Running Head: The cost of a photism

Cost of mental set reconfiguration between digits and its photisms in synesthesia

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Abstract

In this study we present an experiment investigating the reconfiguration process elicited by the task switching paradigm in synesthesia. We study the time course of the operations involved in the activation of photisms. In the experimental Group, four digit-colour synesthetes 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 the expected pattern in the case of regular shift for the control group: 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 ran exactly the same tasks that the experimental group (with white numbers like targets and a second imaginary colour task). We found no cost for this second control group. It means that the cost of mental set reconfiguration between numbers (inducers) and their photism (concurrent sensations) occurs, that there is a specific cost asymmetry (from photisms to inducers) and that this cost can not be explained by associative learning. The results are discussed in terms of exogenous and endogenous components of mental set reconfiguration.

KEYWORDS: SYNESTHESIA; TASK SWITCHING.

Cost of mental set reconfiguration between digits and its photisms in synesthesia

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.   During preliminary interviews, the four synaesthetes of our experiment were asked about their specific synaesthetic associations. One week later, they were re-interviewed in order to asses the stability of their synaesthesia. All the synaesthetes showed 100% consistence in their claims. To further explore their synaesthetic condition, the subjects were also asked to fill in an online version of the Synaesthesia Battery (http://home.comcast.net/~sean.day/html/tests_for_synesthesia.html). The test results were positive for all the synaesthetes. The control group also fill the online version of the synaesthesia battery with negative results. All the synaesthetes showed color-number synesthesia. The association between colours and numbers one to nine for each of them can be observed in table 1.

INSERT TABLE 1 ABOUT HERE

Since we wanted to examine cognitive flexibility towards colors per se (from numbers to photisms in fact), we used number stimuli as synaesthetic inducers (different synaesthetic inducers, such as words or musical sounds, might not be as emotionally neutral as numbers and could therefore change the patetrn of data – Milán et al., 2007). However, before proceeding with our exploration, it was necessary to obtain a thorough classification of their “phantom” colors. This was achieved by means of a customized computer program developed in the C# language, that would display a synaesthetic inducer (a number in this case) on the left side of the screen and a palette of color shades on the other side. The task was to observe the inducer presented and then to choose the color sample that was closest to his synaesthetic experience. The synesthetes went through numbers from one to ten; their responses were recorded in a data file. The correspondence between the numbers and specific color shades was reliable and consistent over time. In a retest 2 weeks later, they selected the same color hues in 92% of the trials. See in Table 2 the correspondence between colors in RGB code and numbers for the experimental group. When we asked to one of our control groups (G3) to learn an arbitrary relationship between specific color hues and numbers and we retest them two weeks after, the accuracy was 21%.

INSERT TABLE 2 ABOUT HERE

The control groups and the experimental group ran a Stroop like task (to indicate the colour of the number frame). The white numbers were presented in coloured frames congruent or incongruent with the photims (for the synesthetes o group G1) or with the learning imaginary colors associate to numbers (for the control group G3) or without any reference to colors (control group G2). We found a significant Stroop effect for groups G1 and G3. See table 3. It means that the Stroop like tasks are not the best tool for diagnosing synesthesia.

INSERT TABLE 3 ABOUT HERE

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

The goal of this experiment was to investigate the possible differences in the mental set reconfiguration between four digit-colour synesthetes participants, 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 participants 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). A photism is a phantom colour, an endogenous experience that can be elicited by mental imagery. In short, our objective is to determine if the mental set reconfiguration between a number and its photism produces a shift cost and if it was the case, exactly what kind of cost (endogenous or exogenous)?. If photims are a concurrent, dominant and automatic experience (Cytowic, 2002), should we not expect task switching costs?. We can also determine the cost asymetry (from photisms to numbers or viceversa). Synesthesia is normally a one way experience (from inducers to concurrent sensations but not viceversa). In other words, we test wether the cost of task switching paradigm can be a better empirical test than Stroop like tasks to diagnose synesthesia.

