 2003).

The debate about the origin of the LH-lateralized categorical perception is ongoing and resolving such a debate may be of importance for the understanding of the nature of categorical perception. It should be noted, however, that such laterality effects could also result from some other residual factors. Some recent studies (Brown, Lindsey, & Guckes, 2011; Witzel & Gegenfurtner, 2011), for instance, showed that when using the same visual color search tasks as the previous studies but correcting some methodological weakness of previous studies, such as color production or eye movements, yielded categorical perception of color in the LVF as well as RVF.

Another concern could be brought in regard to the tasks; the LH-lateralized categorical perception was predominantly obtained with visual search tasks (e.g., Brown et al., 2011; Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2008; Holmes & Wolff, 2012; Roberson, Pak, & Hanley, 2008; Siok et al., 2009; Witzel & Gegenfurtner, 2011). Visual search tasks seem to be suitable for examining categorical "perception," since this kind of tasks would have little memory demands. In the visual search tasks, however, one can also find some factors that might confound the results. In all of the visual search tasks we reviewed, participants were asked to judge which side (i.e., left or right) did the target appear in, and made their responses by hitting the keys associated with target's position (i.e., left or right key). Since judging left or right side is in the nature of the "categorical" spatial relation processing, which is better processed in the LH (Hellige & Michimata, 1989; Hellige, Laeng, & Michimata, 2010; Jager & Postma, 2003; Kosslyn et al., 1989; Laeng, Chabris, & Kosslyn, 2003), this kind of tasks would produce residual laterality effects. The visual search tasks, moreover, seem to consist of detection of the target among distractors. Kitterle, Christman, and Hellige (1990) argued that laterality for the spatial frequency processing could be obtained in an identification task (or a delayed discrimination task) but not in a detection task. Although it is not clear whether laterality for categorical perception and these other types of "categorical" processing share the same mechanisms (c.f., Franklin, Drivonikou, Bevis, Davies, Kay, & Regier, 2008; Holmes & Wolff, 2012; Suegami & Laeng, 2013), employing the visual search task, which seems to be another variation of a detection task, might diminish or cancel the lateralization of categorical perception. Thus, one could argue that some recent studies (Brown et al., 2011; Witzel & Gegenfurtner, 2011) failed to replicate LH-lateralized categorical perception since laterality effects were cancelled out by residual factors.

Thus, the present study aimed to provide further evidence for either LH-lateralized or bilateral categorical perception of color by means of a delayed discrimination task with divided visual field method, rather than the visual search tasks (e.g., Drivonikou et al., 2007; Gilbert et al., 2006). The delayed discrimination task employed here was the classical method for exploring an LH's advantage in categorical processing of spatial relations and patterns (e.g., Hellige & Michimata, 1989; Kosslyn et al, 1989; Saneyoshi & Michimata, 2009; Suegami & Laeng, 2013). Following previous studies (e.g., Siok et al., 2009), four colors with a constant color difference in CIE L* u* v* perceptually uniform color space were emulated. The experiment consisted of an initial training for eye-fixation (Guzman-Martinez, Leung, Franconeri, Grabowecky, & Suzuki, 2009) and two main tasks: a delayed discrimination task and a color categorization task.

In the delayed discrimination task, moreover, two different lengths of delays (500 ms or 5000 ms) were employed since both theories for the LH-lateralized categorical perception expected that such a LH-lateralized pattern should be enhanced by longer delays. A 5000 ms or longer delay in the delayed discrimination task would enhance using verbal codes rather than visual codes (Posner & Keele, 1967), and also enhance an LH's advantage in "categorical" spatial relation processing (Postma, Huntjens, Meuwissen, & Laeng, 2006).

After the delayed discrimination task, the participants also took part in a color categorization task to validate the categories of the four colors. The color categorization task was conducted after the delayed discrimination task in order to avoid any biases to the discrimination task.

Method

Participants

Thirty participants were recruited as volunteers for an experiment on color perception. Each participant received a gift card for 200 Norwegian Crowns (i.e., about 35 U.S. dollars). Edinburgh Handedness Inventory (Oldfield, 1971) and Farnsworth-Munsell 100-Hue test were conducted for screening out left-handers and individuals with abnormal color vision.

