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Cost of Mental Set Reconfiguration between Digits and their Photisms in Synaesthesia

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In this study we present an experiment investigating the reconfiguration process elicited by the task switching paradigm in synaesthesia. We study the time course of the operations involved in the activation of photisms. In the experimental Group, four digit-color synaesthetes alternated between an odd-even task and a color task (to indicate the photism elicited by each digit). In both tasks, the target stimuli were numbers between 1 and 9 written in white. One of the control groups ran the same tasks but this time with colored numbers (Naïve Control Group). The results of these studies showed the expected pattern for the control group in the case of regular shift: a significant task switch cost with an abrupt offset and a cost reduction in long RSI. However for the experimental group, we found switch cost asymmetry in the short RSI and non-significant cost in the long RSI. A second control group performed exactly the same tasks as the experimental group (with white numbers as targets and a second imaginary color task) -Trained Control Group-. We found no cost for this second control group. This means that the cost of mental set reconfiguration between numbers (inducers) and their photisms (concurrent sensations) occurs, that there is a specific cost asymmetry (from photisms to inducers) and that this cost cannot be explained by associative learning. The results are discussed in terms of exogenous and endogenous components of mental set reconfiguration.
Keywords: synaesthesia, task switching, mental-set reconfiguration, attention, executive functions.

En este estudio presentamos un experimento en el que se investiga el proceso de reconfiguración mental empleando el paradigma de cambio de tarea en sinestesia. Estudiamos el tiempo de preparación necesario en la activación de un fotismo. En el grupo experimental, cuatro sinestetas dígito-color alternaban entre una tarea de números (par-impar) y otra de color (indicar el fotismo evocado por cada dígito). En ambas tareas, el estímulo era un número entre el 1 y el 9 escrito en blanco. Uno de los grupos control realizó la misma tarea pero con los números coloreados (Naïve Control Group). Los resultados muestran el patrón de datos esperado para el grupo control en el caso de cambio de tarea predecible: un coste por cambio de tarea que desaparece en el primer ensayo de repetición usando un intervalo respuesta-estímulo (RSI) largo. Sin embargo, en el grupo experimental, encontramos asimetrías en el patrón del costo usando RSI corto y un coste no significativo en el RSI largo. Un segundo grupo control realizó exactamente la misma tarea que el grupo experimental (con números en blanco y una segunda tarea de "color imaginario") -Trained Control Group-. Encontramos que no existe costo en este segundo grupo de control. Esto significa que el coste por la reconfiguración mental al alternar entre tarea de números (inductores) y su fotismo (sensación concurrente) ocurre, que hay una asimetría del costo específica (del fotismo a los inductores) y que este costo no puede ser explicado mediante el aprendizaje asociativo. Estos resultados se discuten en términos de los componentes exógenos y endógenos de la reconfiguración mental.
Palabras clave: sinestesia, cambio de tarea, reconfiguración de la preparación mental, atención, funciones ejecutivas.

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In synaesthesia, ordinary stimuli elicit extraordinary experiences (Dixon, Smilek, Cudahy, & Merikle, 2000). When N., a digit-color synaesthete, views white digits, each number elicits a photism (a visual experience of a specific color). For example, in the case of N., the photism elicited by the number 3 is the visual experience of red. It has been proposed that synaesthetic experience is consistent and automatic, but may be induced independently of external stimuli. During preliminary interviews, the four synaesthetic participants in our experiment were asked about their specific synaesthetic associations. To further explore their synaesthetic condition, the subjects were also asked to fill in an online version of the Synaesthesia Battery (http://www.synesthete.org) from Eagleman, Kagan, Nelson, Sagaram, and Sarma (2007). The test results were positive for all the synaesthetes. The control groups also filled in the online version of the synaesthesia battery with negative results. All the synaesthetes showed number-color synaesthesia. The association between colors and the numbers one to nine for each of them can be observed in Table 1. All the synaesthetes showed 100% consistency in their claims in successive tests. In previous research Stroop (1935) type tasks were used like a behavioural test of synesthesia (Rich & Matligley, 2002). However Stroop effects can be learned (Meier & Rothen, 2009). These authors have already shown that a simple conditioned response task serves to create this distinction (between natural synesthetes and learned synesthesia). Therefore, our main goal here is not just to present a new test for synaesthesia but to show that photisms are real and have cognitive consequences. For that we will use the task switching paradigm (Tornay & Milán, 2001). However we also expect that our results parallel Meier & Rothen's significance of task switching paradigm as a better method of confirming synaesthesia.

