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Cost of mental set reconfiguration in a digit-photism synesthete

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Abstract

The task switch paradigm has helped psychologists gain insight into the processes involved in changing from one activity to a new one. In this study we present experiments in which we investigate the reconfiguration process elicited by the task switching paradigm in synesthesia. In Group 1, N., a digit-colour synesthete, alternated between an odd-even task and a colour 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 coloured numbers. The results of these studies showed: a significant task switch cost with an abrupt offset; a cost reduction in long RSI; and a significant interaction between the switch cost and the Stroop effect. Taken together, our results indicate that the conceptual mental set reconfiguration shown by the participant with synesthesia is similar to the perceptual mental set reconfiguration of the control group.

KEYWORDS: ATTENTION; SYNESTHESIA; TASK SWITCHING; RECONFIGURATION PROCESSES; STROOP EFFECT.

Cost of Mental Set Reconfiguration in a Digit-Photism Synesthete

In synesthesia, ordinary stimuli elicit extraordinary experiences (Dixon, Smilek, Cudahy and Merikle, 2000). When N., a digit-colour synesthete, views white digits, each number elicits a photism (a visual experience of a specific colour). For example, in the case of N., the photism elicited by the number 3 is the visual experience of red and the photism elicited by the number 4 the visual experience of blue. It has been proposed that synesthetic experience is consistent and automatic but may be induced independent of external stimuli.

Following Dixon et al. (2000), as a measure of consistency, we asked N. to name the colour of her photisms elicited by the digits 1 to 9 shown in random order, 10 times for each digit. N.´s pairings between digits and colours were 100% consistent across repetitions. To assess automaticity, the Stroop task is used (Dixon et al., 2000). Whether or not the Stroop effect is significant, the experience can be considered automatic. In our case, colour reaction times were recorded in N.'s trials for digits displayed in white that were either congruent or incongruent with the photism elicited by the digit displayed in the previous trial (sequential Stroop effect).

However, our main goal was to assess the endogenous (For example: activating the concept of a digit) and exogenous (an externally presented inducing stimulus) components necessary to trigger a photism, by means of the task switching paradigm (Rogers and Monsell, 1995; Tornay and Milan, 2001).

The task switching paradigm

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, Styles, and Hsieh, 1994; Allport and Wylie, 1999; Gilbert and Shallice, 2002; Meiran, 1996; Meiran, Chorev, and Sapir, 2000; Rogers and Monsell, 1995; Spector and Biederman, 1976; Tornay and Milán, 2001; see Jersild, 1927, for an early study. This effect has been termed switch cost (e.g., Roger and Monsell, 1995).

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. response-stimulus interval) 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*).

Results such as these showed the importance of exploring the exogenous component and finding out how it operates and what factors activate it. Such an abrupt disappearance has been replicated a number of times (e.g., Allport et al., 1994; Rogers & Monsell, 1995, Experiment 6; Meiran, 1996; Tornay & Milán, 2001, Experiment 3; Milán et al., 2005). It has generally been assumed that the appearance of a task-related stimulus is the key feature causing the disappearance of cost. Rogers and Monsell argued that mental reconfiguration always waits for a new stimulus before completion. In their opinion, the exogenous component, reflected in the residual cost with long RSI and triggered by stimulus presentation, would consist of a bottom-up completion of task set reconfiguration.

However, we must now 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 et al., 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.

Experiment 1

The goal of this experiment was to investigate the possible differences in the mental set reconfiguration between a digit-colour synesthete participant, N., and non-synesthete participants. We used regular sequences of task switch with short and long RSIs in order to maximise the probability of obtaining switch cost. 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 shorter switch cost but a still significant residual cost. However, in the case of the participant with synesthesia 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).

Method

Participants

Eleven undergraduate students (5 women, 6 men) from the University of Granada took part in Experiment 1. They were given course credits in exchange for their participation. All the participants reported normal or corrected-to-normal vision. One of them had number-colour synesthesia.