Apparatus

All the stimuli were presented on a 21-in. CRT monitor with 75 Hz refreshing rate (EIZO Flex Scan T961), connecting with Apple MacBook Pro (2.8 GHz Intel Core 2 Duo). The distance between the CRT monitor and participant's eyes was fixed in 85.5 cm. The experiment was operated by MATLAB 2008b with Psychophysics Toolbox 3 (Brainard, 1997). A 10-key pad was connected to the computer and served as a response console. Both the training and two main tasks were conducted in a dark room.

Stimuli

Eye-fixation training The stimuli in the original training task (Guzman-Martinez et al., 2009) were closely duplicated. Two circles of 17.27° (visual angle) diameter, filled with black and white random-dot pattern or its contrast-reversed pattern, were created. Each of the two circle had 1.00° by 1.00° of a black fixation cross at its center.

Delayed discrimination task Four colors used in the previous studies (e.g., Siok et al., 2009) were emulated. Each adjacent pair had approximately constant distance in the CIE L* u* v* color space. Two of them ought to belong to blue category and other two to green (hereafter, the four colors were termed as *Blue 1*, *Blue 2*, *Green 2*, and *Green 1* respectively). The CIE L* u* v* coordinates for each color were measured by means of Datacolor Spyder 4 ELITE (CIE L* u* v* coordinates for each color were listed on Table 1). The mean color difference (ΔE in CIE L* u* v* space) of within-category pairs was 17.76, and slightly larger than the ΔE for the between-category pair (17.10).

Four color patches of 2.00° by 2.00° and a hairline fixation cross of 1.00° by 1.00° were created as the stimuli. Each color patch had one of the 4 colors, and the fixation cross was depicted by the neutral orange color which had approximately constant distance from all of the 4 colors in terms of CIE L* u* v* coordinates.

Color categorization task The same color patches as the delayed discrimination task were employed as the stimuli.

Procedure

Eye-fixation training The procedure was based on the original work by Guzman-Martinez et al. (2009). Each participant was seated in front of the CRT monitor, and fixed her/his eyes into the fixation cross. Participant's hitting the appropriate key led to 5000 ms of 37.5 Hz flickering presentation of the two random-dots circles. The participant was instructed that random-dots circles would turn into an uniform gray circle if her/his eyes were fixed into the fixation cross. After 5000 ms of flickering presentation, the participant could take a short break, and was allowed to start next trial by her/his own pace. The training had 30 trials and took approximately 5 min.

Delayed discrimination task After the eye-fixation training, the participant took part in the delayed discrimination task. The apparatus was identical to those for the eye-fixation training.

Typical trial sequence was shown in the Figure 1. Each trial began with 200 ms of a fixation cross against black background. Then two identical color patches filled with one of the 4 colors appeared 3.9° left and right from the center as probes[1], and a blank screen followed for 300 ms or 4800 ms. After the blank, a fixation cross appeared again for 200 ms (therefore, the ISI was 500 ms or 5000 ms), and then target color patch was presented 3.9° left or right from the center for 200 ms. The target could have an adjacent color or the same color as the probes. The participant judged if the color of the target was identical to that of the probes by hitting the left or right key as quickly as s/he could. A half of the participants hit the left key if the target and probes had the same color, and the other half hit the right key instead. Response times (RTs) were recorded from the onset of the target. If no response occurred until 2000 ms had elapsed from the onset, the trial was classified as an error. After a response had been made or 2000 ms had elapsed, the next trial started through a 1500 ms of inter trial interval. Twenty trials constituted an experimental block. The length of the ISI was manipulated between the experimental blocks. Half of the participants performed 10 blocks with 500 ms of ISI first, and then another 10 blocks with 5000 ms of ISI second. Another half of the participants performed each 10 blocks in reversed order.

For both ISI conditions, a practice block was held before starting each task. In the practice block, each trial had instant feedback, and another block was repeated if the accuracy rate of the block had not reached 65.0%.

Color categorization task After the delayed discrimination task, a color categorization task took place. In each trial, a color patch filled with one of the 4 colors appeared in the center. The participant judged if the color was blue or green by manual response. The color patch was presented until the response had been made (with no time limitation). The participant could take a short break after each 20 trials, and the whole task consisted in a total of 100 trials.

[1] The probes were presented left and right from the center of the screen simultaneously, ensuring that the probes and the target had identical retinal eccentricity.

