1

2

3

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

6

Takashi Suegami, Samira Aminihajibashi, and Bruno Laeng

Department of Psychology, University of Oslo

9

10

11

12

21

1 **Abstract**

2   The present study aimed to replicate category effects on colour perception and

3 their lateralisation to the left cerebral hemisphere (LH). Previous evidence for

4 lateralisation of colour category effects has been obtained with tasks where a

5 differently-coloured target was searched within a display and participants reported the

6 lateral location of the target. However, a left/right spatial judgment may yield LH-

7 laterality effects per se. Thus, we employed an identification task that does not require a

8 spatial judgment and used the same colour set that previously revealed LH-lateralised

9 category effects. The identification task was better performed with between-category

10 colours than with within-category task both in terms of accuracy and latency, but such

11 category effects were bilateral or RH-lateralised, and no evidence was found for LH-

12 laterality effects. The accuracy scores, moreover, indicated that the category effects

13 derived form low sensitivities for within-blue colours and did not reflect the effects of

14 categorical structures on colour perception. Furthermore, the classic "category effects"

15 were observed in participants' response biases, instead of sensitivities. The present

16 results argue against both the LH-lateralised category effects on colour perception and

17 the existence of colour category effects per se.

18

19 *Key words:*   category effect; colour perception; laterality; identification task

1   *Another look at category effects on colour perception and their left hemispheric*

2   *lateralisation: No evidence from a colour identification task*

3

4   **Introduction**

5   A growing number of studies have shown that discrimination of stimuli from

6   adjacent categories is more accurate or faster than discrimination of those from a same

7   category. Such category effects have been observed in many different modalities or

8   domains, such as speech perception (e.g., Liberman, Harris, Hoffman, & Griffith, 1957),

9   object recognition (e.g., Newell & Bülthoff, 2002) and the perception of colour (e.g.,

10   Bornstein, 1987; Suegami & Michimata, 2010; Winnawer, Witthoft, Frank, Wu, Wade,

11   & Boroditsky, 2007; Wiggett & Davies, 2008). In relation to the latter topic, Gilbert,

12   Regier, Kay, and Ivry (2006) published a seminal study, where they employed a visual

13   search task for one target colour that differed from 11 distracters; the target was detected

14   faster when the target and distracters belonged to different colour categories than when

15   the target was in the same colour category as the distracters. Such category effects,

16   however, were observed only when the target appeared in the right visual field (RVF)

17   but not in the left visual field (LVF), this suggesting a left hemisphere's (LH's)

18   specialisation for the effects of categories on colour perception. Subsequent behavioural

19   studies on colour perception (e.g., Drivonikou et al., 2007; Roberson, Pak, & Hanley,

20   2008) as well as neuroimaging studies (e.g., Siok et al., 2009), or behavioural studies on

21   object recognition (e.g., Gilbert, Regier, Kay, & Ivry, 2007; Holmes & Wolff, 2012)

22   have also obtained stronger category effects in the RVF relative to the LVF, further

23   supporting the conclusion of a special role of the LH.

24   What seems particularly relevant about such a lateralisation pattern is that it may

25   shed light on the neural and cognitive mechanisms behind such category effects.

26   Specifically, the LH is thought to be a centre of verbal or language-related processing

27   (e.g., Ojemann, Ojemann, Lettich, & Berger, 1989), thus a RVF-lateralised category

28   effect could be interpreted as an effect of verbal or language-related processing on our

29   perception and cognition (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al.,

30   2007; Roberson et al., 2008; Siok et al., 2009).

31   It should be noted, however, that some other studies failed to replicate such RVF-

32   lateralised category effects. Witzel and Gegenfurtner (2011), for instance, employed two

33   stimulus sets from Gilbert et al. (2006) and Siok et al. (2009), and carefully controlled

1 the colours, and then found that both colour sets yielded the category effects on colour

2 perception not only in the RVF but in the LVF as well. Such RVF-advantages in

3 category effects could also result from some other uncontrolled factors. Although Witzel

4 and Gegenfurtner (2011) did not refer to what factor(s) caused such bilateral category

5 effects rather than RVF-lateralised effects, several possible factors could be considered.

6 The RVF-advantages in category effects, for example, could reflect another of the LH's

7 key specialization in visual perception. Several studies have shown that the LH has an

8 advantage in processing qualitative or "categorical" spatial relations, whereas the right

9 cerebral hemisphere (RH) is better at processing quantitative or "coordinate" spatial

10 relations (Hellige & Michimata, 1989; Hellige, Laeng, & Michimata, 2010; Kosslyn et

11 al., 1989; for reviews see Jager & Postma, 2003; Laeng, Chabris, & Kosslyn, 2003;

12 Laeng, 2014). Moreover, analogous lateralised specialisation has been proposed for

13 object recognition mechanisms of the brain's ventral system (Jacobs & Kosslyn, 1994;

14 Laeng, Shah, & Kosslyn, 1999). Thus, the RVF-advantages in category effects could be

15 also attributed to LH's superiority in "categorical" perceptual processing in general,

16 instead of verbal processing per se (cf. Holmes & Wolff, 2012). In fact, we would like

17 to point out that RVF-advantages in category effects were typically obtained with visual

18 search tasks where a spatial decision about the location of the target had to be made

19 (e.g., Gilbert et al., 2006; Gilbert et al., 2007; Holmes & Wolff, 2012; Roberson et al.,

20 2008; Siok et al., 2009; Witzel & Gegenfurtner, 2011). Although visual search tasks

21 may seem to be more suitable than identification tasks for examining the effects of

22 categories on "perception," since the target and distracters are presented at the same

23 time and therefore memory components can contribute very little, it seems that these

24 visual search tasks might have left uncontrolled other factors. Remarkably, in all of the

25 visual search tasks we reviewed, participants were asked to judge which side (i.e., left

26 or right) did the target appear in, and made her/his responses by hitting the key

27 associated with target's position (i.e., left or right key). Because, as we discussed above,

28 judging the left or right side of a stimulus is a categorical spatial relation judgment,

29 which is also better processed in the LH, we are led to think that the use of such a

30 paradigm may have yielded some residual laterality effects.

