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Another look at category effects on colour perception and their left hemispheric lateralisation: No evidence from a colour identification task

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Abstract

The present study aimed to replicate category effects on colour perception and their lateralisation to the left cerebral hemisphere (LH). Previous evidence for lateralisation of colour category effects has been obtained with tasks where a differently-coloured target was searched within a display and participants reported the lateral location of the target. However, a left/right spatial judgment may yield LH-laterality effects per se. Thus, we employed an identification task that does not require a spatial judgment and used the same colour set that previously revealed LH-lateralised category effects. The identification task was better performed with between-category colours than with within-category task both in terms of accuracy and latency, but such category effects were bilateral or RH-lateralised, and no evidence was found for LH-laterality effects. The accuracy scores, moreover, indicated that the category effects derived form low sensitivities for within-blue colours and did not reflect the effects of categorical structures on colour perception. Furthermore, the classic “category effects” were observed in participants’ response biases, instead of sensitivities. The present results argue against both the LH-lateralised category effects on colour perception and the existence of colour category effects per se.

Key words: category effect; colour perception; laterality; identification task
Another look at category effects on colour perception and their left hemispheric lateralisation: No evidence from a colour identification task

**Introduction**

A growing number of studies have shown that discrimination of stimuli from adjacent categories is more accurate or faster than discrimination of those from a same category. Such category effects have been observed in many different modalities or domains, such as speech perception (e.g., Liberman, Harris, Hoffman, & Griffith, 1957), object recognition (e.g., Newell & Bülthoff, 2002) and the perception of colour (e.g., Bornstein, 1987; Suegami & Michimata, 2010; Winnawer, Witthoft, Frank, Wu, Wade, & Boroditsky, 2007; Wiggett & Davies, 2008). In relation to the latter topic, Gilbert, Regier, Kay, and Ivry (2006) published a seminal study, where they employed a visual search task for one target colour that differed from 11 distracters; the target was detected faster when the target and distracters belonged to different colour categories than when the target was in the same colour category as the distracters. Such category effects, however, were observed only when the target appeared in the right visual field (RVF) but not in the left visual field (LVF), this suggesting a left hemisphere’s (LH’s) specialisation for the effects of categories on colour perception. Subsequent behavioural studies on colour perception (e.g., Drivonikou et al., 2007; Roberson, Pak, & Hanley, 2008) as well as neuroimaging studies (e.g., Siok et al., 2009), or behavioural studies on object recognition (e.g., Gilbert, Regier, Kay, & Ivry, 2007; Holmes & Wolff, 2012) have also obtained stronger category effects in the RVF relative to the LVF, further supporting the conclusion of a special role of the LH.

What seems particularly relevant about such a lateralisation pattern is that it may shed light on the neural and cognitive mechanisms behind such category effects. Specifically, the LH is thought to be a centre of verbal or language-related processing (e.g., Ojemann, Ojemann, Lettich, & Berger, 1989), thus a RVF-lateralised category effect could be interpreted as an effect of verbal or language-related processing on our perception and cognition (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2007; Roberson et al., 2008; Siok et al., 2009).