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 participants had to perform. The plus sign (+) signalled the number task while the asterisk (*) indicated the colour 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. Three of these varied on a trial-by-trial basis: task (number vs. colour), and 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 (N., the participant with colour-number synesthesia, who ran through the experiment twice with white numbers as target stimuli. The photisms elicited by target stimuli 4 and 5 were blue, while the digits 3 and 8 elicited red); G2 (a control group of five non-synesthetes. They conducted the same experiment four times with white numbers as target stimuli, but with instructions to indicate the imaginary colour blue for the numbers 4 and 5 and to press the red button in the presence of numbers 3 and 8 in a simulated colour task); and G3 (a second control group of five non-synesthetes, who ran through a new experiment twice with coloured numbers. The numbers 4 and 5 appeared in blue and the numbers 3 and 8 in red). We computed the sequential Stroop effect in the colour task as the difference in Reaction Time between the congruent and incongruent colour conditions associated to the digits in trials N and N-1. To compute the Stroop effect in G1, we considered the photisms elicited by the digits; in G2, the instructed and imaginary colour for each number; and in G3 the real colour of the numbers. In all groups, the digit repetition priming was excluded.

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 colour was red or blue (colour task). 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 participants had to press "b" when the number was even or the colour was red and "n" when the number was odd or the colour 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.

Tasks were alternated every 3 trials (e.g. CCC-NNN sequences). Each time, the participants completed 700 trials distributed between two experimental sessions related to the two values of RSI. The two sessions were counterbalanced across participants. The participants completed 5 blocks of 70 trials in each condition, separated by a short rest. Prior to each session, participants completed a practice block of 70 trials in order to familiarise 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) was our main Dependent variable.

Results

The RT (for correct responses only) and accuracy data were submitted to a four-way repeated-measures analysis of variance (ANOVA) with the factors RSI (short vs. long), Task (number vs. colour), 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) = 20.40, p<.001 (mean RT for the number task was 740 ms and for colour task 525 ms), and Number of repetitions F(2, 18) = 15.93, p<.001, and a significant interaction between Group, RSI and Number of repetitions, F(4, 18) = 4.93, p<.001, (see Figure 1). We then analysed the data separately for each RSI condition and for each Group. Only in G1 and G3, was the interaction between RSI and Number of repetitions significant and unaffected by Group, F(2, 10) = 10.35, p<.003.

In the short RSI condition, we found a significant interaction between Group, Task and Number of repetitions, F(4, 18) = 6.56, p<.001. The difference between G1 and G3 was not significant, F <1. However, the differences between G1 and G2, F(2,

10) = 29.81, $p<.001$ and between G2 and G3 were significant, $F(2, 16) = 6.48$, $p<.008$.

The switch cost (i.e. the difference in RT between 0 repetition trials and 1 repetition trials) and the difference between 1 repetition trials and 2 repetition trials were not significant in G2, $F < 1$. However, the switch cost, $F(1, 5) = 197.35$, $p<.001$, though not the difference between 1 repetition trials and 2 repetition trials, $F < 1$, reached significance in G1. G3 showed a significant switch cost, $F(1, 8) = 16.34$, $p<.001$, but the difference in RT between the first and the second repetition trials was not reliable, $F < 1$. Only in G1 was the interaction between Task and Number of repetitions marginally significant, $F(2, 10) = 3.27$, $p<.08$: The switch cost was greater in the number task (300 ms versus 180 ms).

In the long RSI condition, a significant interaction between Task and Group was found, $F(2, 9) = 6.77$, $p<.04$, and the main effect of Number of repetitions was marginally significant, $F(2, 18) = 3.11$, $p<.06$. Only in G3 was the switch cost significant in the long RSI, $F(2, 8) = 5.12$, $p<.048$. The Task effect was significant in G1, $F(1, 1) = 225$, $p<.004$, and marginally significant in G3, $F(1, 4) = 5.26$, $p<.08$. The mean RT for the number task was 540 ms and for the photism task in G1, 400 ms. In G3, the mean RT for the number and colour tasks were 590 ms and 510 ms, respectively.

The ANOVA of the accuracy data revealed a significant interaction between Groups 1 and 3 and Number of repetitions, $F(2,10) = 24.88$, $p< 0.001$. The switch cost was significant only for Group 3, $F(1, 4) = 11.5$, $p<0.02$. There were no other significant effects of any relevance. See table 1.