Method

Participants

Fourteen undergraduate students (8 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. Four 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 (the participants with colour-number synesthesia, who ran through the experiment four times with white numbers as target stimuli. G2, a control group of five non-synesthetes, who ran through the experiment four times but with coloured numbers. The numbers 4 and 5 appeared in blue and the numbers 3 and 8 in red. G3, a second control group of five non-synesthetes. They conducted the same experiment of G1 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. We used for all groups 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 synesthetes. For each synesthete the correspondence between response set and colours 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 colour was red or blue for the control groups and synesthetes A and B ((colour task). For the synesthete C, the colour task was to indicate if the colour was yellow or not yellow and for the participant D, the colour task was to indicate if 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 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 1400 trials distributed between two experimental sessions in two consecutive days and related to the two values of RSI. The sessions were counterbalanced across participants. The participants completed 5 blocks of 70 trials twice in each session, separated by a short rest of ten minutes. 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, 11) = 32.58, p<.0001 (mean RT for the number task was 580 ms and for colour task 470 ms), and Number of repetitions, F(42, 22) = 23.52, p<.00001, and a significant interaction between Group, RSI and Number of repetitions, F(4, 22) = 8.98, p<.0001. The interaction between Task, Group, Number of repetitions and RSI was also significant, F(4, 22) = 3.94, p<.01. We then analysed the data separately for each RSI condition. See figures 1 a (Short RSI) and 1 b(long RSI).

In the short RSI condition, we found a significant interaction between Group, Task and Number of repetitions, F(4, 22) = 9.24, p<.0001. The difference between G1 and G2 was not significant, F <1. However, the differences between G3 and G2, F(1, 11) = 18.06, p<.001 and between G1 and G3 were significant, F(1, 11) = 8.78, p<.01.

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 G3, F < 1. In G3, only for the first session, there is a non significant cost and a clear but non significant tendency for cost asymetry: the cost for the colour task tends to be bigger than the cost for the number task, being of about 103 msec for the colour task and of - 64 msec for the letter task. However, the switch cost, though not the difference between 1 repetition trials and 2 repetition trials, $F < 1$, reached significance in G1, $F(1, 11) = 37.89$, $p<.00001$, and G2, $F(1, 11) = 22.08$, $p<.0006$. Only for G1 (the group of synesthetes) we found cost asymmetry, $F(1, 11) = 95.31$, $p<.00001$, being the cost for the colour task (146 msec) shorter than the cost for the number task (435 msec). For G2 the cost was similar for both tasks (about 180 msec for the letter task and 218 for the color task). The cost for the colour task was not different in G1 with respect to G2, $F<1$, but the cost for the number task was bigger in G1 with respect to G2, $F(1, 7) = 126.79$, $p<.009$.

In the long RSI condition, we found a main effect of task, $F(1, 11) = 14.14$, $p<.003$, and number of repetitions $F(2, 22) = 4.79$, $p<.01$. The interaction between Group and number of repetitions was only marginally significant, $F(4, 22) = 2.35$, $p<.08$. However, the switch cost was significant only for G2, $F (1, 11) = 6.89$, $p<.02$.The differences in cost magnitude between G1 and G2, $F (1, 11) = 3.59$, $p<.08$, and between G2 and G3 were marginally significant, $F (1, 11) = 3.29$, $p<.09$. There were no differences between G1 and G3, $F<1$.

The ANOVA of the accuracy data revealed a significant interaction between Groups and Number of repetitions only in the long RSI, $F (2,22) = 21.09$, $p< 0.00001$. The switch cost was significant only for Group 2, $F (1, 11) = 6.49$, $p<0.02$. There were no other significant effects of any relevance. See table 4.

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 and 2 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 3 (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 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 asymetry. What is clear is that these results cannot be learned or simulated.

General Discussion

In groups 1 and 2 the switch cost decreased with RSI, but although in group 2 it was still significant with long RSI (residual cost), for the participants 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 participants, 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 2, 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 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 that represents the residual cost is not present in the persons with synesthesia. These ideas could be discussed in the context of the relationship between synesthesia and creativity or cognitive flexibility. Is it easier for a synesthete to shift his/her mental set, at least between numbers and colours?. The colour task was easier (with respect to the number task) for groups 1 and

2, but the cost asymmetry only happens for synesthetes (G1), being more difficult for them to shift from photisms to numbers than from numbers to photisms. However the cost was significant for both tasks in short RSI in G1 and G2, but it was bigger for the number task in G1 than in G2 and tends to be shorter for the colour task. What is clear is that the activation of photisms implies a mental cost and that the relationship between inducers and concurrent sensations is not bidirectional.

The results can be summarised in the following way: The synesthetes' data pattern is similar to the coloured-numbers control group 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 in the long RSI condition (i.e., no task-switch costs). The question is if this data pattern is consistent with the idea that the synethete's colour task set fades away more quickly than the non-synesthetes' colour task set?

Confronted with the question of which processes are involved in the reconfiguration of the task-set in the case of the participants 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 better than Stroop like tasks (Ruthruff, Remington and Johnston, 2001). The results with the task switching paradigm are less afected by associative learning. 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).

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Figure and Table Captions

Figure 1a. 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 for short RSI.

Figure 1b. 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 for long RSI.