In recent decades, it has been demonstrated that switching from one activity to a new one usually causes an impairment in performance, which can be measured both as a decrease in accuracy and an increase in reaction time (RT; e.g., Allport & Wylie, 1999; Gilbert & Shallice, 2002; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Rogers & Monsell, 1995; Tornay & Milán, 2001); see Jersild, 1927, for an early study. This effect has been termed switch cost (e.g., Roger & Monsell, 1995). Usually there is a cost asymmetry: the cost only occurs for one of the tasks combined, frequently the easier task – with shorter RT and more accuracy - (Allport, Styles, & Hsieh, 1994; Tornay & Milan, 2001).

In a seminal paper on task switching, Allport, Styles, and Hsieh (1994) interpreted the switch cost reported in their study as a form of 'proactive interference' from a recently adopted task-set elicited by the same type of stimulus. They called this phenomenon task-set inertia. In a different study, Rogers and Monsell (1995) reported a consistent decrease in switch cost as preparation time (i.e.

Table 1
Description of number-color synaesthesia for each synaesthete participant

NUMBERS	SYNAESTHETE A	SYNAESTHETE B	SYNAESTHETE C	SYNAESTHETE D
1	BLACK	YELLOW	WHITE	WHITE
2	YELLOW	ORANGE	BLUE	RED
3	RED	BLUE	YELLOW	YELLOW
4	LIGHT BLUE	RED	ORANGE	BLUE
5	BLUE	LIGHT BLUE	VIOLET	RED
6	PINK	BLUE	GREEN	PINKISH GREY
7	GREEN	BROWN	LIGHT GREEN	NO COLOR
8	DARK RED	RED	DARK YELLOW	RED BLACK
9	WHITE	GREY	BROWN	OCHRE

Table 2
Correspondence between colors in RedGreenBlue (RGB) code and numbers for the synaesthete participants

NUMBER	A-RGB CODE	B-RGB CODE	C-RGB CODE	D-RGB CODE
1	0,0,0	238,238,0	255,250,250	220,220,220
2	255,185,15	255,165,0	30,144,255	178,34,34
3	139,0,0	24,116,205	255,215,0	167,167,89
4	99,184,255	255,0,0	238,118,0	79,148,205
5	152,245,255	152,245,255	145,44,238	205,0,0
6	255,182,193	67,110,238	34,139,34	181,181,181
7	85,107,47	139,69,19	154,205,50	
8	139,26,26	139,0,0	205, 149,12	54,26,1
9	248,248,255	190,190,190	139,90,43	255,255,1

response-stimulus interval or RSI) increased. However, in Rogers and Monsell's (1995) study, the switch cost never disappeared, even when a long RSI was used. They concluded that there are two different components in switch cost: one (the endogenous component), which can be eliminated by an active process of reconfiguration (i.e. it acts during the RSI) and another which cannot (i.e. residual or exogenous cost). Interestingly, the results showed that the residual cost disappeared after the first repetition trial, so that no further improvement occurred in subsequent task repetitions. Rogers and Monsell explained the abrupt disappearance of the residual switch cost in the first trial as an exogenous process triggered by the stimulus associated with the task, which eliminates the remaining or residual switch cost (i.e. *the stimulus-cued completion hypothesis*).