With regard to the Stroop effect (see figure 2), the RT (for correct responses only) in the colour task was submitted to a four-way repeated-measures analysis of variance (ANOVA) with the factors RSI (short vs. long), Stroop (congruent vs.

incongruent) and Number of repetitions (0, 1 – we broke down the data through task repetition trials) for each Group (G1, G2 and G3). The interaction between Group, Stroop effect and Number of repetitions was significant, $F(2, 9) = 7.80$, $p<.01$.Only in G1 and G3 was the Stroop Effect marginally significant, $F(1, 1) = 46,19$, $p<.09$, and $F(1, 4) = 7.26$, $p<.054$, respectively. The interaction between the Stroop effect and Number of repetitions was also significant for both groups, $F(1, 1) = 94.76$, $p<.02$ and $F(1, 4) = 10.25$, $p<.03$, respectively. For both groups, the Stroop effect was significant only in the repetition trials, $F(1, 1) = 237.67$, $p<.04$ and $F(1, 4) = 16.47$, $p<.01$, respectively. In G2, the Stroop effect and the interaction between the Stroop effect and Number of repetitions were not significant, $F<1$.

The main conclusion to draw from Experiment 1 is that a different pattern of switch cost reconfiguration can be observed depending on the group. The results in groups 1 (participant with synesthesia) and 3 (control group with coloured number targets) 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 and Monsell, 1995; Tornay and Milan, 2001). In group 2 (control group with white number targets), there was no evidence of mental set reconfiguration or task switching cost. We can therefore discard the idea of colour-number synesthesia as an associative learning or practice effect. The mental set reconfiguration between numbers and photisms in synesthesia was similar to the real mental set reconfiguration in control group 3 in several factors, such as general mean RT, cost magnitude and cost reduction with RSI. The only possible difference might be in the role of the target stimulus as the cue to complete reconfiguration. What is clear is that these results cannot be learned or simulated.

General Discussion

In groups 1 and 3, the switch cost decreased with RSI, but although in group 3 it was still significant with long RSI (residual cost), for the participant with synesthesia there was no residual cost. If we consider the residual cost as a real cognitive limitation and an index of exogenous reconfiguration, in the case of our synesthete participant, N., we should interpret the results in terms of full endogenous reconfiguration. However, the mental set reconfiguration was similar for both groups. In the case of group 3, the participants alternated between two perceptual tasks; in the case of the synesthete participant, we can speak of a conceptual task shift. But in both cases we found indices of 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 that the cognitive limitation with regard to shifting mental set or intention that represents the residual cost is not present in the person with synesthesia. These ideas could be discussed in the context of the relationship between synesthesia and art or creativity. It is easier for a synesthete to shift his/her mental set, at least between colours and numbers.

With reference to the Stroop effect, as we mentioned earlier, Stroop paradigms have shown that photisms are automatic and involuntary. Here we replicate these findings. The interaction between the Stroop effect and the switch cost probably reflects activation of the same underlying mechanism, the central executive or an endogenous attentional mechanism for controlling information processing (Pardo et al., 1990; Sohn et al., 2000). On the other hand, the Stroop effect shown by synesthetes could be the result of semantic associations between alphanumeric stimuli and colours. However, the switch cost (its temporal course and components) shown here represents a different piece of data, which must be considered before reaching any conclusion based on semantic associations or associative learning.

Confronted with the question of which processes are involved in the reconfiguration of the task-set in the case of the participant with synesthesia, our results probably just reflect an interaction between endogenous and exogenous reconfiguration processes (Sohn and 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 behavioural 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 synesthesia.

The task-shift paradigm could help us to study the interaction between endogenous and exogenous components in the activation of photisms (Ruthruff, Remington and Johnston, 2001). This paradigm may also be relevant to the question of whether alphanumeric-colour synesthesia involves perceptions of colour and in general to study how photisms influence responses to subsequent stimuli (Smilek and Dixon, 2002).

References

Allport, A. D., and Wyllie, G. (1999). Task-switching: positive and negative priming of task set. In G., Humphreys, J. Duncan, & A. Treisman, (Eds.), *Attention, space, and action: Studies in cognitive neuroscience.* Oxford: University Press.

Allport, A., Styles, E. A., and Hsieh, S. L. (1994). Shifting intentional set: Exploring the dynamic control of tasks. In C. Umiltá & M. Moscovitch (Eds), *Attention and performance XV*. Cambridge, MA: MIT Press.