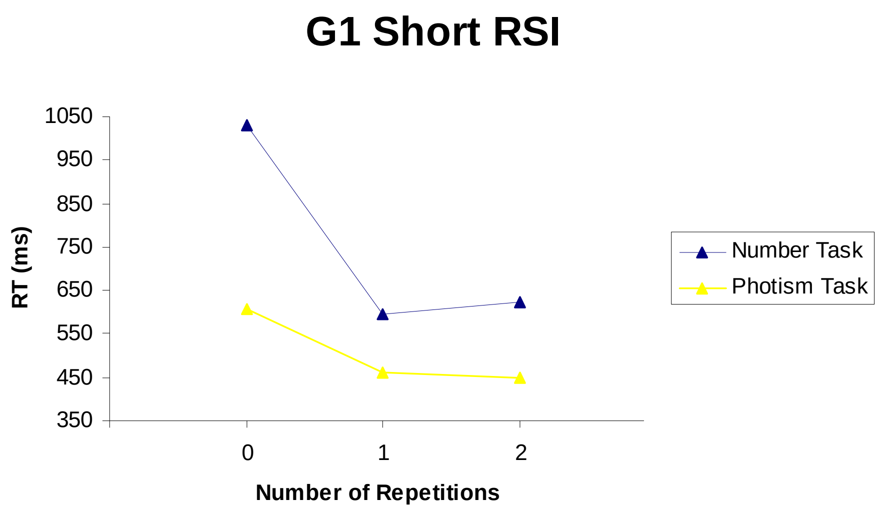
Table 1. Description of number-color synesthesia for each synesthete participant.

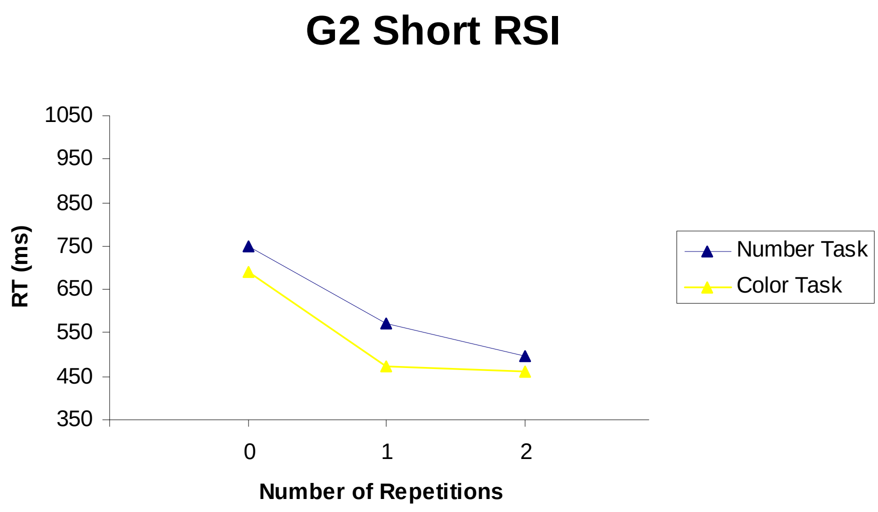
Table 2. Correspondence between color in rgb code and numbers for the synesthete participants.

Table 3. Stroop like effect. The interaction between Group and Stroop effect was significant, $F(1, 11) = 23.35$, $p<0.005$. The effect was significant for G1, $F(1, 3) = 11.55$, $p<0.05$, and G3, $F(1, 4)=13.21$, $p<0.02$, but not for G2, $F(1,4)=0.68$, $p<0.45$.

Table 4. Percentage of errors in Experiment 1, as a function of the Group and the Number of repetitions factors for each RSI level

Figure 1a.