However, we must point out that some conditions (random switch between tasks) yield a different pattern of results, namely, the absence of residual cost and a progressive decrease of RT with the number of repetitions of the same task (Tornay and Milán, 2001; Milán, Sanabria, Tornay, & Gonzalez, 2005). These data are consistent with the fact that most of the switch cost in the random condition in Tornay and Milan's study disappeared during the RSI, before the first repetition trial. Note that, while the pattern of results in the predictable switch condition appeared to agree with Rogers and Monsell's account of exogenous task-set reconfiguration, the results in the random switch condition suggest a full endogenous reconfiguration.

In short, our objective is to determine whether the mental set reconfiguration between a number and its photism produces a shift cost, and if this is indeed the case, exactly what kind of cost (endogenous or exogenous). In other words, our main goal is to assess the endogenous and exogenous components necessary to trigger a photism, by means of the task switching paradigm (Rogers & Monsell, 1995; Tornay & Milan, 2001). We ask our participants to shift between two tasks: a number task (to indicate whether the number is odd or even) and a photism task (to indicate the color of the photism elicited by the number). With the task switching paradigm described, we can determine which stimulus is dominant (the number or its photism), the time course of photism activation and whether the photism produces mental set inertia or proactive interference (time course of photism activation decay).

Experiment

The main objective of this experiment was to investigate the possible differences in the mental set reconfiguration between four digit-color synaesthete participants (all of them of the sub-type associators) and non-synaesthete participants. We used regular sequences of task switching with short and long RSIs in order to maximize the probability of obtaining switching costs. For the control groups, we predicted that the switch cost would dissipate after the first repetition of the task, suggesting that the appearance of the stimuli is of great relevance for the complete reconfiguration of the task-set (cued-stimulus completion hypothesis). In the long RSI condition, we expected a decrease in the RT and a lower switch cost but a still significant residual cost. However, in the case of the participants with synaesthesia we expected a full endogenous reconfiguration (a non-significant residual cost in long RSI) due to a reduced or null effect of the exogenous factors, considering that an externally presented inducing stimulus is not necessary to trigger a photism (Dixon et al., 2000). A photism is a phantom color, an endogenous experience that can be elicited by mental imagery. We can also establish the cost asymmetry (from photisms to numbers or vice versa). Synaesthesia is normally (but not always) a one-way experience (from inducers to concurrent sensations).

Method

Participants

12 undergraduate students (6 women, 6 men) from the University of Granada took part in the experiment. They were given course credits in exchange for their participation. All the participants reported normal or corrected-to-normal vision. Four of them had number-color synaesthesia. They were aged from 20 to 30 years, half were women and with the left hand dominant. We reproduced the same proportions in the control groups.

Apparatus

The stimuli were presented on a computer screen controlled by a Pentium III computer, also used to collect participants' responses. We used the MEL program (Schneider, 1988) to generate and control the presentation of stimuli. During the experiment, each participant sat in a comfortable chair in a dimly lit room. In each trial, either a plus sign (+) or an asterisk (*) appeared in the centre of the screen, depending on the task that participants had to perform. The plus sign (+) signaled the number task while the asterisk (*) indicated the color task. Both signs subtended at a visual angle of 1.5º x 1.5º. Later in the trial, a stimulus (1.5º x 1.5º degrees) consisting of a number was presented in the centre of the screen, replacing the fixation point. We manipulated the interval between fixation point (or cue) and digit, as will be explained later. The target remained on the screen until a response was made.

