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Episodic Retrieval and Decaying Inhibition in the Competitor-rule suppression Phenomenon

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Abstract

The Competitor Rule Suppression (CRS) effect is the performance impairment observed in task switching when the currently relevant task rule is the same rule that had generated a response conflict in the preceding trial. This effect could reflect (a) episodic tagging, in which a competitor rule is retrieved with relative difficulty in subsequent trials or (b) residual active inhibition of the competing rule. In order to help distinguishing between the two accounts, the authors manipulated the Response-Cue Interval (RCI), which may influence both processes. CRS increased with increasing temporal distinctiveness between the previous and current episode (operationalized by the ratio of the current RCI to the previous RCI, RCI/pRCI), thus supporting episodic tagging. CRS additionally decreased numerically with increasing RCI even when the RCI/pRCI ratio was fixed, thereby providing suggestive support for the decay account.

Keywords: task-switching, reaction time, suppression, episodic tagging, decaying inhibition

1. Introduction

In everyday life, people are continually confronted with changing environments that require them to be able to adjust quickly to changing demands on their attention. To understand how one can flexibly switch from one task to another, researchers employ various task-switching paradigms (Karayanidis, Jamadar, Ruge, Phillips, Heathcote, & Forstmann, 2010; Kiesel, et al., 2010; Meiran, 2010; Monsell, 2003, Vandierendonck, Liefooghe, & Verbruggen, 2010, for review. See Koch, Gade, Schuch, & Philipp, 2010, for review on inhibition in task switching). In a typical task-switching paradigm, participants are asked to classify multidimensional objects according to a particular dimension (or a 'task rule'). For example, participants may be asked to classify a target stimulus according to its shape, color, or spatial location, etc. In one version of the task switching paradigm, the relevant task rule for classification changes randomly and participants are given a task cue in the beginning of each trial, instructing them which rule is currently in effect.

In the context of task-switching, the present study focuses on a mechanism believed to enable participants deal with the control dilemmas which are invoked in situations involving frequent task switches. As noted by Goschke (2000), cognitive control often involves maintaining a delicate balance between conflicting demands. In task-switching, the conflict arises because participants need to maintain high readiness to execute any one of the possible task rules while remaining focused just on one task rule, which is the relevant task rule. In a recent behavioral experiment (Meiran, Hsieh, & Dimov, 2010), we showed evidence for a finely targeted mechanism – labeled "competitor rule suppression" (CRS) – that operates only on the rule which has generated the response conflict and does so at the relatively abstract level of the task rule (see Tipper, Weaver, & Houghton, 1994, for a related idea). To demonstrate CRS, we used a paradigm involving four tasks (two location tasks: up-down, right-left; and two tasks performed on photographs of faces: gender and hair color) (see Meiran et al., 2010, Figure 1). Thus, each trial involved a relevant (to be executed) task rule and three irrelevant task rules. Moreover, these irrelevant rules could activate either competing or congruent responses. For example, if the relevant rule indicates *Key 1* as the correct response, the other three irrelevant rules may activate either the *competing Key 2* response or the same *Key 1 (congruent)* response. CRS is a sequential effect, because it refers to the relationship between the response-competition that took place in the preceding trial (Trial n-1) to performance in the current trial (Trial *n*). The rationale was that if a given rule was suppressed in Trial n-1, then when the same rule becomes relevant in the following trial (Trial n), its execution is hampered. This CRS+ trial condition is compared against CRS- trial condition in which the currently relevant rule did not generate response conflict in the preceding Trial n-1 (we

use the suffixes "+" and "-" to denote the conditions in which suppression was presumably present or absent in the previous trial).

The choice of task in the paradigm made it possible to distinguish CRS from conflict adaptation (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992) as well as from rule suppression effects that are less finely tuned as compared to CRS. Specifically, the paradigm (see Meiran et al., 2010, Figure 1) involved two pairs of similar rules: two rules related to object identity (hair color and gender) and two rules related to object location (vertical location and horizontal location). Thus, in addition to CRS, we also compared two other scenarios, namely "Similar" and "Other". These two are also sequential effects as CRS, but with different relationship between the competing irrelevant rule in the preceding trial and the relevant rule in the current trial. "Similar" refers to the scenario in which the current relevant rule belongs to the same task category as the irrelevant rule that generated response conflict in the preceding trial. An example is if the currently relevant task rule is gender and the competitor rule in Trial n-1 was hair color. This scenario was labeled "Similar+" and it was compared with scenarios in which the similar rule was not a competitor rule in Trial n-1 ("Similar-"). "Other+" refers to a scenario in which the current relevant rule does not belong to the same task category as the irrelevant rule that generated response conflict in the preceding trial. An example is if the current task rule is gender and a location rule competed in Trial n-1. Again, "Other-" is the scenario in which this "other" rule did not generate conflict. Table 1 provides a formal representation of these conditions.