It should be noted, however, that some other studies failed to replicate such RVF-lateralised category effects. Witzel and Gegenfurtner (2011), for instance, employed two stimulus sets from Gilbert et al. (2006) and Siok et al. (2009), and carefully controlled
the colours, and then found that both colour sets yielded the category effects on colour perception not only in the RVF but in the LVF as well. Such RVF-advantages in category effects could also result from some other uncontrolled factors. Although Witzel and Gegenfurtner (2011) did not refer to what factor(s) caused such bilateral category effects rather than RVF-lateralised effects, several possible factors could be considered. The RVF-advantages in category effects, for example, could reflect another of the LH’s key specialization in visual perception. Several studies have shown that the LH has an advantage in processing qualitative or “categorical” spatial relations, whereas the right cerebral hemisphere (RH) is better at processing quantitative or “coordinate” spatial relations (Hellige & Michimata, 1989; Hellige, Laeng, & Michimata, 2010; Kosslyn et al., 1989; for reviews see Jager & Postma, 2003; Laeng, Chabris, & Kosslyn, 2003; Laeng, 2014). Moreover, analogous lateralised specialisation has been proposed for object recognition mechanisms of the brain’s ventral system (Jacobs & Kosslyn, 1994; Laeng, Shah, & Kosslyn, 1999). Thus, the RVF-advantages in category effects could be also attributed to LH’s superiority in “categorical” perceptual processing in general, instead of verbal processing per se (cf. Holmes & Wolff, 2012). In fact, we would like to point out that RVF-advantages in category effects were typically obtained with visual search tasks where a spatial decision about the location of the target had to be made (e.g., Gilbert et al., 2006; Gilbert et al., 2007; Holmes & Wolff, 2012; Roberson et al., 2008; Siok et al., 2009; Witzel & Gegenfurtner, 2011). Although visual search tasks may seem to be more suitable than identification tasks for examining the effects of categories on “perception,” since the target and distracters are presented at the same time and therefore memory components can contribute very little, it seems that these visual search tasks might have left uncontrolled other factors. Remarkably, 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 her/his responses by hitting the key associated with target’s position (i.e., left or right key). Because, as we discussed above, judging the left or right side of a stimulus is a categorical spatial relation judgment, which is also better processed in the LH, we are led to think that the use of such a paradigm may have yielded some residual laterality effects.

Thus, in the present study we attempted to replicate the LH-lateralised category effects in the previous studies (e.g., Gilbert et al., 2006) while controlling the presence of residual categorical processing that may contribute to a LH’s advantage. For this
purpose, we decided to use an identification task combined with the divided visual field method. In the identification task, the participants judged whether the colour of the probe and of the successive target were the same or different. In “different” trials, the target could belong either to the same colour category as the probes (i.e., within-category condition) or to an adjacent colour category (i.e., between-category condition). Category effects can be defined by higher accuracy or shorter response times (RTs) for the between-category condition relative to the within-category condition. Crucially, although the present paradigm requires a memory process, the present identification task avoids the confounding with categorical spatial decisions (e.g., left or right).

In addition, the identification task employed two different lengths of inter-stimulus-intervals (ISI). It can be argued that longer ISI would enhance the laterality effects if the RVF-advantage in category effects resulted from a LH’s superiority in language-related processing (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2007; Roberson et al., 2008; Siok et al., 2009). Specifically, a 5000 ms or longer ISI in the identification task may increase the likelihood of using verbal codes rather than visual codes (Posner & Keele, 1967, but see also Wiggett & Davies, 2008). If the RVF-advantages in category effects were brought by the LH’s advantage in categorical processing (of spatial relations), such lateralised category effects could be also enhanced by longer ISI. Postma, Huntjens, Meuwissen, and Laeng (2006) showed the LH’s advantage in categorical spatial relation processing was enhanced with a 5000 ms ISI compared to a 500 ms ISI, and therefore argued that (spatial) representations could be gradually distorted towards a (spatial) category with accumulating time. Thus, we employed the same variety of the ISI as that of Postma et al. (2006), consisting a 500 ms versus a 5000 ms ISI.

After the identification task, the same participants took part in a colour categorisation task so as to obtain a validation of the categories of the four colours employed in the study. In this colour categorisation task, each of the four colours were presented separately while the participants judged whether the colours belonged to either the ‘blue’ or ‘green’ category.

We also chose to employ Siok et al.’s (2009) colour set with black background\(^1\), since this set has been used in the most recent works that revealed a RVF-advantage in

\(^1\) Since we employed an uniform black background, instead of gray background (Siok et al.,
category effects (Siok et al., 2009; Zhou et al., 2010). In subsequent studies, however, the choice of boundary between blue and green category has been criticised. For example, Brown, Lindsey, and Guckes (2011) conducted a visual search task as Gilbert et al. (2006) did, using their colour set, and showed that the shortest RTs were obtained within the blue category but not at the blue-green categorical boundary. Thus, Brown and colleagues argued that the perceptual uniformity of CIE L*u*v* system may be too coarse to keep the same perceptual distance among all the colour stimuli, and therefore such category effects may be best explained by differences in early stage processing within the visual system (i.e., sensitivities of the colour-opponent channels), instead of differences in colour categories per se (see also Lindsey, Brown, Reijnen, Rich, Kuzmova, & Wolfe, 2010; Witzel & Geggenfurtner, 2013). Although we were aware of the possibility that Siok et al.’s colour set could also have this problem, we did choose this set for the purpose of ensuring a replication of the LH-lateralised category effects. Moreover, we did further analyses by dividing the “within-category” pairs (e.g., Gilbert et al., 2006) into “within-blue” and “within-green” pairs.