Design

We used a repeated-measures design with four independent variables. Two of these varied on a trial-by-trial basis: task (number vs. color); number of repetitions, which had three levels: 0 (trials in which the task was different from that used in the previous trial), 1 (trials in which the task was the same as in the previous trial) and 2 (trials in which the task was the same as that used in the two previous trials). There was another variable, which was blocked: the RSI (The Response Stimulus Interval), with two values, short (300 ms) and long RSI (1300 ms). The last independent variable was Group, a between-subjects variable, which had three levels: G1 (the participants with color-number synaesthesia, who performed the experiment four times with white numbers as target stimuli. G2, a control group of four non-synaesthetes, who performed the experiment four times but with colored numbers (naive control group). The numbers 4 and 5 appeared in blue and the numbers 3 and 8 in red. G3, a second control group of four non-synaesthetes (trained control group). They conducted the same experiment as G1, four times with white numbers as target stimuli, but with instructions to indicate the imaginary color blue for the numbers 4 and 5 and to press the red button in the presence of numbers 3 and 8 in a simulated color task. For all the groups, we used only the numbers 3, 4, 5 and 8 to facilitate the task for the control groups and to organize the response set in two keys for synaesthetes. See Appendix 1 for a more in-depth explanation of the control groups. For each synaesthete, the correspondence between response set and colors was adapted following Tables 1 and 2.

Procedure

Participants were asked to perform one of two possible tasks. They had either to indicate whether the number was odd or even (number task) or whether the color was red or blue for the control groups and synaesthetes A and B (color task). For synaesthete C, the color task was to indicate whether the color was yellow or not yellow and for participant D, the color task was to indicate whether the photism was red or not red. In both tasks the participants responded by pressing either the "b" or the "n" key on the keyboard. Thus, both tasks shared the same stimuli and responses. Half the control participants had to press "b" when the number was even or the color was red and "n" when the number was odd or the color blue. The reverse stimulus-key mapping was used for the other half of the group. Each participant was randomly assigned to a particular mapping. The participants were given a maximum of 2,500 ms after the appearance of the stimulus pair to produce the response before proceeding to the next trial. The RSI was 300 ms or 1,300 ms, allowing for the addition of the inter-trial interval (ITI; i.e. the time interval between the participant's response and the onset of the cue), which was 100 ms and the stimulus onset asynchrony (SOA; i.e. the time interval between the cue and the target), which was 200 or 1,200 ms.

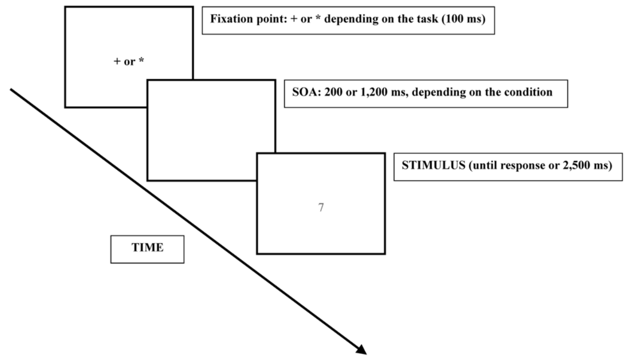

Figure 1. Experimental trial sequence from top left to bottom right.

The tasks were alternated every 3 trials (e.g. CCC-NNN sequences). Each time, the participants completed 1,400 trials, split into two experimental sessions on two consecutive days, one for each of the two values of RSI (the order of sessions was counterbalanced across participants). Participants completed 5 blocks of 70 trials twice in each session, separated by a ten-minute rest period. Prior to each session, participants completed a practice block of 70 trials in order to familiarize themselves with the task. The data from this block were not considered in the analysis.

Participants were instructed to respond as quickly as possible while trying to avoid errors. Reaction Time (RT) and accuracy were our main Dependent variables.

Results

The RT (for correct responses only) between 300 and 2000 milliseconds and accuracy data were submitted to a four-way repeated-measures analysis of variance (ANOVA –sphericity is accomplished) with the factors RSI (short vs. long), Task (number vs. color), Number of repetitions (0, 1, and 2) and Group (1, 2 and 3).