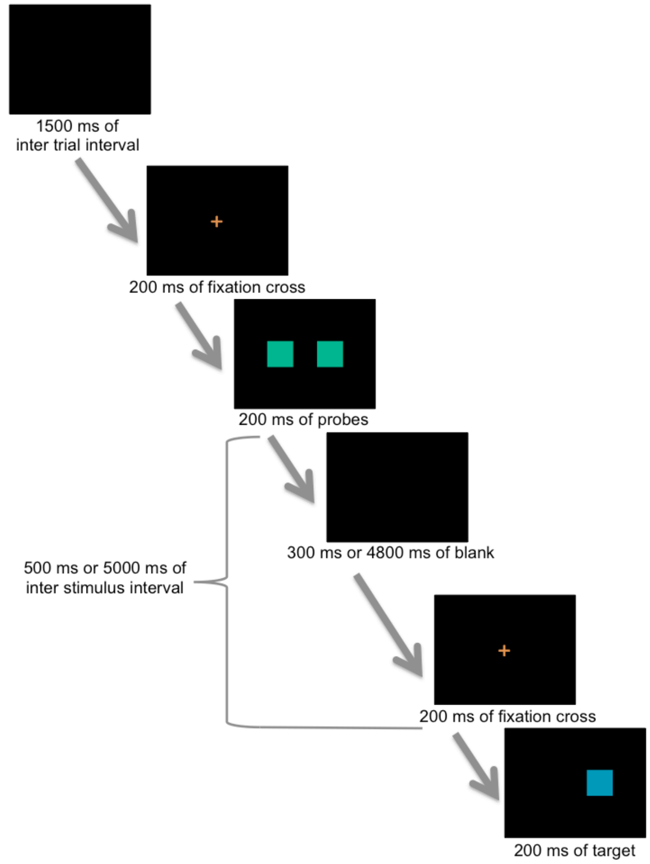

Figure 1: Illustration of a trial sequence of the delayed discrimination task.

Results

Eight participants were excluded from the analysis. One of them did not get a score above +50 on the Edinburgh Handedness Inventory and therefore was ruled out for excluding potential left-handed or mix-handed (see Dragovik, 2004). Another showed significant positive correlation between accuracies and RTs ($\boldsymbol{r} = +.\mathbf{91}$), suggesting a speed-accuracy trade-off. Three participants were screened out due to their abnormal scores on the Farnsworth-Munsell 100-Hue test. Other three showed atypical categories of color; the boundary between blue and green category did locate at between *blue 1* and *blue 2*, instead of between *blue 2* and *green 2* (see Gilbert et al., 2006). Thus, the data from the remaining 22 participants were employed for the statistical analysis. Six of them were native Norwegian speakers, five were Lithuanian speakers, two were Chinese and two were English, and each of the other participants spoke, respectively, Bosnian, French, Italian, Persian, Portuguese, Spanish, and Swedish as a native language. Fifteen of them were female, and the mean age of the participants was 27.76 years (*SD* = 5.32). The mean score on the Edinburgh Handedness Inventory was 91.57 (*SD* = 9.06).

Color categorization task

The rates of the trials in which the color was categorized "blue" were calculated for all of the four colors (Table 1). One-sample *t*-tests for each rate revealed that all the rates were significantly different form the chance level of 50.0%, *p*s < .001. That is, both of *blue 1* and *blue 2* were categorized as "blue" robustly, and likewise both of *green 2* and *green 1* were categorized as "green." These results confirmed that *blue 1* and *blue 2* indeed belonged to "blue" category, and likewise *green 2* and *green 1* were belonged to "green" category.

Table 1: CIE L* u* v* coordinates and rate of categorized "blue" in the color categorization task for each color.

Color	L*	u*	v*	Rate of "blue" response (%)
Blue 1	56.655	-41.973	-27.120	99.6 (0.3)
Blue 2	62.963	-48.252	-10.988	86.6 (2.9)
Green 2	62.141	-50.880	6.534	1.6 (0.7)
Green 1	62.432	-52.346	23.564	0.2 (0.2)
Neutral orange	27.004	40.084	16.971	--

Note: Standard errors for the rates of "blue" responses are within parentheses.