G1 Short RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Photism Task


G2 Short RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Color Task

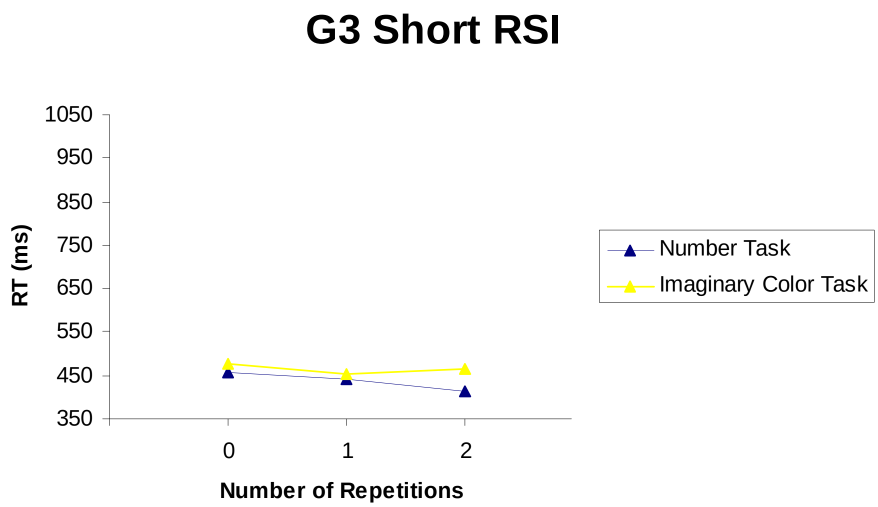
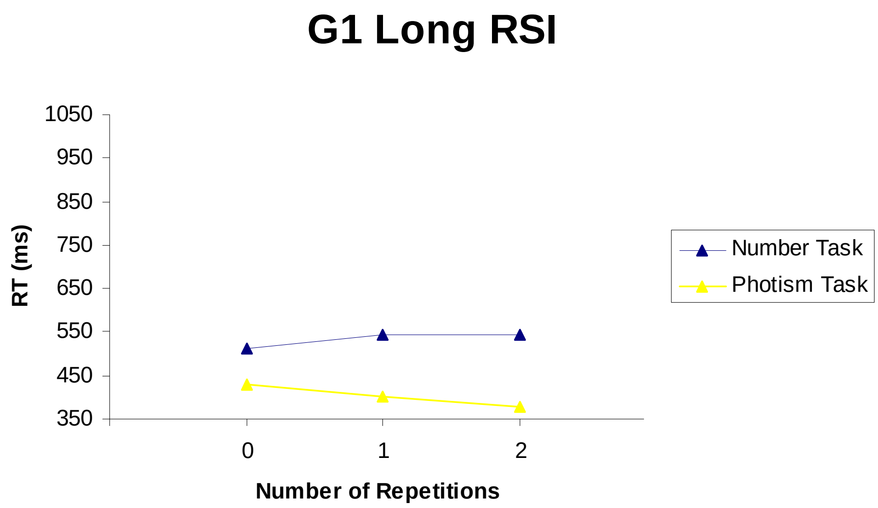

G3 Short RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Imaginary Color Task

Figure 1b.


G1 Long RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Photism Task


G2 Long RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Color Task

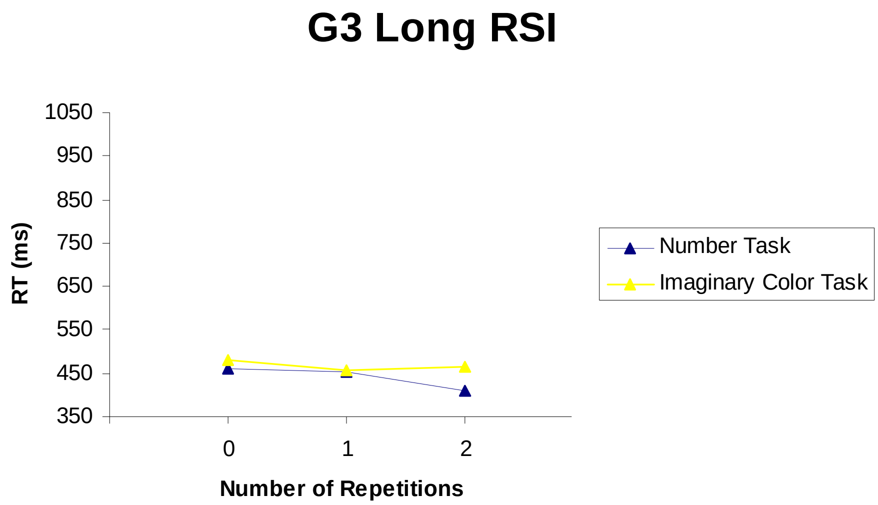

G3 Long RSI
1050
950
850
750
650
550
450
350
RT (ms)
0
1
2
Number of Repetitions
Number Task
Imaginary Color Task

Table 1

NUMBERS	SYNESTHETE A	SYNESTHETE B	SYNESTHETE C	SYNESTHETE 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 COLOUR
8	DARK RED	RED	DARK YELLOW	RED BLACK
9	WHITE	GREY	BROWN	OCHER

Table 2.

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

Table 3.

Stroop like task	Exp. Group G1	Control Group G2	Control group G3
Congruent trials	505	456	480
Incongruent Trials	625	485	542

Table 4.

Short RSI

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

Long RSI

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

Author Notes

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