The ANOVA of the RT data revealed main effects of Task, $F(1,9) = 28.52$, $p < .0001$ (mean RT for the number task was bigger than RT for the color task), and Number of repetitions, $F(2,18) = 25.50$, $p < .00001$, and a significant interaction between Group, RSI and Number of repetitions, $F(4,18) = 9.88$, $p < .0001$. The interaction between Task, Group, Number of repetitions and RSI was also significant, $F(4,18) = 5.08$, $p < .01$. We then analyzed the data separately for each RSI condition. See Figures 2a (short RSI) and 2b (long RSI).

In the short RSI condition, the interaction between Group, Task and Number of repetitions was significant, $F(4,18) = 9.22$, $p < .0001$. Only for G1, the interaction between Task and Number of repetitions was significant, $F(2,6) = 86,66$, $p < .0001$. In other words, only for G1 (the group of synaesthetes) did we find cost asymmetry, $F(1,3) = 78.36$, $p < .00001$. The cost for the color task was 166 ms., $F(1,3) = 21.9$, $p < .005$, being shorter than

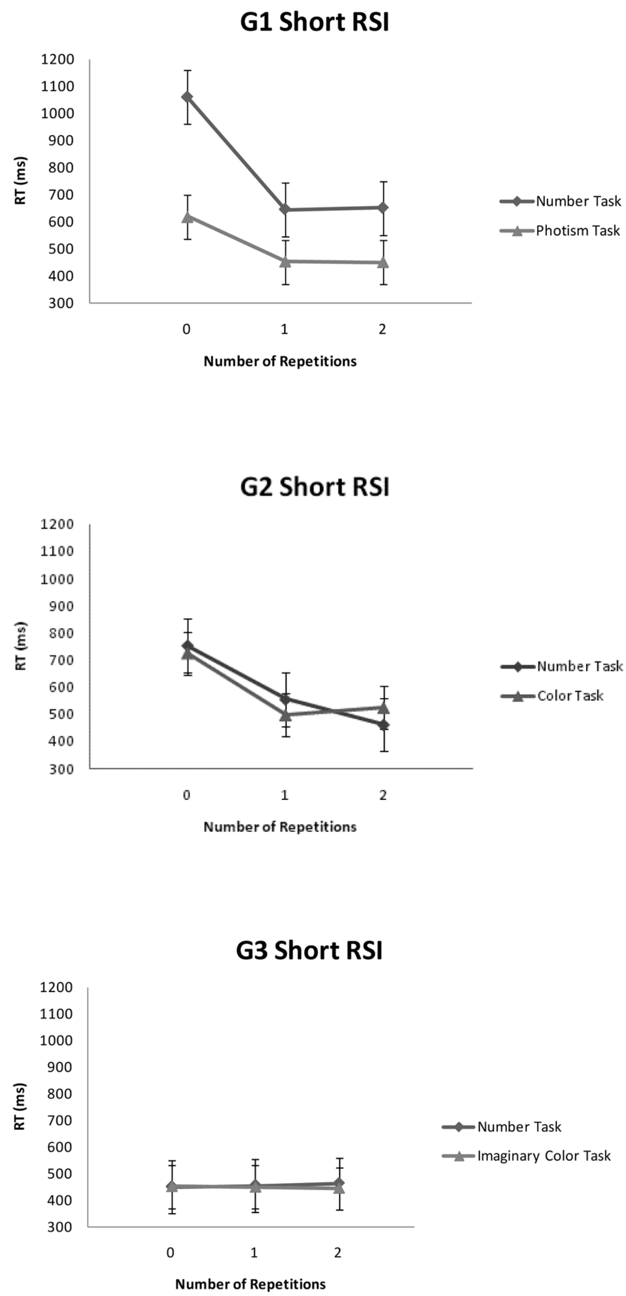

Figure 2a. Graph showing the mean RT for responding to the target stimuli in Experiment 1, as a function of the Group, RSI and the Number of repetitions factors for short RSI.