31   Thus, in the present study we attempted to replicate the LH-lateralised category

32 effects in the previous studies (e.g., Gilbert et al., 2006) while controlling the presence

33 of residual categorical processing that may contribute to a LH's advantage. For this

1   purpose, we decided to use an identification task combined with the divided visual field

2   method. In the identification task, the participants judged whether the colour of the

3   probe and of the successive target were the same or different. In "different" trials, the

4   target could belong either to the same colour category as the probes (i.e., within-

5   category condition) or to an adjacent colour category (i.e., between-category condition).

6   Category effects can be defined by higher accuracy or shorter response times (RTs) for

7   the between-category condition relative to the within-category condition. Crucially,

8   although the present paradigm requires a memory process, the present identification

9   task avoids the confounding with categorical spatial decisions (e.g., left or right).

10   In addition, the identification task employed two different lengths of inter-stimulus-

11   intervals (ISI). It can be argued that longer ISI would enhance the laterality effects if the

12   RVF-advantage in category effects resulted from a LH's superiority in language-related

13   processing (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2007; Roberson

14   et al., 2008; Siok et al., 2009). Specifically, a 5000 ms or longer ISI in the identification

15   task may increase the likelihood of using verbal codes rather than visual codes (Posner

16   & Keele, 1967, but see also Wiggett & Davies, 2008). If the RVF-advantages in

17   category effects were brought by the LH's advantage in categorical processing (of

18   spatial relations), such lateralised category effects could be also enhanced by longer ISI.

19   Postma, Huntjens, Meuwissen, and Laeng (2006) showed the LH's advantage in

20   categorical spatial relation processing was enhanced with a 5000 ms ISI compared to a

21   500 ms ISI, and therefore argued that (spatial) representations could be gradually

22   distorted towards a (spatial) category with accumulating time. Thus, we employed the

23   same variety of the ISI as that of Postma et al. (2006), consisting a 500 ms versus a

24   5000 ms ISI.

25   After the identification task, the same participants took part in a colour

26   categorisation task so as to obtain a validation of the categories of the four colours

27   employed in the study. In this colour categorisation task, each of the four colours were

28   presented separately while the participants judged whether the colours belonged to

29   either the 'blue' or 'green' category.

30   We also chose to employ Siok et al.'s (2009) colour set with black background[1],

31   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.,

1   category effects (Siok et al., 2009; Zhou et al., 2010). In subsequent studies, however,

2   the choice of boundary between blue and green category has been criticised. For

3   example, Brown, Lindsey, and Guckes (2011) conducted a visual search task as Gilbert

4   et al. (2006) did, using their colour set, and showed that the shortest RTs were obtained

5   within the blue category but not at the blue-green categorical boundary. Thus, Brown

6   and colleagues argued that the perceptual uniformity of CIE L*u*v* system may be too

7   coarse to keep the same perceptual distance among all the colour stimuli, and therefore

8   such category effects may be best explained by differences in early stage processing

9   within the visual system (i.e., sensitivities of the colour-opponent channels), instead of

10   differences in colour categories per se (see also Lindsey, Brown, Reijnen, Rich,

11   Kuzmova, & Wolfe, 2010; Witzel & Gegenfurtner, 2013). Although we were aware of

12   the possibility that Siok et al.'s colour set could also have this problem, we did choose

13   this set for the purpose of ensuring a replication of the LH-lateralised category effects.

14   Moreover, we did further analyses by dividing the "within-category" pairs (e.g., Gilbert

15   et al., 2006) into "within-blue" and "within-green" pairs.

16   Finally, most studies on laterality effects simply assume that the participants will

17   maintain fixation during each trial. Therefore we decide to begin the experiment with an

18   initial training of eye-fixation (see Guzman-Martinez, Leung, Franconeri, Grabowecky,

19   & Suzuki, 2009) so as to improve the reliability of the divided visual field method.

20

21   **Method**

22   **Participants**

23   Thirty participants were recruited as volunteers for an experiment on colour

24   perception. Participants were recruited from the multi-ethnic participants pool at the

25   University of Oslo, which differed widely in their mother languages. However, in order

26   to ensure that the participants possessed the same categorical structures regarding

27   colours, those participants that showed atypical categorical structures in the colour

28   categorisation task were subsequently excluded from statistical analyses. Each

29   participant received a gift card for 200 Norwegian Crowns (i.e., about 35 U.S. dollars).

30   The Edinburgh Handedness Inventory (Oldfield, 1971) and Farnsworth-Munsell 100-

31   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.

1   abnormal colour vision.

2   **Apparatus**

3   All the stimuli were presented on a 21-in. CRT monitor with 75 Hz refreshing rate

4   (EIZO Flex Scan® T961), connected with an Apple MacBook® Pro (2.8 GHz Intel Core

5   2 Duo). The distance between the CRT monitor and participant's eyes was fixed to 85.5

6   cm. The experiment was operated by MATLAB® 2008b with Psychophysics Toolbox 3

7   (Brainard, 1997). A 10-key pad was connected to the computer and served as a response

8   console. Both the training and two main tasks were conducted in a windowless dark

9   room.

10   **Stimuli**

11   **Eye-fixation training.** The stimuli in the original training task by Guzman-Martinez

12   et al. (2009) were closely duplicated. Two circles of 17.27° (visual angle) diameter,

13   filled with black and white random-dots pattern or its contrast-reversed pattern, were

14   created. Each of the two circles had 1.00° by 1.00° of a black hairline fixation cross

15   at its centre.

16   **Identification task.** Four colours used in the previous studies (Siok et al., 2009;

17   Zhou et al., 2010) were emulated. Two of them ought to belong to the blue category and

18   the other two to the green (hereafter, the four colours were termed as *Blue 1*, *Blue 2*,

19   *Green 2*, and *Green 1* respectively). The CIE xyY coordinates for each colour were

20   measured by means of Datacolor Spyder 4® ELITE (CIE xyY coordinates for each

21   colour are listed on Table 1).

