Routledge
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Turning univalent stimuli bivalent: Synesthesia can cause cognitive conflict in task switching

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In this study we investigated whether synesthetic color experiences have similar effects as real colors in cognitive conflict adaptation. We tested 24 synesthetes and two yoke-matched control groups in a task-switching experiment that involved regular switches between three simple decision tasks (a color decision, a form decision, and a size decision). In most of the trials the stimuli were univalent, that is, specific for each task. However, occasionally, black graphemes were presented for the size decisions and we tested whether they would trigger synesthetic color experiences and thus, turn them into bivalent stimuli. The results confirmed this expectation. We were also interested in their effect for subsequent performance (i.e., the bivalency effect). The results showed that for synesthetic colors the bivalency effect was not as pronounced as for real colors. The latter result may be related to differences between synesthetes and controls in coping with color conflict.

Keywords: Synesthesia; Task switching; Cognitive control.

People differ substantially in how they experience the physical world. For example, in grapheme-color synesthesia, black digits or letters (i.e., the inducers) automatically trigger color experiences (i.e., the concurrents) which are idiosyncratic and consistent over time (see Simner & Hubbard, 2013; Ward, 2013; for reviews). There is evidence that synesthesia can have beneficial effects for cognitive performance, for example, in the domain of memory (Meier & Rothen, 2013b; Rothen, Meier, & Ward, 2012). However, it can also have adverse effects. For example, when the veridical color of a grapheme is incongruent to the synesthetic color, then naming the veridical color is substantially slowed (i.e., the synesthetic Stroop effect). Stroop effects are associated with increased activation in the anterior cingulate cortex (ACC) which indexes the demand for control in order to overcome conflict (Botvinick, 2007). A similar conflict occurs in task switching, when switching between different cognitive tasks involves bivalent stimuli, that is, stimuli with features that are relevant for more than one task. This kind of conflict, and specifically the possibility that synesthetic experiences may turn univalent stimuli into bivalent stimuli, is the focus of the present study.

We used a task-switching paradigm that involved predictable switches between three simple binary decision tasks: Making color decisions, making form

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We thank Felicitas Wagner and Melanie Hegi for testing the participants.
No potential conflict of interest was reported by the authors.
BM is supported by the Swiss National Science Foundation [Grant Nr. 149692]. NR is supported by the Swiss National Science Foundation [Grant PA00P1_145370].

decisions, and making size decisions. For each trial one stimulus was presented. For the color decisions, the stimuli were two differently colored graphemes, with the colors tailored to the specific concurrents of each individual synesthete such that the colors were congruent to their experiences. For the form decisions we presented a square or a circle. For the size decisions, we presented the hashmark symbol either in large or small font size. Thus, typically, the stimuli were univalent, in that they were specific for each task and had no relevant features overlapping with another task of the task set. However, occasionally, the graphemes were also presented in black for the size decisions (i.e., in either large or small font size). We expected that synesthetes would induce the concurrent color experience and turn them into bivalent stimuli. In order to test this hypothesis, we used two separate control groups of non-synesthetes. In the standard control condition, we presented exactly the same stimuli as for the synesthetes (i.e., the graphemes were presented in black). As for the controls the graphemes did not trigger color experiences, this condition allowed to control for effects of the relative infrequency of the stimuli which may also slow the size decisions independent of stimulus bivalency. In the second control condition, we presented the graphemes in the specific colors experienced by the synesthetes (color control condition). Thus, this condition allowed assessing potential similarities and differences between the effect of synesthetic and real colors. In general, we expected that synesthetic experiences would induce stimulus bivalency and as a consequence would cause a response time slowing for the grapheme size decisions compared to the (univalent) hashmark size decisions, and that this slowing would be similar to the effect of real bivalency in the color control condition, but larger than in the standard control condition.