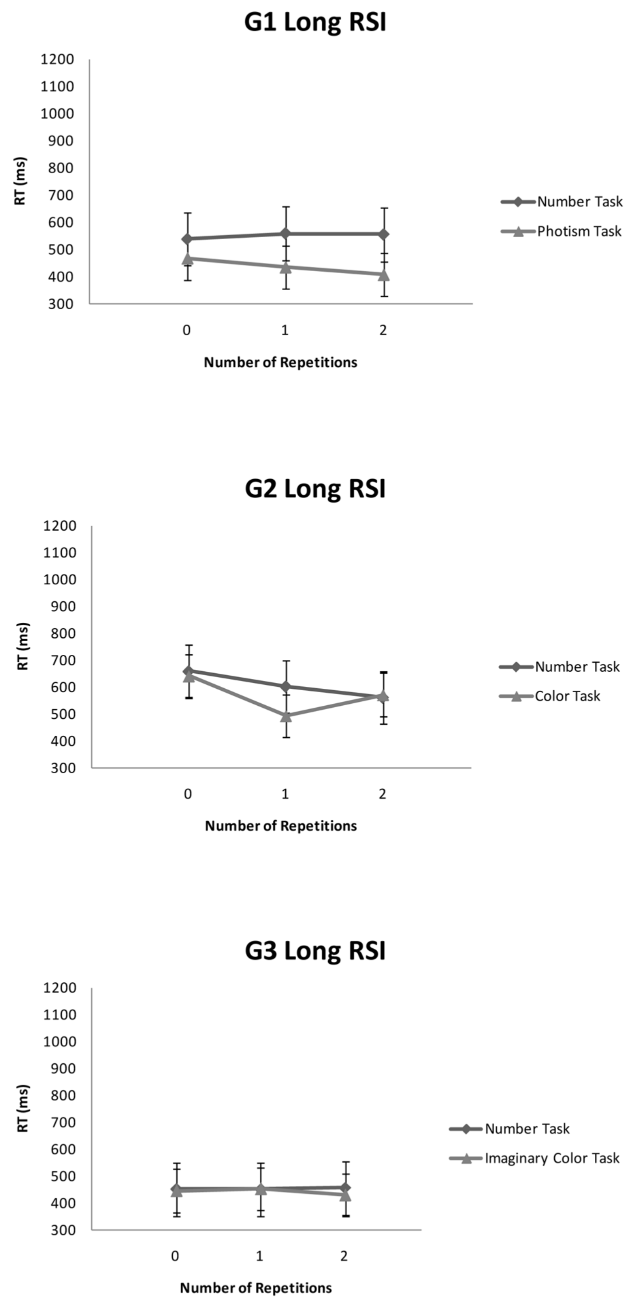

Figure 2b. Graph showing the mean RT for responding to the target stimuli in Experiment 1, as a function of the Group, RSI and the Number of repetitions factors for long RSI.

the cost for the number task (415 ms.), $F(1,3) = 57.97$, $p < .00001$. For G2 (naive control), the cost was similar for the two tasks (about 198 ms. for the number task and 233 ms. for the color task) and significant for both tasks, $F(1,3) = 23.08$, $p < .0005$. The cost for the color task was no different in G1 and in G2, $F < 1$, but the cost for the number task was greater in G1 than in G2, $F(1,6) = 113.83$, $p < .006$. However, the difference between 1 repetition trial and 2 repetition trials, $F < 1$, did not reached significance in G1 (synaesthesia group) and G2 (naïve control). Also the switch cost (i.e. the difference in RT between 0 repetition trials and 1 repetition trial) and the difference between 1 repetition trial and 2 repetition trials were not significant in G3 (trained control), $F < 1$.

In the long RSI condition, we found a main effect of task, $F(1,9) = 17.11$, $p < .004$, and number of repetitions

$F(2,18) = 4.36$, $p < .01$. The interaction between Group and number of repetitions was only marginally significant, $F(4,18) = 2.40$, $p < .08$. However, the switch cost was significant only for G2 (naïve control), $F(1,3) = 7.09$, $p < .01$. The differences in cost magnitude between G1 (synaesthesia group) and G2 (naïve control), $F(1,6) = 4.69$, $p < .06$, and between G2 (naïve control) and G3 (trained control) were marginally significant, $F(1,6) = 3.47$, $p < .08$. There were no differences between G1 (synaesthesia group) and G3 (trained control), $F < 1$.