22   Four colour patches of 2.00° by 2.00° and a hairline fixation cross of 1.00° by

23   1.00° were created as the stimuli. Each colour patch had one of the 4 colours, and the

24   fixation cross was depicted by the neutral colour.

25   --- Insert Figure 1 about here ---

26   **Colour categorisation task.** The same colour patches as the identification task were

27   employed as the stimuli.

28   **Procedure**

29   **Eye-fixation training.** The procedure was based on the original work by Guzman-

30   Martinez et al. (2009). Each participant was seated in front of the CRT monitor, and

31   fixed her/his eyes into the fixation cross. Participant's hitting "0" key on the 10-key pad

32   (labelled as "S") led to 5000 ms of 37.5 Hz flickering presentation of the two random-

33   dots circles described in the *Stimuli* section. The participant was instructed that

1   flickering random-dots circles would turn into an uniform grey circle if her/his eyes

2   were fixed into the fixation cross. After 5000 ms of flickering presentation, the

3   participant could take a short break and was allowed to begin the next trial at her/his

4   own pace. The training session had a total of 30 trials and took approximately 5 min.

5   **Identification task.** After the eye-fixation training, the participant took part in the

6   identification task. The apparatus was identical to that used in the eye-fixation training.

7   Each trial began with 200 ms of a fixation cross across black background. Then two

8   identical colour patches, filled with one of the 4 colours, appeared 3.9° to the left and

9   the right of the centre as probes. The probes were presented both in RVF and LVF

10   simultaneously so that the probes and the successive target in ether RVF or LVF had an

11   identical retinal eccentricity. A blank screen then followed for 300 ms or 4800 ms. After

12   the blank, a fixation cross appeared for 200 ms and then, after a constant ISI of either

13   500 ms or 5000 ms (depending on the experimental block), the target colour patch was

14   presented 3.9° to the left or right from the centre for 200 ms. The duration of both the

15   probes and target was set at 200 ms since this duration could be within the temporal

16   window required for a saccadic movement in experimental conditions (see Yang, Bucci,

17   & Kapoula, 2002). That is, 200 ms of the duration appeared to be long sufficient for

18   allowing attentional shifts and sampling of the colour information while guaranteeing

19   that the stimuli would disappear before a saccade may land directly on the lateral

20   stimuli. The target could be of the same or adjacent colour of the probes. The participant

21   judged if the colour of the target was identical to that of the probes by hitting the left or

22   right key as quickly as s/he could. A half of the group of participants hit the left key for

23   the "same" response, and the other half hit the right key instead. RTs were recorded

24   from the onset of the target. If no response occurred until 2000 ms had elapsed from the

25   onset, the trial was classified as an error. After a response had been made or 2000 ms

26   had elapsed, the next trial started after a 1500 ms of inter trial interval. Twenty trials

27   constituted one experimental block. The length of the ISI was manipulated between the

28   experimental blocks. Half of the participants performed 10 blocks with 500 ms of ISI

29   first, and then another 10 blocks with 5000 ms of ISI. Another half of the participants

30   performed each of the 10 blocks in reversed order.

31   For both ISI conditions, 20 practice trials were held before starting each task. Each

32   practice trial had instant feedback, and another 20 trials were repeated if the accuracy

33   rate had not reached a criterion of 65% accuracy.

1   **Colour categorisation task.** After the identification task, a colour categorisation

2   task took place. In each trial, a colour patch filled with one of the 4 colours that had

3   been used previously appeared in the centre. The participant judged if the colour was

4   either blue or green and gave a manual response. The participants were told that they

5   could choose either type of response as many times as wanted. Each colour patch

6   remained visible until a response had been made (there were no time limits). The

7   participant could take a short break after 20 trials and the whole task was terminated

8   after 100 trials.

9   <div align="center">**Results**</div>

10   Eight participants were excluded from the analysis. One of them did not obtain a

11   score above +50 on the Edinburgh Handedness Inventory and therefore was deemed to

12   be a non-righthander (see Dragovik, 2004). Another participant showed a significant

13   positive correlation between accuracies (A´s) and RTs ($r = +.91$), suggesting the

14   presence of a speed-accuracy trade-off. Three participants were screened out due to

15   their abnormal scores on the Farnsworth-Munsell 100-Hue test (see Kinnear & Sahraie,

16   2002). Another three participants showed atypical categories of colour; i.e., the

17   boundary between blue and green category was not located at between *blue 2* and *green*

18   *2* (see Gilbert et al., 2006), and was located at between *blue* 1 and *blue 2* instead. Thus,

19   the data from the remaining 22 participants were employed for the statistical analyses.

20   Six of them were native Norwegian speakers, five were Lithuanian speakers, two were

21   Chinese and two were native English speakers, and each of the other participants spoke

22   respectively as a native language: Bosnian, French, Italian, Persian, Portuguese, Spanish,

23   and Swedish. Fifteen of them were female, and the mean age of the participants was

24   27.76 years ($SD = 5.32$). The mean score on the Edinburgh Handedness Inventory was

25   91.57 ($SD = 9.06$).

26   **Colour Categorisation Task**

27   The proportions of trials in which a colour was categorised "blue" were calculated

28   for all of the four colours (Table 1). One-sample *t*-tests on these rates revealed that they

29   were significantly different form the chance level of 50.0%, $ps < .001$. That is, both

30   *blue 1* and *blue 2* were categorised as "blue" robustly, likewise both *green 2* and *green 1*

31   were categorised as "green." These results confirmed that *blue 1* and *blue 2* indeed

32   belonged to the blue category and likewise *green 2* and *green 1* belonged to the green

33   category.

1   --- Insert Table 1 about here ---

2   **Identification Task**

3   **Within-category versus between-category analyses.** As indices of accuracies, A's

4   (Aaronson & Watts, 1987; Pollack, Norman, & Galanter, 1964; Pollack & Norman,

5   1964) were employed instead of raw accuracy rates (%), so as to exclude possible

6   participants' response bias (see also Pilling, Wiggett, Özgen, & Davies, 2003). The A's

7   showed significant positive correlation with raw accuracy rates, $r = +.894$, $p < .01$.