Finally, most studies on laterality effects simply assume that the participants will maintain fixation during each trial. Therefore we decide to begin the experiment with an initial training of eye-fixation (see Guzman-Martinez, Leung, Franconeri, Grabowecky, & Suzuki, 2009) so as to improve the reliability of the divided visual field method.

**Method**

**Participants**

Thirty participants were recruited as volunteers for an experiment on colour perception. Participants were recruited from the multi-ethnic participants pool at the University of Oslo, which differed widely in their mother languages. However, in order to ensure that the participants possessed the same categorical structures regarding colours, those participants that showed atypical categorical structures in the colour categorisation task were subsequently excluded from statistical analyses. Each participant received a gift card for 200 Norwegian Crowns (i.e., about 35 U.S. dollars). The Edinburgh Handedness Inventory (Oldfield, 1971) and Farnsworth-Munsell 100-Hue tests were used respectively for screening out left-handers and individuals with

2009), participants’ adaptation levels might be different from those of previous studies.
abnormal colour vision.

Apparatus

All the stimuli were presented on a 21-in. CRT monitor with 75 Hz refreshing rate (EIZO Flex Scan® T961), connected with an Apple MacBook® Pro (2.8 GHz Intel Core 2 Duo). The distance between the CRT monitor and participant’s eyes was fixed to 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 windowless dark room.

Stimuli

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

Identification task. Four colours used in the previous studies (Siok et al., 2009; Zhou et al., 2010) were emulated. Two of them ought to belong to the blue category and the other two to the green (hereafter, the four colours were termed as Blue 1, Blue 2, Green 2, and Green 1 respectively). The CIE xyY coordinates for each colour were measured by means of Datacolor Spyder 4® ELITE (CIE xyY coordinates for each colour are listed on Table 1).

Four colour patches of 2.00° by 2.00° and a hairline fixation cross of 1.00° by 1.00° were created as the stimuli. Each colour patch had one of the 4 colours, and the fixation cross was depicted by the neutral colour.

Colour categorisation task. The same colour patches as the identification 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 “0” key on the 10-key pad (labelled as “S”) led to 5000 ms of 37.5 Hz flickering presentation of the two random-dots circles described in the Stimuli section. The participant was instructed that
flickering random-dots circles would turn into an uniform grey 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 begin the next trial at her/his own pace. The training session had a total of 30 trials and took approximately 5 min.

**Identification task.** After the eye-fixation training, the participant took part in the identification task. The apparatus was identical to that used in the eye-fixation training. Each trial began with 200 ms of a fixation cross across black background. Then two identical colour patches, filled with one of the 4 colours, appeared 3.9° to the left and the right of the centre as probes. The probes were presented both in RVF and LVF simultaneously so that the probes and the successive target in ether RVF or LVF had an identical retinal eccentricity. A blank screen then followed for 300 ms or 4800 ms. After the blank, a fixation cross appeared for 200 ms and then, after a constant ISI of either 500 ms or 5000 ms (depending on the experimental block), the target colour patch was presented 3.9° to the left or right from the centre for 200 ms. The duration of both the probes and target was set at 200 ms since this duration could be within the temporal window required for a saccadic movement in experimental conditions (see Yang, Bucci, & Kapoula, 2002). That is, 200 ms of the duration appeared to be long sufficient for allowing attentional shifts and sampling of the colour information while guaranteeing that the stimuli would disappear before a saccade may land directly on the lateral stimuli. The target could be of the same or adjacent colour of the probes. The participant judged if the colour 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 group of participants hit the left key for the “same” response, and the other half hit the right key instead. 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 after a 1500 ms of inter trial interval. Twenty trials constituted one 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. Another half of the participants performed each of the 10 blocks in reversed order.