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

The main reason for contrasting the effects of the three variables, Similar, Other, and CRS is to enable us to explore the different levels of fine-tuning of the inhibitory effort. Because if we compared CRS+ trials to CRS- trials, their difference could be explained in terms of conflict monitoring (Botvinick et al., 2001), as CRS+ trials are characterized by greater conflict in the preceding trial than CRS-. The fact that Similar and Other were not associated with significant effects enabled us to rule out this explanation as well as an explanation that conflict results in the suppression of an entire group of similar rules rather than a specific rule. The results thus led us to conclude that the CRS effect most likely reflects the suppression of a rule that generated incongruence in a preceding trial to resolve task conflict (e.g., Schneider & Verbruggen, 2008).[1] In a subsequent paper, we (Meiran, Hsieh, & Chang, 2011) examined a different set of four tasks, two location tasks (up-down and inner-outer, see Figure 1 in

[1] For those who wish to obtain more detailed discussions regarding the rationale of contrasting the effects of the three variables, Similar, Other, and CRS (i.e., dissociating conflict monitoring and CRS effect), please refer to our two previous two publications (i.e., Meiran et al., 2010; Meiran, Hsieh, & Chang, 2011).

Meiran et al.'s (2011) and the current paper) and two tasks related to object identity, color (red vs. green) and shape (line vs. dot). In this study, we showed that CRS influenced the event related potentials that were locked to the task cue even before the target stimulus appeared and before any response could be generated. These results show that CRS operates at the level of the abstract rule as opposed to more concrete task representations involving stimuli and responses.

1.1. The Current Study

While we termed the effect competitor rule *suppression*, we acknowledged that our design did not permit us to distinguish between two possible accounts, "inhibition" versus "episodic tagging". Similar accounts were discussed in the literature on negative priming (NP, i.e., Tipper, 1985, vs. Neill, Terry, & Valdes, 1994; see Tipper, 2001, for review), which is analogous to CRS in the sense that information that generates conflict is processed less efficiently in the subsequent event.

Two well-known accounts have been proposed, "inhibition" and "episodic tagging" to account for NP. According to the "inhibition" account of NP, while attending to the target, the competing distractors are inhibited (Houghton & Tipper, 1994; Tipper, 1985; Tipper & Cranston, 1985). The inhibition can be sustained for a certain period of the time after the offset of the prime trial. Hence, the NP effect occurs when this inhibited distractor (either an identical or a semantic-related stimulus) becomes the target of the subsequent event target. On the other hand, according to the "episodic tagging" account, NP effect arises from the retrieval of previous episode. It is because when the target is selected, its competing distractor will be labeled as "do-not-respond", hence when this distractor becomes the target, such a "do-not-respond" tag will be retrieved and hamper the processing of the target of the probe trial (Mayr & Buchner, 2006; Neill, 1997; Neill & Mathis, 1998; Neill, Valdes, Terry, & Gorfein, 1992).

Analogous to the NP paradigm, in the current CRS paradigm, according to the "inhibition" account, competitor rule suppression takes place online in Trial n-1 and what is being observed in Trial n is the residue of this suppression activity. According to the "episodic tagging" account, the competitor rule is tagged during Trial n-1 as to-be-suppressed rule. In the next trial, the episode formed in trial n-1 is retrieved along with the "to-be-suppressed" tag, resulting in poorer performance.