The second goal was to test whether synesthetic bivalency would also produce an adjustment of cognitive control on subsequent decisions, a phenomenon known as the *bivalency effect* (Grundy et al., 2013; Meier & Rey-Mermet, 2012; Meier, Rey-Mermet, Woodward, Müri, & Gutbrod, 2013; Meier, Woodward, Rey-Mermet, & Graf, 2009; Rey-Mermet & Meier, 2012, 2013, 2014; Woodward, Meier, Tipper, & Graf, 2003; Woodward, Metzak, Meier, & Holroyd, 2008). The bivalency effect refers to a general and enduring performance slowing that is caused by the occasional occurrence of bivalent stimuli and that occurs even on trials with univalent stimuli which have no overlapping features with the bivalent stimuli. Similar to other effects recruiting cognitive control, it is also associated with increased ACC activation (Woodward et al., 2008). The effect is robust across a variety of different tasks, presentation modalities, and bivalent stimuli. It is long-lasting and can affect performance on subsequent univalent stimuli for more than 20 seconds. Moreover, it can be separated from a simple response to infrequent stimuli which leads to a much shorter, transient slowing.

The bivalency effect can be explained by binding processes that are continuously associating and updating stimuli, tasks, and the context in which they occur. When a bivalent stimulus is processed, conflict spreads to the activated context representation which includes all tasks in the task set. On subsequent univalent trials, the reactivation of this episodic, conflict-loaded context representation interferes with performance. Testing the bivalency effect in synesthesia is informative about the representation of synesthetic stimuli. In particular, it is relevant for the question whether synesthetic colors have cognitive consequences similar to those of real colors. If so, we would expect the typical long-lived bivalency effect for synesthetes, similar to the effect expected for the color control group. In contrast, if synesthetic inducers are simply processed as infrequent events, we would expect only a short-lived-slowing on those trials immediately following the (infrequent) inducer stimuli. This is essentially the pattern that we expected for the standard control group.

METHOD

Participants

A group of 24 grapheme-color synesthetes and two control groups each consisting of 24 non-synesthetes individually matched for age (Synesthetes: $M = 35.5$ years, $SD = 14.9$; Control groups: $M = 35.8$, $SD = 14.8$), gender (Synesthetes: 22 females, Control groups: 44 females) and handedness (Synesthetes: 22 right-handed, Control groups: 44 right-handed) participated in this study (cf. Meier & Rothen, 2013a). In order to verify grapheme-color synesthesia, we administered a test of consistency for which grapheme-color associations were recorded twice with a computerized color palette. RGB-values were converted into CIELUV-space and Euclidian distances were calculated as consistency scores, with smaller values indicating higher consistency (Rothen, Seth, Witzel, & Ward, 2013). For synesthetes, the mean consistency score was 27.5 ($SD = 13.3$), and for the controls, it was 103.4 (SD = 29.1). These scores were statistically different, $t(70) = 12.1$, $p < 0.001$. The study was approved by the local ethical committee of the University of Bern, and all participants gave informed consent.

Material

For the color-decision task, the stimuli were tailored for each synesthete according to their unique color experience such that the colors were congruent to their experiences. Specifically, those two graphemes which elicited the strongest color experience were selected (see supplemental online material). For the form-decision task, the stimuli were a circle and square. For the size-decision task, the stimuli were hashmark symbols either presented in small (20-point) or large (180-point) font size. Critical stimuli were created by presenting one of the graphemes that occurred in the color task instead of the hashmark symbol in 20% of the size-decisions in Block 2. For synesthetes and for the participants in the standard control condition, these graphemes were printed in black 60-point font. For the participants in the color control group, they were presented in color (i.e., the same color as for the color decision). All critical stimuli were selected such that they required a different response for the color and the size task (i.e., an incompatible response mapping). Stimuli for the color task and for the form task extended over about 2.4° of visual angle, stimuli for the size task extended over .33° (small) and 3.8° (large) of visual angle. All stimuli were presented in the center of the computer screen.

Procedure

Participants were tested individually. The synesthetes were first asked which graphemes triggered the strongest synesthetic experiences in order to tailor graphemes individually. Then the participants were informed that they would have to perform three different tasks, a color decision, a form decision, and a size decision, always in the same order. To make their responses, participants had to press one of two keys (*b* or *n*) on the keyboard with their left and right index fingers, respectively, for each of the three tasks. Specifically, they were instructed to respond with their left index finger for a red color, for a round form, and for a small symbol and with their right index finger for a blue color, for an angular form, and for a large symbol. The mapping information, printed