For both ISI conditions, 20 practice trials were held before starting each task. Each practice trial had instant feedback, and another 20 trials were repeated if the accuracy rate had not reached a criterion of 65% accuracy.
**Colour categorisation task.** After the identification task, a colour categorisation task took place. In each trial, a colour patch filled with one of the 4 colours that had been used previously appeared in the centre. The participant judged if the colour was either blue or green and gave a manual response. The participants were told that they could choose either type of response as many times as wanted. Each colour patch remained visible until a response had been made (there were no time limits). The participant could take a short break after 20 trials and the whole task was terminated after 100 trials.

**Results**

Eight participants were excluded from the analysis. One of them did not obtain a score above +50 on the Edinburgh Handedness Inventory and therefore was deemed to be a non-righthander (see Dragovik, 2004). Another participant showed a significant positive correlation between accuracies (A’s) and RTs ($r = +.91$), suggesting the presence of a speed-accuracy trade-off. Three participants were screened out due to their abnormal scores on the Farnsworth-Munsell 100-Hue test (see Kinnear & Sahraie, 2002). Another three participants showed atypical categories of colour; i.e., the boundary between blue and green category was not located at between blue 2 and green 2 (see Gilbert et al., 2006), and was located at between blue 1 and blue 2 instead. Thus, the data from the remaining 22 participants were employed for the statistical analyses. Six of them were native Norwegian speakers, five were Lithuanian speakers, two were Chinese and two were native English speakers, and each of the other participants spoke respectively as a native language: Bosnian, French, Italian, Persian, Portuguese, Spanish, and Swedish. 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 ($SD = 9.06$).

**Colour Categorisation Task**

The proportions of trials in which a colour was categorised “blue” were calculated for all of the four colours (Table 1). One-sample $t$-tests on these rates revealed that they were significantly different form the chance level of 50.0%, $p s < .001$. That is, both blue 1 and blue 2 were categorised as “blue” robustly, likewise both green 2 and green 1 were categorised as “green.” These results confirmed that blue 1 and blue 2 indeed belonged to the blue category and likewise green 2 and green 1 belonged to the green category.
Identification Task

**Within-category versus between-category analyses.** As indices of accuracies, $A$’s (Aaronson & Watts, 1987; Pollack, Norman, & Galanter, 1964; Pollack & Norman, 1964) were employed instead of raw accuracy rates (%), so as to exclude possible participants’ response bias (see also Pilling, Wiggett, Özgen, & Davies, 2003). The $A$’s showed significant positive correlation with raw accuracy rates, $r = +.894$, $p < .01$. Averages of each individual’s $A$’s (Panels a and b in Figure 2) and median RTs for correct responses (Panels c and d in Figure 2) were calculated for within- and between-category conditions and for the two different ISI (500 ms or 5000 ms) conditions in each visual field.

The $A$’s were analysed by a three-way analysis of variance (ANOVA), with category (within-category or between-category), visual field (LVF or RVF), and ISI (500 or 5000 ms) as within-participant factors. The main result was a significant effect of category, $F(1, 21) = 29.00$, $MSE = 0.06^{-1}$, $p < .001$, $\eta_p^2 = .58$, reflecting that the $A$ for the between-category conditions was greater than that for the within-category conditions. A main effect of visual field was also significant, $F(1, 21) = 10.46$, $MSE = 0.03^{-1}$, $p = .004$, $\eta_p^2 = .33$, revealing that the $A$ was greater in the LVF than that in the RVF. The interaction between category and visual field was also significant, $F(1, 21) = 6.96$, $MSE = 0.02^{-1}$, $p = .015$, $\eta_p^2 = .25$. Post hoc $t$-tests revealed that the $A$ for the between-category conditions was larger than that for the within-category conditions in the RVF, $t(21) = 3.84$, $p = .001$, $d = 0.60$, as well as in the LVF, $t(21) = 5.67$, $p < .001$, $d = 1.09$.

In order to further examining the interaction between category and visual field, indices for the category effects, defined as $A$’s for between-category conditions minus those for within-category conditions, were calculated for each visual field with collapsing ISI factors. A paired two samples $t$ test revealed that the category effects were significantly greater in the LVF (the difference was .08 in terms of $A$) than in the RVF (the difference was .05 in terms of $A$), $p = .015$, $d = 0.51$. Neither a main effect of ISI, $p = .227$, $\eta_p^2 = .07$, nor any other interactions were significant, $ps > .184$, $\eta_p^2s < .09$.