Previous studies in the NP literature have attempted to examine the time course of the NP effect to support the inhibition account by assuming that inhibition will decay as a function of passage of time between a prime and a probe trial. However, the results turned out to be equivocal. While some studies have shown a decline in the NP effect as a function of response-to-stimulus intervals (RSIs; measured as the interval between participants' prime-trial (trial n-1) response and the probe-trial (trial n)

response) by using a within-subjects random sequence of RSIs (Neill & Valdes, 1992; Neill & Westberry, 1987); whereas other studies have shown no decrease in the NP effect with increasing RSIs (even up to 6,600 ms, Tipper, Brehaut & Driver, 1990) if using a between-subjects (or between-blocks) design. Neill et al. (Neill, Valdes, & Terry, 1995; Neill, Valdes, Terry, & Gorfein, 1992) reconciled these seemly contrasting results by attributing the discrepant results regarding the time course of the NP effect to the episodic tagging account. They reasoned that with the manipulation of a within-subjects random sequence of RSIs, the ratio of the pRSI (RSI between Trial n-2 to Trial n-1) to the RSI (between Trial n-1 and Trial n) determined the size of NP, such as the shorter of the RSI and the longer of the pRSI would produce a larger NP than vice versa, whereas with the manipulation of a between-subjects design of RSIs, the ratio of the pRSI to the RSI is 1, hence resulting in little effect on the NP effect based on the episodic tagging account. Conversely, the inhibition decay theory would make no such a differential prediction between the within-subject and between-subject design of RSIs. Neill et al. (1992, 1995) have conducted some experiments in support of their reasoning by randomly mixed different lengths of RSIs in a block and have provided empirical evidence showing that the NP effect appeared to be larger when the ratio of the pRSI to the RSI was larger than 1 than that was smaller than or equal to 1. However, some other studies using the same rationale to address a similar issue have obtained the opposite results, such as those by Hasher, Zacks, Stoltzfus, Kane & Connelly (1996) and Conway (1999). In these two studies, the NP effect was not found to be modulated by the ratio of pRSI to RSI – a result which has been even taken as strong evidence showing that NP was resulted from inhibition and such an inhibition is robust and long lasting. The current study manipulated the length of the response-cue interval (RCI) which is analogous to the manipulation of the prime-probe interval in studies on NP. We employed a within-subjects randomly-mixed RCIs and further examined if the ratio of the RCI (between Trial n-1 and Trial n) to the pRCI (previous RCI between Trial n-2 to Trial n-1) (RCI/pRCI) would modulate the CRS effect. Based on the episodic tagging account, we would predict that CRS depends on the retrieval of the N-1st episode and hence should be sensitive to temporal distinctiveness. It is worth metioning that this study is not the first one to transfer and adjust the temporal dinstinctivness concept from the NP literature. Studies on memory for serial order (e.g., Brown, Neath, & Chater, 2007; Oberauer & Lewandowsky, 2008) and task switching (e.g., Gade & Koch, 2005; Horoufchin, Philipp, & Koch, 2011a, 2011b) have also applied the same inferences to disentagle the episodic retrival account versus inhibition decay account.

In this study, two experiments are reported. In Experiment 1, the RCI varied randomly with the range of RCIs was 500, 1,000 and 2,500 ms, and with the

cue-to-target interval (CTI) of 700 ms. The choice of the CTI of 700 ms was to follow our previous studies in order to see if we could replicate the original findings. However, the CTI of 700 ms may appear to be a rather long interval for participants to prepare for the upcoming trial, thus reducing the effect of the CRS as well as the sensitivity to the length of the CTI.[2] Therefore, we ran an additional experiment (i.e., Experiment 2) with the same design but now using a shorter CTI of 100 ms. However, given that our main focus was to examine the effect of RCI on the CRS effect, to increase the statistical power, we joined the data from the two experiments for all the statistical analyses, i.e., with a between-subjects variable of CTI.

2. Method

2.1. Participants

The participants were recruited from National Cheng Kung University, Taiwan. All participants reported being right-handed, free of neurological and psychological disorders, and having normal or corrected-to-normal vision. Each participant completed an informed consent form and was paid for participating in the experiment.

2.1.1. Experiment 1

Thirty-two participants (17 female, age range: 18-24 years, mean age: 21.1 ± 1.68 years; mean years of education: 15.2 ± 1.43 years) participated and were paid NT $300 (US $10).

2.1.2. Experiment 2

Thirty-two participants (17 female, age range: 18-25 years, mean age: 20.81 ± 1.65 years; mean years of education: 15.38 ± 1.45 years) participated and were paid NT $300 (US $10).

2.2. Stimuli and Procedure

The experiments were run on a Pentium 4 computer with a 17-inch monitor. The software was programmed in E-Prime 1.0 (W. Schneider, Eschman, & Zuccolotto, 2002). The stimuli were similar to the stimuli used by Meiran et al., (2011) except for the change in the task cues. They consisted of a vertical array of four boxes, subtending a visual angle of 1.43 x 6.55 degrees. The object placed inside the boxes included a colored dot (diameter = 0.47 degrees) and a colored line (0.19 x 0.95 degrees). The task cues were two Chinese characters denoting category-to-response rules which were presented in the center of the screen (see Figure 1).