Dixon, M.J., Smilek, D., Cudahy, C., and Merikle, P.M. (2000). Five plus two equals yellow. *Nature*, vol. 406, 365.

Gilbert, S. J. and Shallice, T. (2002). Task switching. A PDP model. *Cognitive Psychology*, *44*, 297-337.

Jersild, A.T. (1927) Mental set and shift. *Archives of Psychology*, *89*.

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimentall Psychology: Learning, Memory and Cognition*, *2*, 1423-1442.

Meiran, N., Chorev, Z., and Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology*, *41*, 211-253.

Milan, E.G., Sanabria, D., Tornay, F. and Gonzalez, A. (2005). Exploring task set reconfiguration with random task sequences. *Acta Psychologica, 118*, 319-331.

Monsell, S. (1996). Control of mental processes. In V. Bruce (Ed.), *Unsolved mysteries of the mind*, 93-148. Hove: Erlbaum.

Pardo, J. V., Pardo, P. J., Janer, K. W., and Raichle, M. E. (1990). The anterior cingulate cortex mediates processing selection in the Stroop attentional conflict paradigm. *Proceedings of the National Academy of Science*, *87*, 256-259.

Posse, B., and Hommel, B. (1998). Automatic task cueing. Paper presented at the X Congress of the European Society for Cognitive Psychology, Jerusalem, Israel.

Rogers, R. D., and Monsell, S. (1995). Cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, *124*, 207-231.

Ruthruff, E., Remignton, R. W., and Johnston, J. C. (2001). Switching between simple cognitive tasks. The interaction of top-down and bottom-up factors. *Journal of Experimental Psychology: Human Perception and Performance*. *27*, 1404-1419.

Schneider, W. (1988). Micro Experimental Laboratory: An integrated system for IBM PC compatibles. *Behaviour Research Methods, Instruments, & Computers*, *20*, 206-271.

Smilek, D. and Dixon, M.J. (2002). Towards a synergistic understanding of Synaesthesia. *Psyche* 8(01).

Sohn, M. H. And Anderson, J. R. (2001). Task preparation and task repetition: two component model of task switching. *Journal of Experimental Psychology: General*, *130*, 764-778.

Sohn, M. H., Ursu, S., Anderson, J. R., Stenger, V. A., and Carter, C. S. (2000). The role of prefrontal cortex and posterior parietal cortex in task switching. *Proceedings of the National Academy of Sciences of the USA*. *97*, 13448-13453.

Spector, A., and Biederman, I. (1976). Mental set and mental shift revisited. *American Journal of Psychology*, *89*, 669-679.

Stablum, F., Leonardi, G., Mazzoldi, M., Umilta, C., and Morra, S. (1994). Attention and control deficits following closed head injury. *Cortex, 30*, 603-618.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643-662

Tornay, F. J., and Milan, E. G. (2001). A more complete task-set reconfiguration in random than in predictable task switch. *The Quarterly Journal of Experimental Psychology A*, *54*, 785-803.

Table 1.

Percentage of errors in Experiment 1, as a function of the Group and the Number of repetitions factors for each RSI level.

Short RSI

	Group		
Repetitions	G1	G2	G3
0	5%	6%	12%
1	3%	7%	10%
2	3%	6%	8%

Long RSI

	Group		
Repetitions	G1	G2	G3
0	3%	7%	10%
1	5%	5%	6%
2	2%	4%	3%

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Figure Captions

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

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

Figure 1.