The median RTs were analysed in an analogous three-way ANOVA as for the
accuracies. In line with the above results, a main effect of category was again significant, $F(1, 21) = 12.78$, $MSE = 9104.76$, $p = .002$, $\eta^2_p = .38$, reflecting that the RTs for the between-category conditions were shorter than those for the within-category conditions. In contrast to the results from accuracies, however, neither an interaction between category and visual field, $p = .834$, $\eta^2_p < .01$, nor any other interactions, $ps > .203$, $\eta^2_ps < .08$ were significant. A significant main effect of ISI was also found, $F(1, 21) = 36.45$, $MSE = 25739.96$, $p < .001$, $\eta^2_p = .63$, revealing that the RTs in the 500 ms ISI condition were shorter than those for 5000 ms ISI, simply reflecting the fact that longer ISI slowed overall RTs. A main effect of visual field failed to be significant, $p = .378$, $\eta^2_p = .04$.

**Analyses of within-blue and within-green trials.** Since the “category effects” reported by previous studies (e.g., Bornstein, 1987; Drivonikou et al., 2007; Gilbert et al., 2006; Roberson et al., 2008; Suegami & Michimata, 2010; Winnawer et al., 2007; Wiggett & Davies, 2008) could also result from a coarse uniformity of the colour stimuli, one should examine the effect of categories by separating “within-category” conditions into a within-blue and a within-green condition (e.g., Brown et al., 2011). Thus, the present study further analysed the results from the identification task with dividing within-category conditions into within-blue and within-green conditions. $A'$s were again employed as indices of accuracies. The $A'$s showed significant positive correlation with raw accuracy rates, $r = +.890$, $p < .01$. As indices of participants’ response biases, $B''$s were also calculated. Averages of each individual’s $A'$s (Panels a and b in Figure 3), averages of each individual’s $B''$s (Panels c and d in Figure 3), and median RTs for correct responses (Panels e and f in Figure 3) were calculated for within-blue, between-category, and within-green conditions and for the two different ISI (500 ms or 5000 ms) conditions in each visual field.

--- Insert Figure 3 about here ---

The $A'$s were analysed by a three-way ANOVA, with category (within-blue, between-category, or within-green), visual field (LVF or RVF), and ISI (500 or 5000 ms) as within-participant factors. Most importantly, a significant effect of category was found, $F(2, 42) = 38.80$, $MSE = 0.01$, $p < .001$, $\eta^2_p = .65$. Sidak’s multiple comparisons revealed that the $A'$ for the between-category conditions was significantly greater than that for the within-blue conditions, $p < .001$, $d = 1.64$. The $A'$ for the within-green conditions, interestingly, was also significantly larger than that for the
within-blue conditions, \( p < .001, d = 1.37 \). The difference between the \( A' \) for the
between-category and within-green conditions was not significant, \( p = .841 \) with
negligible effect size, \( d = 0.14 \). A main effect of visual field was also
significant, \( F(1, 21) = 6.98, MSE = 0.01, p = .015, \eta^2_p = .25 \), indicating that the
\( A' \) was greater in the LVF than in the RVF. Neither a main effect of ISI, \( p =
.162, \eta^2_p = .09 \), nor any interactions between or among all factors, \( ps > .105, \eta^2_ps <
.11 \), were statistically significant.

We also analysed response biases for the identification task, by means of the same	hree-way ANOVA with the \( B'' \)s as a dependent variable. A significant effect of category
was observed\(^2\), \( F(1.00, 21.00) = 11.31, MSE = 0.18, p = .003, \eta^2_p = .35 \). Sidak’s
multiple comparisons revealed that the \( B'' \) for both of the within-blue conditions, \( p
= .014, d = 0.63 \), and that for the within-green conditions, \( p < .001, d = 0.72 \), were
significantly greater than that for the between-category conditions. The difference
between \( B'' \) for the within-blue and within-green conditions was negligible, \( p = .998, d
= 0.02 \). In addition, both effects of visual field, \( p = .179, \eta^2_p = .08 \), and ISI, \( p =
.706, \eta^2_p = .01 \), were not significant. None of the interactions were statistically
significant, \( ps > .379, \eta^2_ps < .04 \).