---------- Figure 1 about here ----------

The practice session began with an oral explanation and an illustration of the tasks and the stimuli. Following the illustration, participants were required to execute 4 practice blocks in which the 4 tasks were added one by one until the participants had

[2] We wish to thank one of the anonymous reviewers for reminding us of this important issue. Indeed, the present results showed that with a longer CTI, the effect of the CRS was significantly reduced.

been exposed to all 4 tasks. Participants were required to continuously practice until they reach correct rate of 90% for 5 consecutive blocks (48 trials per block) before entering the formal experimental session. This part of the experiment lasted between 5 and 8 blocks. In the formal experimental session, there were 48 blocks of 48 trials each (2304 trials in total) for each participant. Participants were allowed to take a short rest between blocks. The total session took approximately 2.5-3 hrs for each of the experiments.

A trial started with the presentation of a blank screen for the duration of the RCI. This was followed by the task-cue presentation for 600 ms and a blank screen for 100 ms in Experiment 1, and by the task-cue presentation for 100 ms in Experiment 2, then the target stimulus, which was kept on the screen until the response was given (see Figure 1). A beep sound of 400 Hz was played after the response if an error was made. Participants indicated their response by pressing one of two keys on the keyboard L (right) and A (left) according to the instructed category-to-response mapping (e.g., "IF {green} THEN {press right}") and according to the currently relevant task rule, Color ("Red-Green"), Shape ("Dot-Line"), Vertical ("Up-Down"), and Area ("In-Out") (whether the target stimulus occupied an inner or outer box, see Figure 1 for an example that a green line occupies an inner box). The task in each trial was randomly chosen with the constraint that there would not be any task repetition. That is, all the trials were "switch" trials. The position, color and shape of the target were randomly chosen. Participants were asked to respond to the target stimulus as quickly and accurately as possible.

We fully counterbalanced key assignments for all participants (there were 16 counterbalancing conditions in total). The keypad was aligned with the center of the screen and the participants were instructed to respond with their index fingers of the two hands. In each experiment, the three RCIs (500, 1,000 and 2,500 ms) were randomized in each block.

2.3. Design

The design of the core analysis employed four within-subject independent variables, RCI, CRS, (CRS+ vs. CRS-), Similar (Similar+ vs. Similar-) and Other (Other+ vs. Other-). (We use the suffixes "+" and "-" to denote the conditions in which inhibition was presumably present or absent.) In addition, the two experiments with different CTIs were merged into a single analysis of variance with CTI as a between-subject independent variable.

3. Results

The first two trials in each block and the two trials following an error were omitted from all analyses. Trials with an error or with RT shorter than 100 ms or longer than 3,000 ms were analyzed for accuracy only. An Alpha=.05 was adopted in all the

analyses.

---------- Figures 2 & 3 about here -----

We ran three sets of analyses on the results. The first set was designed to show that we obtain a CRS effect and can show its specificity by showing non-significant (or reversed) Similar and Other effects. Additionally, the first analysis was run in order to show that CRS is modulated by RCI. Once these core findings are identified, the two subsequent sets of analyses focused, each on episodic tagging and decay, respectively.

3.1 Showing that CRS is modulated by RCI.

3.1.1 Reaction time (RT)

There was a significant main effect of CTI, $F(1, 62)=38.15$, $p<.001$, $\eta^2_p=.38$, showing that mean RT was generally faster for the experiment with a longer 700-ms CTI (638 ms) than that with a shorter 100-ms CTI (890 ms). There was also a significant main effect of CRS, $F(1, 62)=45.93$, $p<.001$, $\eta^2_p=.43$, showing that mean RT for CRS+ (771 ms) was slower than CRS- (757 ms). Althought there was also a significant main effect of Similar, $F(1, 62)=19.66$, $p<.001$, $\eta^2_p=.24$, the trend of their mean RTs were in the opposite to the expected direction, that is, Similar+ (760 ms) was faster than Simlar- (769 ms). There was no significant main effect of Other, $F(1, 62)=2.01$, $p=.16$. These results clearly show the specificity of the CRS effect as opposed to conflict adaptation (e.g., Botvinick et al., 2001) which should have been reflected in slowing in all, CRS+, Similar+ and Other+ (see Meiran et al., 2010, for discussion).