8   Averages of each individual's A's (Panels a and b in Figure 2) and median RTs for

9   correct responses (Panels c and d in Figure 2) were calculated for within- and between-

10   category conditions and for the two different ISI (500 ms or 5000 ms) conditions in

11   each visual field.

12   --- Insert Figure 2 about here ---

13   The A's were analysed by a three-way analysis of variance (ANOVA), with category

14   (within-category or between-category), visual field (LVF or RVF), and ISI (500 or 5000

15   ms) as within-participant factors. The main result was a significant effect of category,

16   $F(1, 21) = 29.00$, $MSE = 0.06^{-1}$, $p < .001$, $\eta_p^2 = .58$, reflecting that the A' for

17   the between-category conditions was greater than that for the within-category

18   conditions. A main effect of visual field was also significant, $F(1, 21) = 10.46$,

19   $MSE = 0.03^{-1}$, $p = .004$, $\eta_p^2 = .33$, revealing that the A' was greater in the LVF

20   than that in the RVF. The interaction between category and visual field was also

21   significant, $F(1, 21) = 6.96$, $MSE = 0.02^{-1}$, $p = .015$, $\eta_p^2 = .25$. Post hoc t-tests

22   revealed that the A' for the between-category conditions was larger than that for the

23   within-category conditions in the RVF, $t(21) = 3.84$, $p = .001$, $d = 0.60$, as well

24   as in the LVF, $t(21) = 5.67$, $p < .001$, $d = 1.09$.

25   In order to further examining the interaction between category and visual field,

26   indices for the category effects, defined as A's for between-category conditions minus

27   those for within-category conditions, were calculated for each visual field with

28   collapsing ISI factors. A paired two samples t test revealed that the category effects

29   were significantly greater in the LVF (the difference was .08 in terms of A') than in the

30   RVF (the difference was .05 in terms of A'), $p = .015$, $d = 0.51$. Neither a main effect of

31   ISI, $p = .227$, $\eta_p^2 = .07$, nor any other interactions were significant, $ps >$

32   $.184$, η_p^2s $< .09$.

33   The median RTs were analysed in an analogous three-way ANOVA as for the

1 accuracies. In line with the above results, a main effect of category was again

2 significant, $F(1, 21) = 12.78$, $MSE = 9104.76$, $p = .002$, $\eta_p^2 = .38$, reflecting

3 that the RTs for the between-category conditions were shorter than those for the within-

4 category conditions. In contrast to the results from accuracies, however, neither an

5 interaction between category and visual field, $p = .834$, $\eta_p^2 < .01$, nor any other

6 interactions, $ps > .203$, $\eta_p^2 s < .08$ were significant. A significant main effect of ISI

7 was also found, $F(1, 21) = 36.45$, $MSE = 25739.96$, $p < .001$, $\eta_p^2 = .63$,

8 revealing that the RTs in the 500 ms ISI condition were shorter than those for 5000 ms

9 ISI, simply reflecting the fact that longer ISI slowed overall RTs. A main effect of visual

10 field failed to be significant, $p = .378$, $\eta_p^2 = .04$.

11   **Analyses of within-blue and within-green trials.** Since the "category effects"

12 reported by previous studies (e.g., Bornstein, 1987; Drivonikou et al., 2007; Gilbert et

13 al., 2006; Roberson et al., 2008; Suegami & Michimata, 2010; Winnawer et al., 2007;

14 Wiggett & Davies, 2008) could also result from a coarse uniformity of the colour

15 stimuli, one should examine the effect of categories by separating "within-category"

16 conditions into a within-blue and a within-green condition (e.g., Brown et al., 2011).

17 Thus, the present study further analysed the results from the identification task with

18 dividing within-category conditions into within-blue and within-green conditions. *A´*s

19 were again employed as indices of accuracies. The *A´*s showed significant positive

20 correlation with raw accuracy rates, $r = +.890$, $p < .01$. As indices of participants'

21 response biases, *B"*s were also calculated. Averages of each individual's *A´*s (Panels a

22 and b in Figure 3), averages of each individual's *B"*s (Panels c and d in Figure 3), and

23 median RTs for correct responses (Panels e and f in Figure 3) were calculated for

24 within-blue, between-category, and within-green conditions and for the two different ISI

25 (500 ms or 5000 ms) conditions in each visual field.

26   --- Insert Figure 3 about here ---

27   The *A´*s were analysed by a three-way ANOVA, with category (within-blue,

28 between-category, or within-green), visual field (LVF or RVF), and ISI (500 or 5000

29 ms) as within-participant factors. Most importantly, a significant effect of category was

30 found, $F(2, 42) = 38.80$, $MSE = 0.01$, $p < .001$, $\eta_p^2 = .65$. Sidak's multiple

31 comparisons revealed that the *A'* for the between-category conditions was significantly

32 greater than that for the within-blue conditions, $p < .001$, $d = 1.64$. The *A'* for the

33 within-green conditions, interestingly, was also significantly larger than that for the

1 within-blue conditions, $p < .001$, $d = 1.37$. The difference between the A' for the

2 between-category and within-green conditions was not significant, $p = .841$ with

3 negligible effect size, $d = 0.14$. A main effect of visual field was also

4 significant, $F(1, 21) = 6.98$, $MSE = 0.01$, $p = .015$, $\eta_p^2 = .25$, indicating that the

5 A' was greater in the LVF than in the RVF. Neither a main effect of ISI, $p =$

6 $.162$, $\eta_p^2 = .09$, nor any interactions between or among all factors, $ps > .105$, η_p^2s $<$

7 $.11$, were statistically significant.