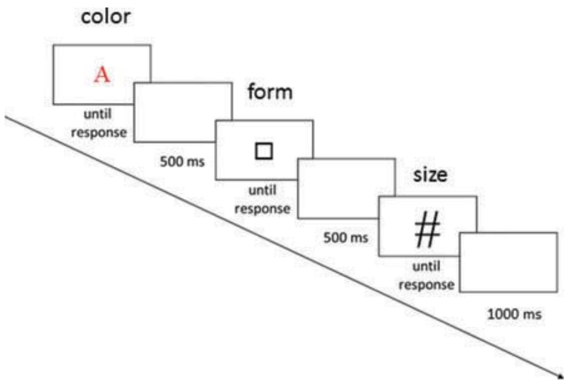

Figure 1. Example of a univalent task triplet. Participants carried out a color decision on graphemes (e.g., red vs. blue), a form decision (angular vs. round), and a size decision (small vs. large). For the *mixed* block (not pictured here), a grapheme was occasionally presented (in black) for the size decision.

on paper, was displayed below the computer screen for the duration of the experiment. Participants were further informed that they would be shown graphemes for some of the size decisions. They were specifically instructed to ignore stimulus identity and to keep making size decisions.

After these instructions, a block of 30 task triplets was presented for practice. Each triplet included a color decision, a form decision, and a size decision, always in the same order, as illustrated in Figure 1. The stimulus for each task was displayed until the participant responded. Doing so blanked the screen for 500 ms, and then the next stimulus appeared. After each triplet, an additional 500 ms blank interval was included. After the practice block and a brief break, each participant completed three experimental blocks, each with 30 triplets, without a break between blocks.

For the first and third blocks (i.e., the purely univalent blocks), only univalent stimuli were presented. For the second block (i.e., the mixed block), critical stimuli were presented for 20% of the size-decision tasks. Critical stimuli were evenly interspersed among the 30 triplets of the block; they occurred on every fifth triplet, specifically triplets 3, 8, 13, 18, 23, and 28. The entire experiment lasted about 20 minutes.

Data analysis

For each participant, error-rates and mean response times (RTs) for correct responses were computed for each task and each block. Following Woodward et al. (2003), responses longer than 3000 milliseconds or shorter than 200 milliseconds were excluded. For the mixed block, error rates and RTs for univalent and bivalent stimuli were computed separately. An alpha level of 0.05 was used for all statistical tests.

RESULTS

Accuracy

Mean accuracy for univalent decisions was close to ceiling, $M = .98$, across tasks, blocks, and groups (see Table 1). A three-factorial analysis of variance (ANOVA) with task and block as within-subject factor and group as between-subjects factor gave no significant effect, all Fs < 2.62, MSEs < .005, ps > .08. Mean accuracy for bivalent stimuli was .94 ($SE = .15$) for synesthetes, .91 ($SE = .16$) for the color control group, and .98 ($SE = .05$) for the standard control group. A one-factorial ANOVA revealed no significant group difference, $F(2, 69) = 2.56$, $MSE = .017$, $p = .09$.

Stimulus valence

To test whether introducing black graphemes affected performance in the size-decision task in Block 2, we used a two-factorial ANOVA with type of stimulus (hashmark = univalent; grapheme = bivalent) as within-subject factor and group (synesthete, color control group, standard control group) as between-subjects factor. The results, depicted in Figure 2, showed a main effect of stimulus type, $F(1, 68) = 142.67$, $MSE = 51014$, $p < .001$, which was qualified by a significant interaction, $F(2, 69) = 4.98$, $MSE = 51014$, $p < .01$. The difference between RTs to bivalent versus univalent size decisions were 517, 550, and 283 ms, for the synesthetes, the color control group, and the standard control group, respectively. These scores were all statistically different from zero, ts > 6.5, ps <.001. Post-hoc comparisons showed a significant difference between synesthetes and the standard control group and between the color control group and the standard

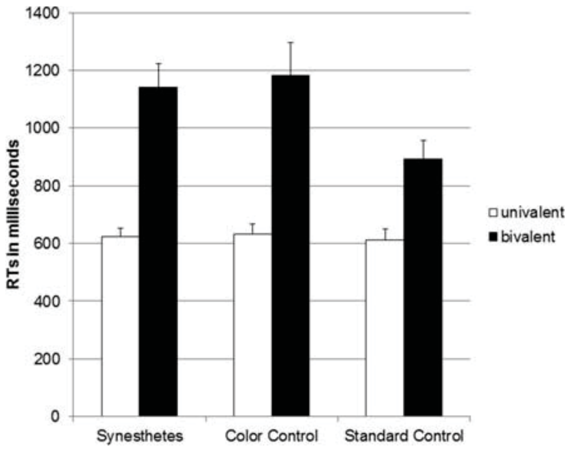

Figure 2. The effect of stimulus bivalency for size decisions.