The main effect of RCI was significant, $F(2, 124)=11.33$, $p<.001$, $\eta^2_p=.15$, showing that mean RT increased with increasing RCIs (Figure 2). Of the main interest, there was a two-way significant interaction of CRS and RCI, $F(2, 124)=4.07$, $p<.05$, $\eta^2_p=.06$, showing that the CRS effect decreased with increasing RCI (17, 19 and 6 ms for RCI=500, 1000 and 2500 ms, resectively). There was also a significant 2-way interaction of CTI and CRS, $F(1, 62)=4.02$, $p<.05$, $\eta^2_p=.06$, showing that the CRS effect also decreased with increasing CTI (18 and 10 ms for CTI=100 and 700 ms, respectively).

3.1.2. Proportion of Errors (PE)

The core findings from the ANOVA results on PE were similar to those on RT, that is, there was a significant main effect of CRS, $F(1, 62)=31.84$, $p<.001$, $\eta^2_p=.33$, showing mean PE was larger for CRS+ (3.8%) than CRS- (3.0%), and a significant 2-way interaction of CRS and RCI, $F(2, 124)=4.36$, $p<.05$, $\eta^2_p=.07$, showing that the CRS effect on mean PE decreased with increasing RCI (12%, 8% and 3% ms for RCI=500, 1000 and 2500 ms, resectively).

There were also some high-order modulations of the interaction of CRS and RCI by Other or Similar factor and CTI factor (two different 4-way interactions: CRS x

Similar x RCI x CTI: $F(2, 124)=4.43$, $p<.05$, $\eta^2_p=.07$; CRS x Other x RCI x CTI: $F(2, 124)=4.41$, $p<.05$, $\eta^2_p=.07$). These interactions indicated mostly quantitative modulations of the general pattern – namely that the CRS effect was reduced with RCI in all cases.

3.2. RCI/ pRCI Analysis

The core analysis to disentagle the episodic trace retrieval and the inhibition decay account is based on the temporal distinctiveness. Specifically, Brown et al. (2007) suggest that temporal information helps retrieving previous episodes and that the distinctiveness of this information (and hence, retrieval likelihood) depends on the temporal separation between trials, which in our case is the RCI/pRCI ratio (pRCI=RCI in the preceding trial). When RCI/pRCI ratio is high, Trial n-2 and Trial n-1 are temporally proximal (short pRCI) while Trial n-1 and Trial n are temporally separated (long RCI). In such cases, the temporal distinctiveness of Trial n-1's episode is low. Since, according to the episodic tagging hypothesis, CRS depends on the retieval of the N-1st episode, this effect should decrease with increasing RCI/pRCI ratio.

We therefore computed the RCI/pRCI ratio (7 ratios: .2, .4, .5, 1, 2, 2.5, 5; see Figure 3). The ANOVA design included 2 within-subjects independent variables, RCI/pRCI Ratio and CRS. CTI was a between-subjects independent variable.

The 2-way omnibus interaction between CRS and RCI/pRCI ratio, $F(6, 372)=1.18$, $p=.32$, $\eta^2_p=.02$, provides an inappropriate test of our hypothesis. This is because we predicted a particular trend whereas the aforementioned omnibus interaction test examines all 6 possible orthogonal trends, simultaneously, resulting in a pronounced reduction in statistical power. We therefore examined just the predicted trend that CRS decreased (or increased) linearly with increasing RCI/pRCI ratio. The contrast weights that were used were proportional to the RCI/pRCI ratio. The results indicated a significant effect, $F(1, 62)=5.10$, $p<.05$, thus supporting the predictions. Furthermore, the interaction of this interaction contrast with CTI was not significant, $F(1, 62)=0.24$, $p=.63$.