The median RTs were also analysed by the same three-way ANOVA as for the \( A' \)s
and \( B'' \)s. Only a significant effect of ISI was obtained\(^2\), \( F(1.00, 21.00) = 15.32,
MSE = 65477.04, p = .001, \eta^2_p = .42 \), reflecting that the longer ISI slowed overall
RTs. Neither an effect of category, \( p = .110, \eta^2_p = .11 \), nor an effect of visual field,
\( p = .976, \eta^2_p < .01 \), was significant. Any interactions, moreover, did not reach
significance level, \( ps > .082, \eta^2_ps < .13 \).

**Discussion**

The present study attempted to replicate the LH-lateralised category effects in the
previous studies (e.g., Gilbert et al., 2006; Siok et al., 2009) while controlling the
presence of residual categorical processing that may contribute to a LHI’s advantage. We
employed an identification task, rather than a visual search task, combined with the
divided visual field method. A colour categorisation task was also conducted after the
identification task, for the purpose of assessing the categorical structures of the blue and
green categories, and their categorical border.

\(^2\) The degrees of freedom were adjusted by employing .50 of the epsilon for lower-bound.
Category Structures and Their Border

First of all, the structures of blue and green categories, and the position of their border were critical and therefore should be validated prior to the discussion of the effect of categories.

The results from the colour categorisation task indicated that both blue 1 and blue 2 actually belonged to blue category. Likewise, both green 2 and green 1 were categorised into green category. Thus, it could be argued that the categorical structures for both blue and green category, and their border, were well established in the present study.

One could argue, however, that these two categories could reflect a response bias, instead of the categorical structures. If the participants made “blue” responses to blue 2, for instance, then green 2 could be categorised as “green” so as to keep an equal distribution of the two alternatives (i.e., “blue” or “green” responses). While we accept this possibility, we did emphasise to our participants that there was no limitation in using one of the possible responses. In fact, as mentioned above, three participants were excluded because they revealed, with the present task, atypical colour category structures. For these three participants, blue 1 was categorised as “blue” with 100% rates, whereas blue 2 was categorised “blue” with average 23.3% rates ($SD = 2.89$). Green 2 and green 1, moreover, were categorised as “blue” with 0% rates. These results suggest that the categorisation task did reflect the categorical structures and it was not just an artefact of the response bias.

It could also be argued that the large variety of participants’ mother languages in our sample would be inappropriate for examining the laterality of the category effects. Several studies have reported that people may possess different colour categories in their native languages and consequently this could yield different patterns of category effects (e.g., Roberson, Davies, & Davidoff, 2000; Winawer et al., 2007) as well as of lateralisation (Roberson et al, 2008). Thus, what seems crucial is that all participants possess the same colour categorical structures regardless of being able to use different colour terms. In the present study, the colour categorisation task served for the purpose of validating that the participants did not show atypical categorical structures and that they did share the same colour categories. Moreover, the native languages of all participants (except for three participants) did distinguish between blue and green at the lexical level. The three participants showing atypical categorical structures, furthermore, were native Russian or Turk speakers, whose mother language have different blue
categorical structure(s) from other languages such as English (Özgen & Davies, 1997; Winawer et al., 2007). Thus, we could conclude that the participants in the present study indeed shared the same categorical structures to a satisfactory extent.

**Lateralisation of “Category Effects” on Colour Perception**

For the main results of the identification task, within-category versus between-category analyses showed that the between-category identification was better performed than within-category identification, in terms of accuracies and RTs. These findings seem to be consistent with previous studies showing category effects on colour perception with an identification task (Pilling et al., 2003; Roberson & Davidoff, 2000; Wiggett & Davies, 2008), though without using the divided visual field method. Such between-category advantages, however, were obtained not only in the RVF (i.e., LH) but also in the LVF (i.e., RH). In fact, the results of accuracies revealed that the between-category advantages were greater in the RH rather than the LH. These results provide eloquent evidence against previous finding that “category effects” were lateralised in the LH. Although the present study could not explain how greater between-category advantages in the RH were obtained, the present results, together with those of another recent study showing bilateral category effects on colour perception (Witzel & Gegenfurtner, 2011), argue against the possibility that the category effects are mediated by verbal/language processing (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2007; Roberson et al., 2008; Siok et al., 2009) or “categorical” perceptual processing in general (Holmes & Wolff, 2012).