The ANOVA of the accuracy data revealed a significant interaction between Groups and Number of repetitions only in the long RSI, $F(4,18) = 21.09$, $p < .00001$. The switch cost was significant only for Group 2 (naïve control), $F(1,3) = 8.25$, $p < .01$. There were no other significant effects of any relevance. See table 3.

Table 3
Accuracy data (error rate average per condition)

	Repetitions	Group G1	G2	G3
Short RSI				
	0	5%	10%	6%
	1	3%	9%	7%
	2	3%	8%	6%
Long RSI				
	0	3%	10%	7%
	1	5%	5%	6%
	2	2%	3%	4%

General Discussion

The main conclusion to draw from Experiment 1 is that a different pattern of switch cost reconfiguration can be observed according to the group. The results in Groups 1 (synaesthetes) and 2 (naïve control) showed the typical presence of a reliable decrease in RT between 0 and 1 repetition trials and the lack of a further decrease between 1 and 2 repetition trials. Note that this result replicates the previous findings reported in the literature (e.g., Rogers & Monsell, 1995; Tornay & Milan, 2001). In Group 3 (control group with white number targets or trained control), there was no evidence of mental set reconfiguration or task switching cost. We can therefore discard the idea of color-number synaesthesia as an associative learning or practice effect, at least when measured with the task switching cost paradigm. However, we recognise that it depends on the type of associative learning paradigm. Meier and Rothen (2009) used a "weak" learning paradigm that did not yield a synaesthetic effect, but others employed a more powerful learning paradigm (Cohen Kadosh et al., 2005). It is possible that our learning paradigm is weak and for that reason we are unable to give strong support to the previous statement (synaesthesia is not the result of associative learning).

The mental set reconfiguration between numbers and photisms in synaesthesia was similar to the real mental set reconfiguration in control group 2 in several factors, such as general mean RT, cost magnitude and cost reduction with RSI. The possible differences might be in the role of the target stimulus as the cue to complete reconfiguration and in cost asymmetry.

In Groups 1 (synaesthetes) and 2 (naïve control), the switch cost decreased with RSI, but although it was still significant with long RSI (residual cost) in Group 2, there was no residual cost for the synaesthete participants (G1). If we consider the residual cost as a real cognitive limitation and an index of exogenous reconfiguration, we should, in the case of our synaesthete participants, interpret the results in terms of full endogenous reconfiguration. However, the mental set reconfiguration was similar for both groups. In the case of Group 2, the participants alternated between two perceptual tasks; in the case of the synaesthete participants, we can speak of a conceptual task shift. However, in both cases we found mental set reconfiguration with an endogenous (the reduction of cost with RSI) and an exogenous (the abrupt offset of cost) component. As we have already pointed out, perhaps the only difference is the cognitive limitation discussed in the context of the relationship between synaesthesia and cognitive flexibility: It is easier for a synaesthete to shift his/her mental set, at least between numbers and photisms. The color task was easier than the number task for Groups 1 (synaesthetes) and 2 (naïve control), but the cost asymmetry only occurred with synaesthetes (G1), it being more difficult for them to shift from photisms to numbers than from numbers to photisms. However, in short RSI in both G1 and G2, the cost was significant for both tasks but bigger in G1 than in G2 for the number task and tending to be shorter for the color task. What looks clear is that the activation of photisms implies a mental cost and that the relationship between inducers and concurrent sensations appears not to be bidirectional. However, in the graph for G2 (naïve control), the result of the numerical task after switching from the color task was substantially lower than for the G1 group (synaesthetes) and similar to the color task. This might imply that color activates numerical information. In other words this particular result could be in line with bidirectionality.