8   We also analysed response biases for the identification task, by means of the same

9 three-way ANOVA with the B''s as a dependent variable. A significant effect of category

10 was observed[2], $F(1.00, 21.00) = 11.31$, $MSE = 0.18$, $p = .003$, $\eta_p^2 = .35$. Sidak's

11 multiple comparisons revealed that the B'' for both of the within-blue conditions, p

12 $= .014$, $d = 0.63$, and that for the within-green conditions, $p < .001$, $d = 0.72$, were

13 significantly greater than that for the between-category conditions. The difference

14 between B'' for the within-blue and within-green conditions was negligible, $p = .998$, d

15 $= 0.02$. In addition, both effects of visual field, $p = .179$, $\eta_p^2 = .08$, and ISI, $p =$

16 $.706$, $\eta_p^2 = .01$, were not significant. None of the interactions were statistically

17 significant, $ps > .379$, η_p^2s $< .04$.

18   The median RTs were also analysed by the same three-way ANOVA as for the A's

19 and B''s. Only a significant effect of ISI was obtained[2], $F(1.00, 21.00) = 15.32$,

20 $MSE = 65477.04$, $p = .001$, $\eta_p^2 = .42$, reflecting that the longer ISI slowed overall

21 RTs. Neither an effect of category, $p = .110$, $\eta_p^2 = .11$, nor an effect of visual field,

22 $p = .976$, $\eta_p^2 < .01$, was significant. Any interactions, moreover, did not reach

23 significance level, $ps > .082$, η_p^2s $< .13$.

24   **Discussion**

25   The present study attempted to replicate the LH-lateralised category effects in the

26 previous studies (e.g., Gilbert et al., 2006; Siok et al., 2009) while controlling the

27 presence of residual categorical processing that may contribute to a LH's advantage. We

28 employed an identification task, rather than a visual search task, combined with the

29 divided visual field method. A colour categorisation task was also conducted after the

30 identification task, for the purpose of assessing the categorical structures of the blue and

31 green categories, and their categorical border.

---

[2] The degrees of freedom were adjusted by employing .50 of the epsilon for lower-bound.

1 **Category Structures and Their Border**

2 First of all, the structures of blue and green categories, and the position of their

3 border were critical and therefore should be validated prior to the discussion of the

4 effect of categories.

5 The results from the colour categorisation task indicated that both *blue 1* and *blue 2*

6 actually belonged to blue category. Likewise, both *green 2* and *green 1* were categorised

7 into green category. Thus, it could be argued that the categorical structures for both blue

8 and green category, and their border, were well established in the present study.

9 One could argue, however, that these two categories could reflect a response bias,

10 instead of the categorical structures. If the participants made "blue" responses to *blue 2*,

11 for instance, then *green 2* could be categorised as "green" so as to keep an equal

12 distribution of the two alternatives (i.e., "blue" or "green" responses). While we accept

13 this possibility, we did emphasise to our participants that there was no limitation in

14 using one of the possible responses. In fact, as mentioned above, three participants were

15 excluded because they revealed, with the present task, atypical colour category

16 structures. For these three participants, *blue 1* was categorised as "blue" with 100%

17 rates, whereas *blue 2* was categorised "blue" with average 23.3% rates ($SD = 2.89$).

18 *Green 2* and *green 1*, moreover, were categorised as "blue" with 0% rates. These results

19 suggest that the categorisation task did reflect the categorical structures and it was not

20 just an artefact of the response bias.

21 It could also be argued that the large variety of participants' mother languages in our

22 sample would be inappropriate for examining the laterality of the category effects.

23 Several studies have reported that people may possess different colour categories in

24 their native languages and consequently this could yield different patterns of category

25 effects (e.g., Roberson, Davies, & Davidoff, 2000; Winawer et al., 2007) as well as of

26 lateralisation (Roberson et al, 2008). Thus, what seems crucial is that all participants

27 possess the same colour categorical structures regardless of being able to use different

28 colour terms. In the present study, the colour categorisation task served for the purpose

29 of validating that the participants did not show atypical categorical structures and that

30 they did share the same colour categories. Moreover, the native languages of all

31 participants (except for three participants) did distinguish between blue and green at the

32 lexical level. The three participants showing atypical categorical structures, furthermore,

33 were native Russian or Turk speakers, whose mother language have different blue

1 categorical structure(s) from other languages such as English (Özgen & Davies, 1997;

2 Winawer et al., 2007). Thus, we could conclude that the participants in the present study

3 indeed shared the same categorical structures to a satisfactory extent.

4 **Lateralisation of "Category Effects" on Colour Perception**

5 For the main results of the identification task, within-category versus between-

6 category analyses showed that the between-category identification was better performed

7 than within-category identification, in terms of accuracies and RTs. These findings seem

8 to be consistent with previous studies showing category effects on colour perception

9 with an identification task (Pilling et al., 2003; Roberson & Davidoff, 2000; Wiggett &

10 Davies, 2008), though without using the divided visual field method. Such between-

11 category advantages, however, were obtained not only in the RVF (i.e., LH) but also in

12 the LVF (i.e., RH). In fact, the results of accuracies revealed that the between-category

13 advantages were greater in the RH rather than the LH. These results provide eloquent

14 evidence against previous finding that "category effects" were lateralised in the LH.

15 Although the present study could not explain how greater between-category advantages

16 in the RH were obtained, the present results, together with those of another recent study

17 showing bilateral category effects on colour perception (Witzel & Gegenfurtner, 2011),

18 argue against the possibility that the category effects are mediated by verbal/language

19 processing (Drivonikou et al., 2007; Gilbert et al., 2006; Gilbert et al., 2007; Roberson

20 et al., 2008; Siok et al., 2009) or "categorical" perceptual processing in general (Holmes

21 & Wolff, 2012).

22 One possible objection is that the present study failed to replicate the LH-lateralised

23 category effects merely due to the employment of a different task than the typical visual

24 search. This is plausible, but accepting this reasoning also goes against the idea that a

25 LH's advantage in verbal processing or "categorical" processing underlies the supposed

26 category effects. In fact, a LH's advantage in both verbal (Posner & Keele, 1967) and

27 categorical spatial processing (Postma, et al., 2006) is typically enhanced with longer

28 time intervals, as it occurs with a delayed identification task like the present study.