One possible objection is that the present study failed to replicate the LH-lateralised category effects merely due to the employment of a different task than the typical visual search. This is plausible, but accepting this reasoning also goes against the idea that a LH’s advantage in verbal processing or “categorical” processing underlies the supposed category effects. In fact, a 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 it occurs with a delayed identification task like the present study. Moreover, delayed identification tasks would seem more suitable for obtaining laterality effects than tasks with no memory demands, like detection tasks (Kitterle, Christman, & Hellige, 1990). Thus, the present task should have been more likely to yield laterality on category effects than previously used tasks. However, we failed to observe any sign of LH-lateralised category effects in the current study.
One could also argue that the bilateral category effects in the present study were caused by information-transfer between the two cerebral hemispheres through the corpus callosum. Indeed, several previous studies (Drivonikou et al., 2007; Roberson et al., 2008) reported category effects on colour perception not only in the RVF but also in the LVF. In their studies, such category effects in the LVF were weaker than that in the RVF, and therefore they argued that weaker category effects in the LVF depended on the information transferred from the LH to the RH. In the present study, however, both accuracies and RTs showed that differences in the between-category conditions relative to the within-category conditions (i.e., category effects) in the LVF were comparable to or even greater than those in the RVF. Thus, according to the callosal information-transfer account and on the basis of the present results, one should conclude that the RH is specialised for category effects on colour perception. It seems more plausible to conclude that such category effects are instead bilateral and that, occasionally, depending on unknown factors, one may obtain slight advantages in one of the two hemifields.

“Category Effects” on Colour Perception

The present study, importantly, could cast doubts not only on the LH-lateralised category effects, but also on the category effects per se. We did obtain apparent “category effects,” from within- versus between-category analyses, but such effects could be merely artefacts of dealing within-blue and within-green colours together. If such “category effects” indeed reflected the effects of colour categories on colour perception, then between-category conditions should have an advantage over both within-blue and within-green conditions in the identification task. After separating “within-category” conditions into within-blue and within-green conditions, we did obtain between-category advantages over the within-blue category conditions, in line with the results from within- versus between-category analyses. By the definition of “category effects”, the sensitivities for the between-category colours should be higher than both for the within-blue and within-green colours. Such patterns, however, were not observed in the present study; instead, within-green category identification was well performed comparable to the between-category identification. Thus, as already pointed out in recent studies (e.g., Brown et al., 2011; Witzel & Gegenfurtner, 2011), “category effects” in the present results could be interpreted as effects of the colour set itself, rather than effects of colour categories on colour.
perception. These results, instead, revealed that apparent “category effects,” observed in the analyses with “within-category” versus between-category conditions, did result from low sensitivities for within-blue category conditions. This finding could be compatible with recent works arguing that “category effects” could be attributed to perceptually-unequal structures of the colour stimulus (e.g., Brown et al., 2011).

Although there appeared to be no evidence for the category effects in terms of participants’ perceptual sensitivities, the present results indicated that participants’ response biases could be categorical; participants’ responses to within-category colours (i.e., both of within-blue and within-green) were more conservatively biased relative to those to between-category colours. While very few studies (e.g., Pilling et al., 2003), at least to our knowledge, applied the signal detection theory to examining category effects on colour perception and therefore little has been known about category effects on participants’ response biases, different response biases may also yield apparent “category effects.” One should also note that each cerebral hemisphere could have different response biases (e.g., Robertshaw & Sheldon, 1976) and consequently these biases may be another confounding factor in regard to lateralised category effects. Thus, category effects and their lateralisation should be further examined by means of response biases as well as sensitivities or RTs. For this purpose, an identification task, like the present study, may be more appropriate than a visual search task.