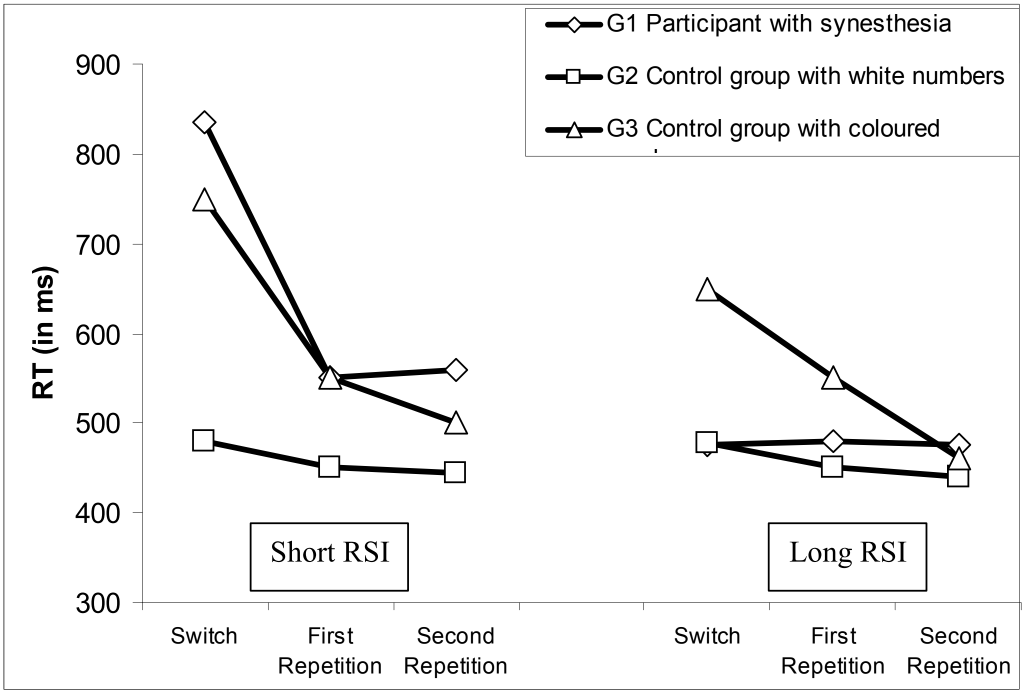
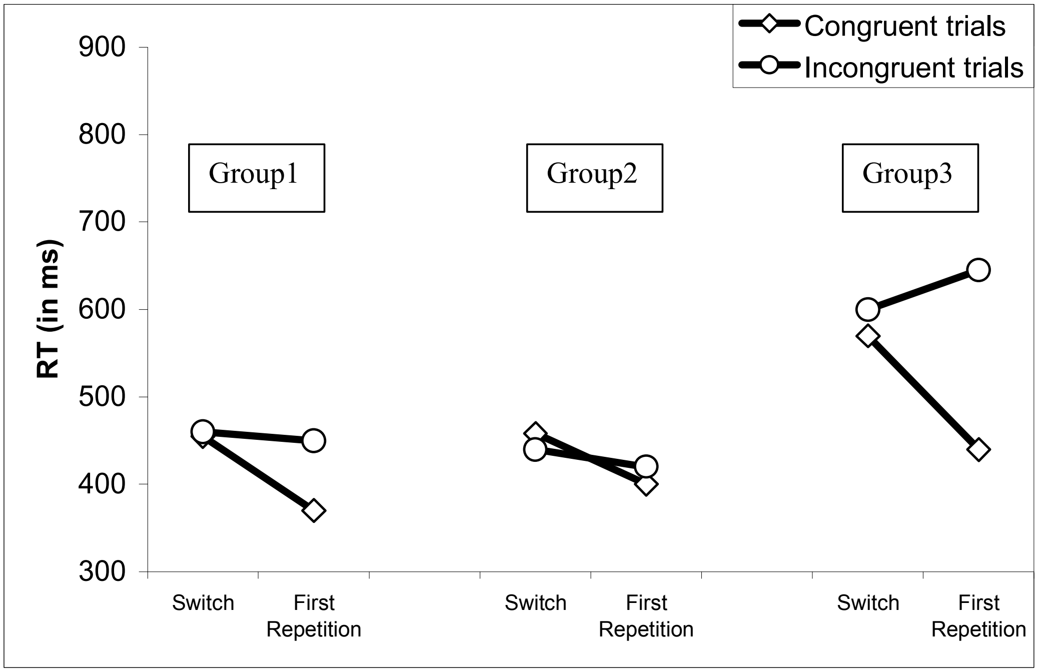

G1 Participant with synesthesia
G2 Control group with white numbers
G3 Control group with coloured
900
800
700
600
500
400
300
RT (in ms)
Short RSI
Long RSI
Switch
First Repetition
Second Repetition
Switch
First Repetition
Second Repetition

Figure 2.


Congruent trials
Incongruent trials
RT (in ms)
900
800
700
600
500
400
300
Group1
Group2
Group3
Switch
First Repetition
Switch
First Repetition
Switch
First Repetition