3.3. Inhibition Decay

Althogh the results support episodic tagging they do not necessarily rule out the inhibition decay account since these two factors are not mutually exclusive. We therefore ran an additional analysis on the results of the two experiments. In this analysis we included trials in which the RCI/pRCI ratio was 1 (namely, trial in which the current RCI and the preceding RCI were the same). Thus, any influence of RCI on CRS in this analysis could *not* be attributed to episodic retrieval as we defined it. The ANOVA included 3 independent variables, CTI, RCI and CRS. None of the interactions approached significance, $F<.75$. Nonetheless, the numeric trend indicated that the CRS effect decreased with increasing RCI, 11, 13 and 4 ms, for RCI=500, 1000

and 2,500 ms, respectively, $p<.05$, $p=.052$, and $p=.38$, respectively. Nonetheless, interaction contrast analyses that compared the CRS effect in the short and intermediate RCI vs. long RCI did not approach significance, $p>.22$. These results show that the CRS effect was significant only when the RCI was short but not when it was long (in accordnace with the decay account) yet they fail to show a significant decrease in the CRS effect with increasing RCI. Thus, the analysis suggests that RCI *may* have a (very modest) influence on the CRS beyond episodic retrieval.

4. Discussion

In two experiments, we examined the influence of increasing RCI on the size of the CRS effect. Merging the data from the two experiments into a single ANOVA, we found a reliable CRS effect in the absence of Other effects and, in general, with "reversed" Similar effects. These results replicate our previous findings (Meiran et al., 2010, 2011) in showing that the CRS effect is not conflict adaptation, but instead represents finely tuned control.

Of greater importance is the general influence of RCI on the CRS effect, such as the CRS effect was reduced with increasing RCI. However, as having been largely disscussed in the NP literature, the significant interaction of RCI and CRS per se could support either account, episodic tagging retrieval and inhibition decay. These two theoretical accounts would predict the same trend of the CRS effect as a funciton of RCI. Fortunately, research in the NP literature has provided a startegic analysis method to disentagle the two accounts (Neill et al., 1992, 1995), that is, to consider temporal distictivness, i.e, the RCI/pRCI ratio. Accordingly, based on the episodic tagging account, we predicted that CRS would depend on the retrieval of the N-1st episode and hence should be sensitive to temporal distinctiveness of that episode. Similarly, according to the inhibition decay account, CRS should decrease with increasing RCI even when RCI/pRCI Ratio is fixed.

The result support episodic tagging by showing a significant linear decrease of the CRS effect with increasing RCI/pRCI ratio. Such an episodic retrieval might be involuntary, given that in the current design where there were no task repetitions, there was probably no case in which retrieval was actually beneficial.[3] Nonetheless, the decaying inhibition account cannot be totally rejected given the fact that the CRS effect decreased numerically with increasing RCI even when RCI/pRCI Ratio was fixed (at 1). Moreover, this analysis shows that the CRS effect was significant when the RCI was 500 ms, marginally significant ($p=.052$) when the RCI was 1,000 ms, and was very far from significance when the RCI was 2,500 ms. A secondary but rather interesting finding is that there was also a significant effect of CTI on CRS effect. Such a result pattern accords with previous suggestions that task preparation helps overcoming

[3] We wish to thank one of the reviewers, Iring Koch, for bringing up this comment.

perseverative tendencies (e.g. Koch & Allport, 2006; Meiran & Daichman, 2005). However, given the core manipulation is RCI and the CTI was secondary in nature in this study – it requires more direct experiments in the future to address the issue. Also note that since CTI length was manipulated across two different experiments, CTI became confounded with the Response-to-Target Interval, which further limits our ability to draw firm conclusions regarding this issue.

The evidence supporting episodic tagging implies that the episodes that are being retrieved contain very abstract information linking *irrelevant* rules to their status as competing rules, indicating that they should be suppressed (e.g., Neill et al., 1994). This information could not be based on a (concrete) task cue (as opposed to an abstract rule). This is because the *competing* rule from Trial n-1 was not cued in that trial. Only the *relevant* rule was cued. Thus, the present analysis suggests that the brain is able to detect the competing rule and tag it online and also suggests that episodic traces contain quite abstract information referring to the type of irrelevant processing (i.e., the application of a competing rule) that had been carried out.

The clear support for episodic retrieval may be interpreted as evidence that the competing rule has not been suppressed online but rather, has been tagged as a to-be-suppressed rule in future encounters. However, this processing mode makes little sense in the present experiments given that the probability that the rule would compete in the next trial (P=1/3) and thus should be suppressed was the same as the probability that this rule would become relevant in the next trial (and thus, should not be suppressed). This theoretical analysis coupled with the suggestive evidence for decay may indicate that a competing rule is suppressed online, and this fact is coded in the episodic trace. Clearly, additional work is needed in order to clarify this issue.

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Table 1: All possible scenarios for Trial n following Trial n-1 (taking Task 'a' on Trial n-1 as an example) for CRS, Similar and Other.