TABLE 1
Mean accuracy (%) and mean response times (RTs in ms) on trials with univalent stimuli. Standard errors in parentheses

			Synesthetes		*Color control group*		*Standard control group*	
Accuracy								
	Color	Block 1	97.00%	(2.09)	98.17%	(0.44)	98.54%	(0.59)
		Block 2	96.71%	(2.08)	98.17%	(0.52)	99.00%	(0.52)
		Block 3	96.83%	(2.08)	98.75%	(0.50)	98.67%	(0.45)
	Form	Block 1	97.63%	(0.47)	96.92%	(0.76)	98.67%	(0.45)
		Block 2	97.21%	(0.82)	97.38%	(0.76)	98.29%	(0.44)
		Block 3	98.46%	(0.39)	98.25%	(0.66)	97.88%	(0.56)
	Size	Block 1	99.38%	(0.25)	98.50%	(0.50)	99.25%	(0.27)
		Block 2	99.33%	(0.39)	99.17%	(0.34)	99.33%	(0.31)
		Block 3	98.46%	(0.47)	99.21%	(0.36)	99.58%	(0.31)
RTs								
	Color	Block 1	655	(49)	736	(49)	769	(49)
		Block 2	710	(46)	846	(46)	786	(46)
		Block 3	631	(47)	706	(47)	713	(47)
	Form	Block 1	720	(40)	650	(40)	688	(40)
		Block 2	718	(40)	745	(40)	709	(40)
		Block 3	666	(39)	658	(39)	650	(39)
	Size	Block 1	574	(35)	554	(35)	607	(35)
		Block 2	625	(35)	632	(35)	611	(35)
		Block 3	561	(32)	550	(32)	567	(32)

control group, both *p*s < .05. The synesthetes and the color control group did not differ statistically, $p = .72$. Thus, making size decisions with black graphemes resulted in a similar slowing for synesthetes as making size decisions with colored graphemes for the color control group. This slowing was larger than the slowing that occurred in the standard control group with black graphemes. Therefore, the results cannot be simply due to the infrequency of the introduction of graphemes into the size task. Rather they demonstrate that synesthetic experiences had turned the univalent stimuli into bivalent stimuli.

Bivalency effect

Next, we examined whether synesthetic experiences result in a typical bivalency effect. Table 1 shows the descriptive data for the univalent stimuli of each block. For analyses, we averaged the data from the purely univalent Blocks 1 and 3 to account for general training effects. The results are presented in Figure 3. A mixed three-factorial ANOVA with block (purely univalent, mixed) and task (color, form, size) as within-subject factors and group (synesthetes, color control, and standard control) as a between-subjects factor revealed main effects of task, $F(2, 138) = 63.04$, $MSE = 12695$, $p < .001$, reflecting the faster RTs for the size task compared to the color and the form tasks, and a main effect of block, $F(1, 69) = 74.72$, $MSE = 5511$, $p < .001$, reflecting a bivalency effect. These main effects were qualified by significant interactions. First, the interaction between task and group was significant, $F(4, 138) = 4.67$, $MSE = 12695$, $p < .005$. This was due to the shorter RTs for the color task in the synesthetes compared to both control groups, an effect that may be due to the fact that for synesthetes, the graphemes for the color decisions were always congruent to the corresponding concurrents. Second, the interaction between task and block was significant, $F(2, 138) = 3.42$, $MSE = 2295$, $p < .05$, reflecting the fact that the bivalency effect was somewhat larger (79 ms) for the color task compared to the form (52 ms) and the size tasks (54 ms). Third, and most critically, there was an interaction between block and group, $F(2, 69) = 6.91$, $MSE = 5511$, $p < .005$, which indicates a difference in the magnitude of the bivalency effect across groups, which was 50 ms for the synesthetes, 98 ms for the color control group, and 37 ms for the standard control group. Post-hoc test revealed that the effect was larger for the color control group compared to the synesthetes and the standard control group ($p < .01$), while the latter two groups did not differ significantly ($p = .45$). Notably, the bivalency effect was significant in all groups when tested against zero, all *t*s > 2.8, *p*s < .01. Finally, the triple interaction between task, block, and group did not approach significance, $F(4, 138) = 1.28$, $MSE = 2295$, $p = .28$.