29 Moreover, delayed identification tasks would seem more suitable for obtaining laterality

30 effects than tasks with no memory demands, like detection tasks (Kitterle, Christman, &

31 Hellige, 1990). Thus, the present task should have been more likely to yield laterality on

32 category effects than previously used tasks. However, we failed to observe any sign of

33 LH-lateralised category effects in the current study.

1   One could also argue that the bilateral category effects in the present study were

2   caused by information-transfer between the two cerebral hemispheres through the

3   corpus callosum. Indeed, several previous studies (Drivonikou et al, 2007; Roberson et

4   al, 2008) reported category effects on colour perception not only in the RVF but also in

5   the LVF. In their studies, such category effects in the LVF were weaker than that in the

6   RVF, and therefore they argued that weaker category effects in the LVF depended on the

7   information transferred from the LH to the RH. In the present study, however, both

8   accuracies and RTs showed that differences in the between-category conditions relative

9   to the within-category conditions (i.e., category effects) in the LVF were comparable to

10   or even greater than those in the RVF. Thus, according to the callosal information-

11   transfer account and on the basis of the present results, one should conclude that the RH

12   is specialised for category effects on colour perception. It seems more plausible to

13   conclude that such category effects are instead bilateral and that, occasionally,

14   depending on unknown factors, one may obtain slight advantages in one of the two

15   hemifields.

16   **"Category Effects" on Colour Perception**

17   The present study, importantly, could cast doubts not only on the LH-lateralised

18   category effects, but also on the category effects per se. We did obtain apparent

19   "category effects," from within- versus between-category analyses, but such effects

20   could be merely artefacts of dealing within-blue and within-green colours together. If

21   such "category effects" indeed reflected the effects of colour categories on colour

22   perception, then between-category conditions should have an advantage over both

23   within-blue and within-green conditions in the identification task.

24   After separating "within-category" conditions into within-blue and within-green

25   conditions, we did obtain between-category advantages over the within-blue category

26   conditions, in line with the results from within- versus between-category analyses. By

27   the definition of "category effects", the sensitivities for the between-category colours

28   should be higher than both for the within-blue and within-green colours. Such patterns,

29   however, were not observed in the present study; instead, within-green category

30   identification was well performed comparable to the between-category identification.

31   Thus, as already pointed out in recent studies (e.g., Brown et al., 2011; Witzel &

32   Gegenfurtner, 2011), "category effects" in the present results could be interpreted as

33   effects of the colour set itself, rather than effects of colour categories on colour

1   perception. These results, instead, revealed that apparent "category effects," observed in

2   the analyses with "within-category" versus between-category conditions, did result from

3   low sensitivities for within-blue category conditions. This finding could be compatible

4   with recent works arguing that "category effects" could be attributed to perceptually-

5   unequal structures of the colour stimulus (e.g., Brown et al., 2011).

6   Although there appeared to be no evidence for the category effects in terms of

7   participants' perceptual sensitivities, the present results indicated that participants'

8   response biases could be categorical; participants' responses to within-category colours

9   (i.e., both of within-blue and within-green) were more conservatively biased relative to

10   those to between-category colours. While very few studies (e.g., Pilling et al., 2003), at

11   least to our knowledge, applied the signal detection theory to examining category

12   effects on colour perception and therefore little has been known about category effects

13   on participants' response biases, different response biases may also yield apparent

14   "category effects." One should also note that each cerebral hemisphere could have

15   different response biases (e.g., Robertshaw & Sheldon, 1976) and consequently these

16   biases may be another confounding factor in regard to lateralised category effects. Thus,

17   category effects and their lateralisation should be further examined by means of

18   response biases as well as sensitivities or RTs. For this purpose, an identification task,

19   like the present study, may be more appropriate than a visual search task.

20   It should be noted that our colour stimuli were presented on black background,

21   instead of grey background (e.g., Siok et al., 2009). As many previous studies showing

22   "category effects" on colour perception (e.g., Drivonikou et al., 2007; Franklin et al.,

23   2008; Gilbert et al., 2006; Roberson & Davidoff, 2000; Roberson et al., 2008; Wiggett

24   & Davies, 2008; Winawer et al., 2009), participants' adaptation levels were unknown in

25   the present study, and thus one could argue that the rendering process was problematic.

26   While we acknowledge that the present study, as well as the previous studies, has

27   methodological weakness in terms of uniformity of the colour stimuli, the present

28   results still indicate that the sensitivities for colour stimuli would not reflect categorical

29   structures. It should also be mentioned that participants' response biases, rather than

30   their sensitivities, could produce apparent "category effects."

31   **Conclusion**

32   The results from the present study provide no evidence for either a LH-lateralised

33   category effects on colour perception or category effects per se. First, the present study

1 yielded RH-lateralised effects, which is the opposite pattern of lateralisation (e.g.,

2 Gilbert et al., 2007; Siok et al., 2009) or non-lateralised (e.g., Witzel & Gegenfurtner,

3 2011). Taken the previous studies and the present study together, "category effects" can

4 be lateralised to the LH, to the RH, or to the both. Given this, it is premature to localise

5 "category effects" to ether cerebral hemisphere. Second, apparent "category effects," at

6 least in terms of participants' sensitivities, may result from lower sensitivities for

7 within-blue colours and do not necessarily reflect an effect of colour categories on

8 colour perception. Instead, the present results are consistent with those of previous

9 studies (e.g., Brown et al., 2011) showing that the "category effects" in the Gilbert et

10 al.'s colour set may have been an artefact of perceptually-unequal colour stimulus.

11 Third, classic "category effects" may be obtained by participants' response biases,

12 instead of sensitivities or RTs. Such response biases may cause apparent "category

13 effects" and also yield residual laterality effects.

14   It should be acknowledged that the present study examined only one colour set

15 developed by Siok et al. (2009) with unknown adaptation levels of participants, and

16 therefore could not provide any conclusive argument either for laterality of the category

17 effects or category effects per se. Further studies should be concerned about the

18 perceptual equal equality in the stimuli as well as the presence of participants' response

19 biases.