The results can be summarized in the following way: the synaesthetes' data pattern is similar to that of the colored-numbers control group (naïve control) in the short RSI condition (i.e., task-switch costs and no further decrease in RT with more task repetitions), but is similar to the white-numbers control group (trained control) in the long RSI condition (i.e., no task-switch costs). The question is whether this data pattern is consistent with the idea that, for synaesthetes, the color task-set fades away faster than for non-synaesthetes. What it is clear is that photisms produced proactive interference, a real impact in information processing.

Confronted with the question of which processes are involved in the reconfiguration of the task-set in the case of the participants with synaesthesia, our results probably just reflect an interaction between endogenous and exogenous reconfiguration processes (Sohn & Anderson, 2001). However, at this stage in the research we cannot make strong claims about the nature of such processes. In the future therefore, it would be interesting to combine behavioral paradigms such as the one used here with neuroimaging techniques to provide further information concerning the processes that might be involved in the reconfiguration of task-set in synaesthesia.

The task-shift paradigm is better suited to studying the interaction between endogenous and exogenous components in the activation of photisms (Ruthruff, Remington, & Johnston, 2001). The results with the task switching paradigm are less affected by associative learning than the Stroop task. This paradigm may also be relevant to the question of whether alphanumeric-color synaesthesia involves perceptions of color and to studying in a general way how photisms influence responses to subsequent stimuli (Smilek & Dixon, 2002).

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APPENDIX 1

The control group was actually made up of 20 participants. With respect to G2, five performed the extended version of the task and five the reduced version with short RSI (these are the controls referred to in the article). The extended version consisted in alternating between numbers and colors, using the ciphers 1 to 9, the colors red/green and yellow/blue (opponent colors). The number task consisted in indicating whether the number was odd or even, whereas the color task consisted in indicating the opponent colors with the left or right key. Colors were randomly assigned to each participant. For example, for a given participant the left key stood for red and blue, and the right key for green and yellow. The reduced version is described in the main article (Methods) and included fewer numbers and colors. We decided to employ the reduced version after observing that there were no significant differences in the pattern of results between the two versions. For the extended version, average RTs in the number task were 880, 670 and 630 ms. for the switch, first repetition and second repetition trials respectively. For the color task, average RTs were 790, 610 and 580 ms. There was a significant main effect of Group in RT, $F(1,11) = 8.56$, $p < .001$. This RT was longer for the extended version of the task, but there were no interactions with Group, Task or Trial Type. In other words, the symmetry/asymmetry relationship was similar for both tasks (absence of cost asymmetry), as was the magnitude of the cost. These results enabled us to discover whether subjects were in fact completing the tasks as instructed, rather than finding simpler routes (to respond with the right button to a “red” number) due to the limited set of stimuli. The similar results obtained in the extended and reduced versions of the tasks led us to believe that participants were indeed following the instructions.

Moreover, the reduced version was necessary given that the G3 group (trained control group) could not perform the extended version within a reasonable time, due to the difficulty of remembering the color-number associations.

Regarding the G3 group, two sub-groups were formed for the short RSI condition. The trained group (described in Methods) carried out the color tasks in the same way as synaesthetes A and B, whereas another group of six participants carried out the color task in the same way as synaesthetes C and D (that is, three participants indicated whether the color was yellow, while the other three indicated whether the color was red). There were no significant differences between the sub-groups, nor were there any interactions involving the Group variable. Average RTs for the sub-group trained as synaesthetes C and D were 550, 530 and 540 in the number task and 475, 480 and 497 in the color task, for switch, first repetition and second repetition trials respectively.

Once the equivalence between control groups was established (that is, the two groups were interchangeable and the global pattern of results, mainly regarding interactions, did not change), we decided to consider four participants who performed the reduced version of the task as the naive control group (G2), while the trained control group (G3) was formed by four subjects, two from the sub-group that simulated synaesthetes A and B and two from the sub-group that simulated synaesthetes C and D.