Delayed discrimination task

Accuracy As indices of accuracies, *A´*s (Aaronson & Watts, 1987; Pollack & Norman, 1964) were employed instead of error rates, so as to exclude possible participants' response bias (see also Pilling et al., 2003). *A´*s for within- and between-category pairs with two ISI conditions were calculated for each visual field (panel a and b in Figure 2).

The *A´*s were analyzed by a three-way analysis of variance (ANOVA), with category (within-category or between-category), visual field (LVF or RVF), and ISI (500 ms of ISI or 5000 ms of ISI) as within-participants factors. As the most important result, a significant effect of category was obtained, $F(1, 21) = 28.40, MSE = 0.06^{-1}, p < .001, \eta_p^2 = .58$, reflecting that the *A´* for the between-category discrimination was larger than that for the within-category discrimination (i.e., categorical perception of color). A main effect of visual field was also significant, $F(1, 21) = 11.12, MSE = 0.03^{-1}, p = .003, \eta_p^2 = .35$, revealing that the *A´* in the LVF was larger than that in the RVF. An interaction between category and visual field, moreover, was significant. Post hoc *t*-tests revealed the *A´* for the between-category discrimination was larger than that for the within-category discrimination in the RVF, $t(21) = 3.75, p = .001, d = 0.60$, and also in the LVF as well, $t(21) = 5.53, p < .001, d = 1.06$. The *A´* for the between-category discrimination was larger in the LVF than that in the RVF, $t(21) = 3.90, p = .001, d = 0.63$, whereas no significant difference was found between in the *A´* for the within-category discrimination in the LVF and RVF, $t(21) = 1.01, p = .326, d = 0.12$. These results suggest that the categorical perception of color was obtained not only in the RVF but also in the LVF, and, unexpectedly, such a category perception was observed stronger in the LVF instead of the RVF. Neither any other main effects nor interactions was significant, $p > .175, \eta_p^2 < .09$.

Response Time Median RTs for correct responses were also calculated for within- and between-category pairs with two ISI conditions in both visual fields (panel c and d in Figure 2).

The RTs were also analyzed by the same three-way ANOVA as the accuracies. In line with the results in the accuracies, a main effect of category was again significant, $F(1, 21) = 12.78, MSE = 9104.76, p = .002, \eta_p^2 = .38$. This main effect reflects that the RTs for the between-category discrimination were shorter than that for the within-category discrimination. Post hoc *t*-tests revealed the RTs for the between-category discrimination were significantly shorter than that for the within-category discrimination in the RVF, $t(21) = 2.80, p = .011, d = 0.28$, and also in the LVF, $t(21) = 2.43, p = .024, d = 0.32$. These results, in accordance with the results in the accuracies, suggest that categorical perception of color was found in the LH as well as in the RH. A significant main effect of ISI was also found, not surprisingly, $F(1, 21) = 36.45, MSE = 25739.96, p < .001, \eta_p^2 = .63$, revealing that the RTs with 500 ms of ISI were shorter than those with 5000 ms of ISI. Any other effects or interactions failed to be significant, $p > .203, \eta_p^2 < .08$.

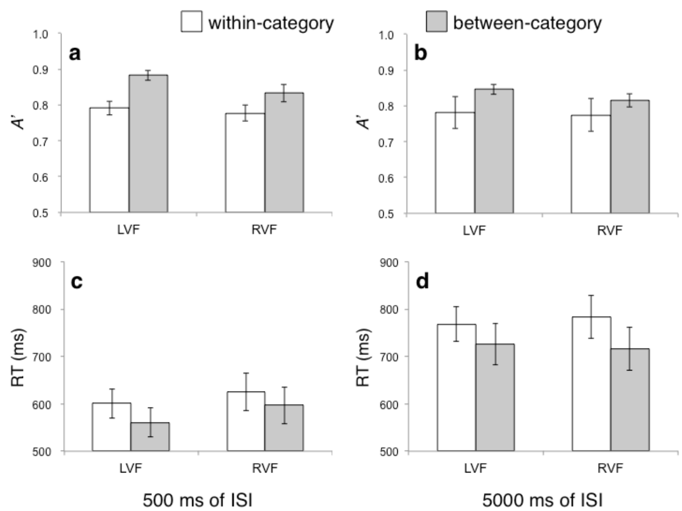

Figure 2: *A´*s (two panels on upper line) and RTs (two panels on lower line) for within- and between-category pairs. The left panels show *A´*s and RTs with 500 ms of ISI (panel a and c, respectively), whereas the right panels show those with 5000 ms of ISI (panel b and d, respectively). Each error bar shows ±1 standard error.