20

21

References

Aaronson, D., & Watts, B. (1987). Extensions of Grier's computational formulas for *A´* and *B´´* to bellow-chance performance. *Psychological Bulletin, 102*(3), 439-442.

Brainard, D. H. (1997). The psychophysics toolbox, *Spatial Vision, 10*(4), 433-436.

Brown, A. M., Lindsey, D. T., & Guckes, K. M. (2011). Color names, color categories, and color-cued visual search: Sometimes, color perception is not categorical. *Journal of Vision, 11*(12), 1-21.

Dragovic, M. (2004). Categorization and validation of handedness using latent class analysis. Acta *Neuropsychiatrica, 16*(4), 212-218.

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

Franklin, A, Drivonikou, G., Bevis, L., Davies, I. R. L., 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 Science of the United States of America*, *105*, 3221-3225.

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 Science of the United States of America, 103*, 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*, 91-98.

Guzman-Martinez, E., Leung, P., Franconeri, S., Grabowecky, M., & Suzuki, S. (2009). Rapid eye-fixation training without eyetracking. *Psychonomic Bulletin & Review, 16*(3), 491-496.

Hellige, J. B., Laeng, B., & Michimata, C. (2010). Processing asymmetries in the visual system. In K. Hugdahl & W. René (Eds.), *The two halves of the brain: information processing in the cerebral hemispheres* (pp. 379-415). Cambridge, MA: MIT Press.

Hellige, J. B., & Michimata, C. (1989). Categorization versus distance: Hemispheric differences for processing spatial information. *Memory & Cognition, 17*(6), 770-776.

Holmes, K. J., & Wolff, P. (2012). Does categorical perception in the left hemisphere depend on language? *Journal of Experimental Psychology: General, 141*(3), 439-443.

Jager, G., & Postma, A. (2003). On the hemispheric specialization for categorical and coordinate spatial relations: a review of the current evidence. *Neuropsychologia, 41*(4), 504-515.

Jacobs, R.A., and Kosslyn, S.M. (1994). Encoding shape and spatial relations: The role of receptive field size in coordinating complementary representations. *Cognitive Science, 18*, 361-386.

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.

Kitterle, F. L., Christman, S., & Hellige, J. B. (1990). Hemispheric-differences are found in the identification, but not the detection, of low versus high spatial-frequencies. *Perception & Psychophysics, 48(4)*, 297-306.

Kosslyn, S. M., Koenig, O., Barrett, A., Cave, C. B., Tang, J., & Gabrieli, D. E. (1989). Evidence for 2 types of spatial representations— Hemispheric-specialization for categorical and coordinate relations. *Journal of Experimental Psychology: Human Perception and Performance, 15*(4), 723-735.

Laeng, B. (2014). Representation of spatial relations. In K. Ochsner and S.M. Kosslyn (Editors), *The Oxford Handbook of Cognitive Neuroscience, Volume 1, Core Topics,* pp. 28-59. Oxford: Oxford University Press.

Laeng, B., Chabris, C. F., & Kosslyn, S. M. (2003). Asymmetries in encoding spatial relations. In K. Hugdahl & R. Davidson (Eds.), *The asymmetrical Brain* (pp. 303-339). Cambridge, MA: The MIT press.

Laeng, B., Shah, J., and Kosslyn, S.M. (1999). Identifying objects in conventional and contorted poses: Contributions of hemisphere-specific mechanisms. *Cognition, 70*(1), 53-85.

Laeng, B., Shah, J., and Kosslyn, S.M. (1999). Identifying objects in conventional and contorted poses: Contributions of hemisphere-specific mechanisms. *Cognition, 70*(1), 53-85.

Lindsay, D. T., Brown, A. M., Reijnen, E., Rich, A., N., Kuzmova, J. I., & Wolfe, J. M. (2010). Color channels, not color appearance or color categories, guide visual search for desaturated color targets. *Psychological Science*, *21*(9), 1208-1214.

Ojemann, G., Ojemann, J., Lettich, E., & Berger, M. (1989). Cortical language localization in left dominant hemisphere –An electrical-stimulation mapping investigation in 117 patients. *Journal of Neurosurgery, 71*(3), 316-326.

Oldfield, R. C. (1971). The Assessment and Analysis of Handedness: The Edinburgh Inventory. *Neuropsychologia, 9*(1), 97-113.

Özgen, E. & Davies, I. R. L. (1997). Do linguistic categories affect colour perception? A comparison of English and Turkish perception of blue. *Perception*, 26 supplement, 129.

Pilling, M., Wiggett, A., Özgen, E., & Davies, I. R. L. (2003). Is color "categorical perception" really perceptual? *Memory & Cognition, 31*, 538-551.

Pollack, I., & Norman, D. A. (1964). A non-parametric analysis of recognition experiments. *Psychonomic Science*, 1(5), 125-126.

Pollack, I., Norman, D. A., & Galanter, E. (1964). An efficient non-parametric analysis of recognition memory. *Psychonomic Science, 1*(11), 327-328.

Posner, M. I. & Keele, S. W. (1967). Decay of visual information from a single letter. Science, 158(3797), 137-139.

Postma, A., Huntjens, R. J. C., Meuwissen, M., & Laeng, B. (2006). The time course of spatial memory processing in the two hemispheres. *Neuropsychologia, 44*(10), 1914-1918.

Roberson, D., Davies, I., & Davidoff, J. (2000). Color categories are not universal: Replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General, 129*(3), 369-398.

Roberson, D., & Davidoff, J. (2000). The categorical perception of colors and facial expressions: The effect of verbal interference. *Memory & Cognition, 28*, 977-986.

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

Robertshaw, S., & Sheldon, M. (1976). Laterality effects in judgment of the identity and position of letters: A signal detection analysis. *Quarterly Journal of Experimental Psychology*, 28(1), 115-121.

Saneyoshi, A., & Michimata, C. (2009). Lateralized effects of categorical and coordinate spatial processing of component parts on the recognition of 3D non-nameable objects. *Brain and Cognition, 71*(3), 181-186.