Trajectory of the bivalency effect

In order to test for potential differences in the trajectory of the bivalency effect across groups, we computed the mean RTs for each task-triplet following the critical size decisions, separately for each task. As a bivalent stimulus was presented on each fifth task triplet in the mixed block, we designated this task triplet as triplet N and the first triplet following the bivalent stimuli with the label N + 1, etc. Figure 4 depicts the trajectory of RTs averaged across tasks on triplets N + 1 to N + 4 from the mixed block and the corresponding RTs from the purely univalent block, separately for each group. As expected the bivalency effect decreased across trials and this decrease seemed to differ across groups. A four-factorial ANOVA with triplet,

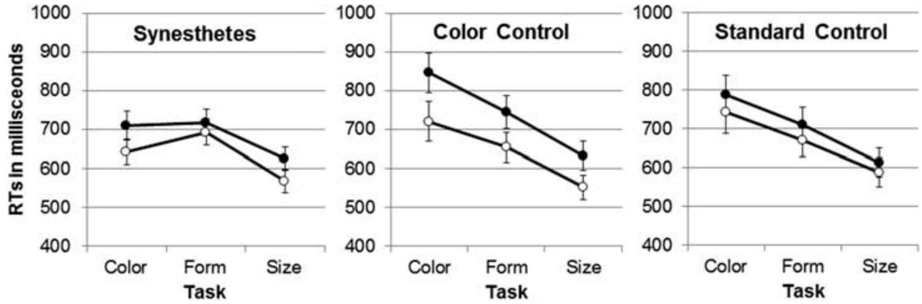

Figure 3. The bivalency effect across tasks, separately for the synesthetes, the color control group, and the standard control group. White circles represent mean RTs of the purely univalent blocks and black circles represent the RTs for univalent stimuli from the mixed block.

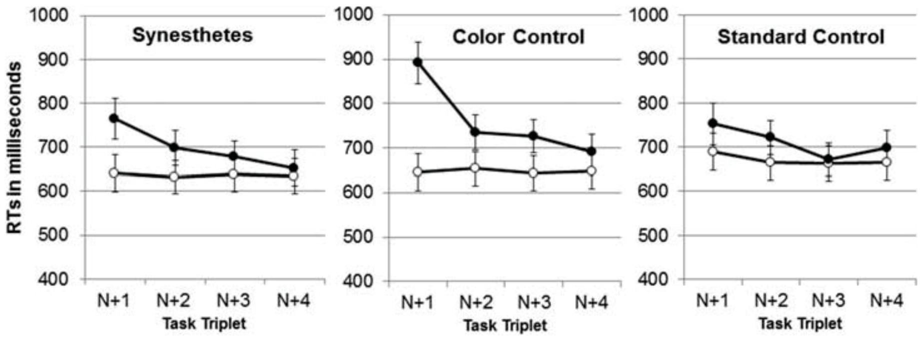

Figure 4. The trajectory of the bivalency effect, separately for the synesthetes, the color control group, and the standard control group. White circles represent mean RTs of the purely univalent blocks and black circles represent the RTs for univalent stimuli from the mixed block.

task, block, and group confirmed this observation by giving a significant triple interaction between group, block, and triplet, $F(6, 207) = 4.46$, $MSE = 9179$, $p < .01$.To follow up this interaction, we compared the purely univalent blocks and the mixed block with separate ANOVAs for each group. For N + 1 and N + 2, the effect was significant for all groups, with Fs (1, 23) > 9.35, MSEs > 15655, ps <.01 and Fs (1, 23) > 5.48, MSEs > 21320, ps < .05, respectively. For N + 3, the effect was still significant for the synesthetes and the color control group, Fs (1, 23) > 4.50, MSEs > 12291, $p < .05$, but not for the standard control group $F(1, 23) = 1.79$, $MSE = 16363$, $p = .68$. For N + 4, a significant bivalency effect occurred only for the color control group $F(1, 23) = 4.69$, $MSE = 14651$, $p < .05$. This latter result replicates the long-lasting nature of the bivalency effect.