It should be noted that our colour stimuli were presented on black background, instead of grey background (e.g., Siok et al., 2009). As many previous studies showing “category effects” on colour perception (e.g., Drivonikou et al., 2007; Franklin et al., 2008; Gilbert et al., 2006; Roberson & Davidoff, 2000; Roberson et al., 2008; Wiggett & Davies, 2008; Winawer et al., 2009), participants’ adaptation levels were unknown in the present study, and thus one could argue that the rendering process was problematic. While we acknowledge that the present study, as well as the previous studies, has methodological weakness in terms of uniformity of the colour stimuli, the present results still indicate that the sensitivities for colour stimuli would not reflect categorical structures. It should also be mentioned that participants’ response biases, rather than their sensitivities, could produce apparent “category effects.”

Conclusion

The results from the present study provide no evidence for either a LH-lateralised category effects on colour perception or category effects per se. First, the present study
yielded RH-lateralised effects, which is the opposite pattern of lateralisation (e.g., Gilbert et al., 2007; Siok et al., 2009) or non-lateralised (e.g., Witzel & Gegenfurtner, 2011). Taken the previous studies and the present study together, “category effects” can be lateralised to the LH, to the RH, or to the both. Given this, it is premature to localise “category effects” to ether cerebral hemisphere. Second, apparent “category effects,” at least in terms of participants’ sensitivities, may result from lower sensitivities for within-blue colours and do not necessarily reflect an effect of colour categories on colour perception. Instead, the present results are consistent with those of previous studies (e.g., Brown et al., 2011) showing that the “category effects” in the Gilbert et al.’s colour set may have been an artefact of perceptually-unequal colour stimulus. Third, classic “category effects” may be obtained by participants’ response biases, instead of sensitivities or RTs. Such response biases may cause apparent “category effects” and also yield residual laterality effects.

It should be acknowledged that the present study examined only one colour set developed by Siok et al. (2009) with unknown adaptation levels of participants, and therefore could not provide any conclusive argument either for laterality of the category effects or category effects per se. Further studies should be concerned about the perceptual equal equality in the stimuli as well as the presence of participants’ response biases.
References


Kinnear, P. R., & Sahraie, A. New Farnsworth-Munsell 100 hue test norms of normal observers for each year of age 5-22 and for decades 30-70. *British Journal of Ophthalmology, 86*(12), 1408-1411.


<table>
<thead>
<tr>
<th>Colour</th>
<th>x</th>
<th>y</th>
<th>Y</th>
<th>Rate of &quot;blue&quot; response (%)</th>
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<tr>
<td>Blue 1</td>
<td>0.213</td>
<td>0.291</td>
<td>24.571</td>
<td>99.4 (0.4)</td>
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<tr>
<td>Blue 2</td>
<td>0.225</td>
<td>0.328</td>
<td>31.543</td>
<td>87.2 (3.5)</td>
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<tr>
<td>Green 2</td>
<td>0.234</td>
<td>0.368</td>
<td>30.568</td>
<td>1.3 (0.7)</td>
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<tr>
<td>Green 1</td>
<td>0.248</td>
<td>0.411</td>
<td>30.911</td>
<td>0.3 (0.3)</td>
</tr>
<tr>
<td>Fixation cross</td>
<td>0.501</td>
<td>0.369</td>
<td>5.095</td>
<td>--</td>
</tr>
</tbody>
</table>

*Note: Standard errors for the rate of "blue" responses are within parentheses.*
Figure 1. Pictorial description of a trial sequence for the identification task.
Figure 2. $A'$ (two panels on upper row) and RTs (two panels on lower row) for each condition in the identification task. The two panels on the left side show $A'$ (panel a) and RTs (panel c) with 500 ms ISI, whereas the two on the right side show $A'$ (panel b) and RTs (panel d) with 5000 ms ISI. Each error bar shows ±1 standard error.
Figure 3. $A'$s (two panels on upper row), $B''$s (two panels on middle row) and RTs (two panels on lower row) for each condition in the identification task with dividing within-blue and within-green pair. The three panels on the left side show $A'$s (panel a), $B''$ (panel c) and RTs (panel e) with 500 ms ISI, whereas the three on the right side show $A'$s (panel b), $B''$ (panel d) and RTs (panel f) with 5000 ms ISI. Each error bar shows ±1 standard error.