Siok, W. T., Kay, P., Wang, W. S. Y., Chan, A. H. D., Chen, L., Luke, K.-K., & Tan, L. H. (2009). Language regions of brain are operative in color perception. *Proceedings of the National Academy of Science of the United States of America, 106*, 8140-8145.

Suegami, T. & Michimata, C. (2010). Effects of Stroop interference on categorical perception in simultaneous color discrimination. *Perceptual and Motor Skills, 110*(3), 857-878.

Wiggett, A. J., & Davies, I. R. L. (2008). The effect of Stroop interference on the categorical perception. *Memory & Cognition, 36*, 231-239.

Winawer, A. J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Science of the United States of America, 104*, 7780-7785.

Witzel, C., & Gegenfurtner, K. R. (2011). Is there a lateralized category effect of color? *Journal of Vision, 13*(7), 1-33.

Witzel, C., & Gegenfurtner, K. R. (2013). Categorical sensitivity to color differences. *Journal of Vision, 11*(12), 1-25.

Yang, Q., Bucci, M. P., & Kapoula, Z. (2002). The Latency of Saccades, Vergence, and Combined Eye Movements in Children and in Adults. *Investigative Ophthalmology & Visual Science, 43*(9), 2939-2949.

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

1   Table 1

2   *CIE xyY coordinates and rate of "blue" responses in the colour categorisation task (%)*

Colour	x	y	Y	rate of "blue" response (%)
Blue 1	.213	.291	24.571	99.4 (0.4)
Blue 2	.225	.328	31.543	87.2 (3.5)
Green 2	.234	.368	30.568	1.3 (0.7)
Green 1	.248	.411	30.911	0.3 (0.3)
Fixation cross	.501	.369	5.095	--

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

3

4

1500 ms of
inter trial interval

200 ms of fixation cross

200 ms of probes

500 ms or 5000 ms of
inter stimulus interval

300 ms or 4800 ms of blank

200 ms of fixation cross
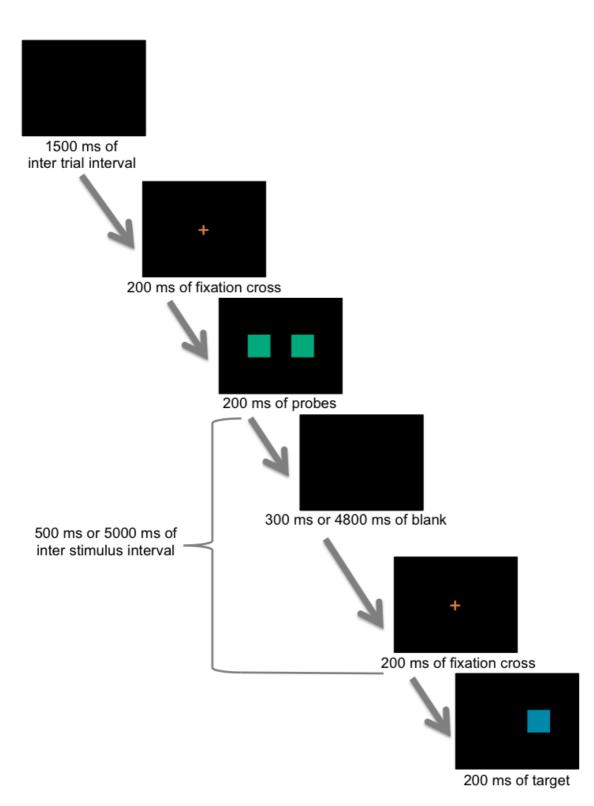
200 ms of target

1

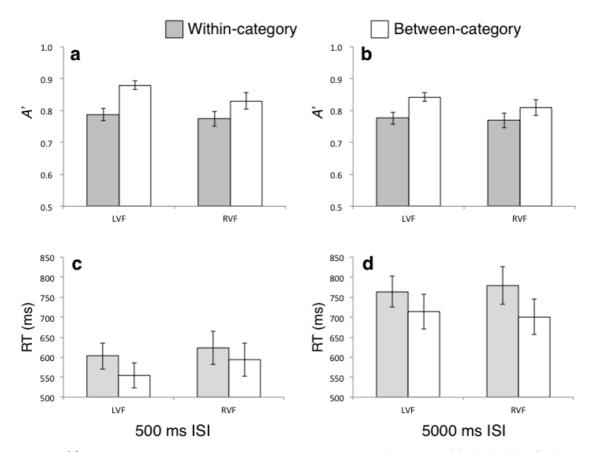2   *Figure 1*. Pictorial description of a trial sequence for the identification task.

3

Figure 2. A´s (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*´s (panel a) and RTs (panel c) with 500 ms ISI, whereas the two on the right side show *A*´s (panel b) and RTs (panel d) with 5000 ms ISI. Each error bar shows ± 1 standard error.
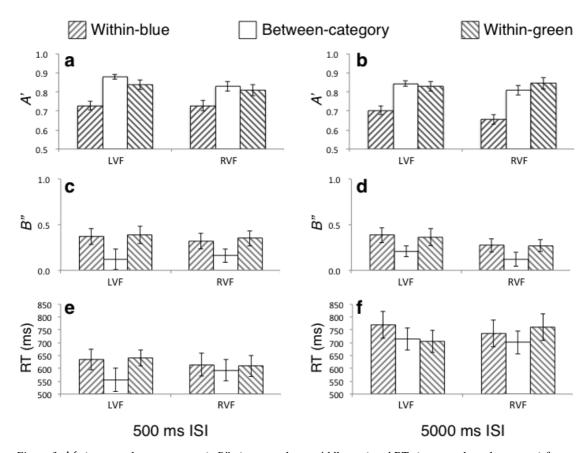
Figure 3. A´s (two panels on upper row), B"s (two panels on middle row) and RTs (two panels on lower row) for each condition in the identification task with dividing within-blue and within-green pair. The three panels on the left side show A´s (panel a), B" (panel c) and RTs (panel e) with 500 ms ISI, 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.