DISCUSSION

The focus of this study was to test the possibility that synesthetic experiences may turn univalent stimuli bivalent when synesthesia is triggered within a task-switching experiment. Participants were required to switch between three simple binary decision tasks, color decisions on colored graphemes, form decisions on geometrical shapes, and size decisions on symbols. We hypothesized that in synesthetes the presentation of a black grapheme for the size decision would turn this stimulus into a bivalent stimulus and would thus induce a slowing similar to the presentation of that grapheme in real color. The latter was tested in a yoke-matched color control group. Our results confirmed this expectation. As the slowing in both the synesthetes and the color control group was much larger than in the standard control group in which the same graphemes were presented in black as for the synesthetes, we can exclude the fact that the effect was simply caused by the infrequency of the presentation of graphemes in the size-decision task. These results support the hypothesis that synesthetic colors can have an effect similar to that of real colors (cf. Laeng, 2009; Laeng, Hugdahl, & Specht, 2011). Moreover, they indicate that conflict triggered by synesthesia can result in a performance disadvantage similar to the incongruency effect that occurs in synesthetic Stroop tasks (Mattingley, Rich, Yelland, & Bradshaw, 2001). Notably, in the present study, we also found a *beneficial* effect of synesthesia. Specifically, on univalent color decisions which were carried out on graphemes colored congruently to the synesthetic experiences, synesthetes were somewhat faster than controls which may reflect a synesthetic congruency effect (cf. Mattingley et al., 2001; Nikolić et al., 2007).

A further goal of this study was to test whether bivalency induced by synesthetic colors would have a similar effect on subsequent performance as bivalency induced by real colors (i.e., the bivalency effect). Consistently, overall the occasional occurrence of bivalent stimuli resulted in a performance slowing in each of the three groups. However, the trajectory of this slowing differed across groups. For the color control group the typical long-lasting bivalency effect occurred. In contrast, for synesthetes the slowing was less pronounced and less enduring. However, it still lasted longer than in the standard control group. These results suggest that synesthetic colors are represented somewhat different than real colors, or at least, that their effect on performance is less pronounced than for real colors. One explanation would be that the synesthetic color experiences trigger less conflict than real colors. However, the similar slowing for the bivalent stimuli in the size task for both synesthetes and the color control group do not support this hypothesis. Another explanation is that the representation of conflict that is built up by synesthetic colors is weaker and thus fades out faster. Moreover, synesthetes may encounter this type of color conflict more often outside of the laboratory and thus, they may be more experienced in down-regulating it faster than non-synesthetes. Together, the results may indicate that the representation activated by real colors is stronger than the representation activated by synesthetic colors. Thus, only when the inducer is present is the effect of synesthetic color similar to veridical color. This latter interpretation would be consistent with the hypothesis that, a priori, synesthesia is perceptual in nature (Kim, Blake, & Palmeri, 2006; Palmeri, Blake, Marois, Flanery, & Whetsell, 2002; Ramachandran & Hubbard, 2001). However, as there still emerged a bivalency effect that lasted longer than for the standard control group our findings suggest that synesthetic colors trigger a conceptual representation that can affect performance even after the actual occurrence of the synesthetic experience (Dixon, Smilek, Wagar, Cudahy, & Merikle, 2002; Meier, 2013; Mroczko-Wasowicz & Nikolic, 2014; Nikolić, Jürgens, Rothen, Meier, & Mroczko, 2011).

In general, our study provides evidence that in some situations, synesthetic colors can produce effects very similar to those of real colors, whereas in other situations the effect is different. Similar evidence has been found for perceptual tasks (Laeng, 2009; Laeng et al., 2011; Nijboer, Gebuis, Te Pas, & van der Smagt, 2011). The present study extends into the domain of conflict adaptation. In particular, in a task-switching environment, for synesthetes univalent stimuli can turn into bivalent stimuli. Moreover, the bivalency effect induced by synesthetic experiences fades out faster compared to real colors, suggesting that the representation of conflict that is built up by synesthetic colors is weaker. As encountering color conflict situations in everyday life is much more likely for synesthetes, they may be better prepared to overcome these conflicts.

Supplementary material

Supplementary Table 1 is available via the 'Supplementary' tab on the article's online page (http://dx.doi.org/10.1080/17588928.2015.1017449).

Original manuscript received 20 November 2014
Revised manuscript received 5 February 2015
First published online 5 March 2015

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