Discussion

The present study aimed to assess whether, by means of a delayed discrimination task, one would observe a LH-lateralized categorical perception of color (e.g., Drivonikou et al., 2007; Gilbert et al., 2006; Siok et al., 2009) or bilateral categorical perception (Brown et al., 2011; Witzel & Gegenfurtner, 2011). In such a delayed discrimination task, we found evidence for bilateral but not LH-lateralized categorical perception. We employed the same color set as some of the previous studies that had found a LH-lateralized categorical perception (e.g., Siok et al., 2009). The results from the categorization task confirmed that both of blue and green categories in the present study were well established. Thus, such bilateral categorical perceptions could not be attributed to the color difference itself, and they confirm recent studies also showing bilateral categorical perception of color (Brown et al., 2011; Witzel & Gegenfurtner, 2011). Interestingly, an unexpected RH-lateralized categorical perception was obtained in terms of accuracies. A possible account for this "reversed" laterality effects could be the RH's advantage in color processing (e.g., Levy & Trevarthen, 1981; Pennal, 1977). Importantly, this result presents another example of counter evidence for the hypothesis of a LH-lateralized categorical perception.

One could argue that the present study failed to replicate the LH-lateralized categorical perception merely due to employing a different task than the typical visual search. This is plausible, but this reasoning contradicts the idea that either an LH's advantage in verbal processing or a hemispheric specialization in "categorical" processing underlies the LH-lateralized categorical perception effect. In fact, an LH's advantage in both verbal (Posner & Keele, 1967) and categorical spatial processing (Postma, et al., 2006) is typically enhanced with longer time intervals, as in a delayed discrimination task. Moreover, a delayed discrimination task would seem more suitable for obtaining laterality effects than the tasks with no memory demands, like the visual search tasks (Kitterle et al., 1990). Therefore it could be argued that the present task should have been more likely to yield laterality effects on categorical perception than the previous visual search tasks. However, we failed to observe any sign of a LH-lateralized categorical perception in the current study. Thus, the present results are best interpreted as supporting the conclusion that categorical perception of color is represented bilaterally in the brain.

One possible weakness of the present study may be due to the large variety of participants' mother languages in our sample. Several studies have reported that people may possess different color categories in their native languages and consequently this could yield different patterns of categorical perception of color (e.g., Winawer et al., 2007) or its lateralization (e.g., Roberson et al., 2008). However, we took care to confirm that all of our participants shared the same color categories, and we found evidence that only three participants showed atypical categorical structures. Moreover, the native languages of all participants (except excluded three participants) distinguish between green and blue at the lexical level. According to the previous studies (e.g., Roberson, Davies, & Davidoff, 2000), it is when the native languages do not distinguish, for example, blue from green that these individuals would also show different patterns of category effects. As mentioned in the *Results* section, moreover, three participants were excluded since their categorical boundary located at between *blue 1* and *blue 2*, instead of *blue 2* and *green 2*. For these participants, two of them were Russian and the other was Turkish. Previous studies showed that Russian (Winawer et al., 2007) and Turkish (Özgen & Davies, 1997) have different structures of blue category relative to native English speakers. The fact that those participants with different color structures in their native languages indeed showed different categorical structures in the categorization task indicates that the results of the categorization task adequately reflect participants' categorical structures. Thus, these results could provide another moderate support for that the participants employed in current analysis shared the same category structures to a satisfactory extent.

In conclusion, the present study revealed bilateral categorical perception with a delayed discrimination task. Although the delayed discrimination task has memory components and therefore could be less appropriate for examining "perception," such a task has the advantage to exclude residual laterality effects caused by previous visual search tasks (e.g., residual categorical spatial processing caused by left/right judgments). Combining recent studies employed visual search tasks with correcting some other methodological flaws (Brown et al., 2011; Witzel & Gegenfurtner, 2011), our results provide further evidence for bilateral categorical perception, and thus throw doubt on the laterality effects of categorical perception.

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