	CRS+				CRS-			
	Similar+		Similar-		Similar+		Similar-	
Trial	Other+	Other-	Other+	Other-	Other+	Other-	Other+	Other-
Trial n-1	$\underline{a}^1b^2c^2d^2$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^1c^2d^2$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^2c^2d^1$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^1c^2d^1$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^2c^1d^2$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^1c^1d^2$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^2c^1d^1$ $a^*b^*\underline{c}^*d^*$	$\underline{a}^1b^1c^1d^1$ $a^*b^*\underline{c}^*d^*$
Trial n								
Trial n-1	$\underline{a}^1b^2c^2d^2$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^1c^2d^2$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^2c^1d^2$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^1c^1d^2$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^2c^2d^1$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^1c^2d^1$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^2c^1d^1$ $a^*b^*c^*\underline{d}^*$	$\underline{a}^1b^1c^1d^1$ $a^*b^*c^*\underline{d}^*$
Trial n								
Trial n-1	---------- ----------	---------- ----------	$\underline{a}^1b^2c^2d^1$ $a^*\underline{b}^*c^*d^*$	$\underline{a}^1b^2c^1d^1$ $a^*\underline{b}^*c^*d^*$	---------- ----------	---------- ----------	$\underline{a}^1b^1c^2d^1$ $a^*\underline{b}^*c^*d^*$	$\underline{a}^1b^1c^1d^1$ $a^*\underline{b}^*c^*d^*$
Trial n								
Trial n-1	---------- ----------	---------- ----------	$\underline{a}^1b^2c^1d^2$ $a^*\underline{b}^*c^*d^*$	---------- ----------	---------- ----------	---------- ----------	$\underline{a}^1b^1c^1d^2$ $a^*\underline{b}^*c^*d^*$	---------- ----------
Trial n								

Note. 'a', 'b', 'c', 'd' denote task types, e.g., 'Color', 'Shape', 'Vertical', 'In-Out' tasks. Tasks 'a' and 'b' are similar tasks (e.g., Color and Shape); Tasks 'c' and 'd' are similar tasks (e.g., Vertical and In-Out). The underlined letter denotes the currently (either with respect to Trial n-1 or Trial n) relevant rule. The superscripts, '1' and '2' over tasks 'a', b', 'c', 'd' denote one of the two response keys respectively, i.e., keyboard 'L' (the right key) and 'A' (the left key); whereas the superscript '' denotes either of these response keys.*

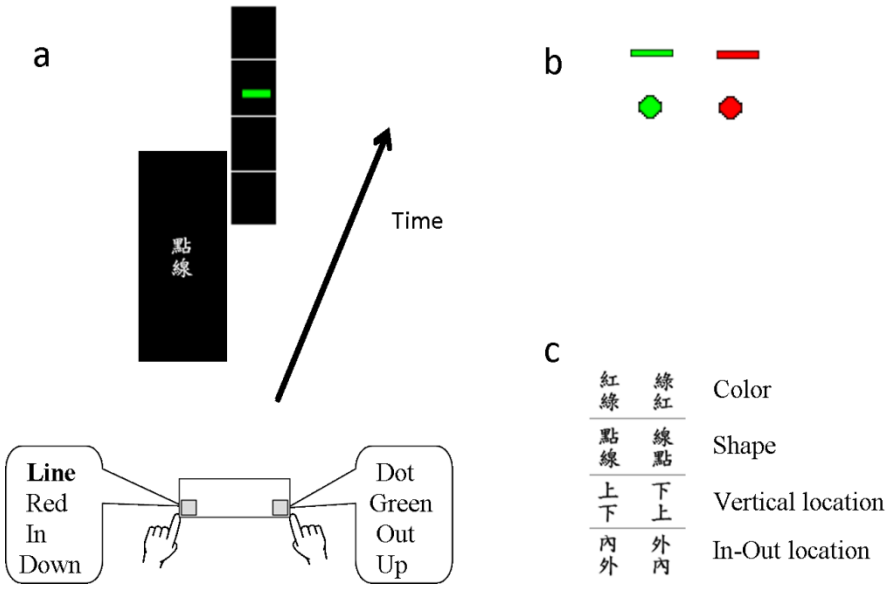

Figure 1: a: Examples of cue–target pairs and response key arrangements in the experiment. b: Objects. c: Task cues.

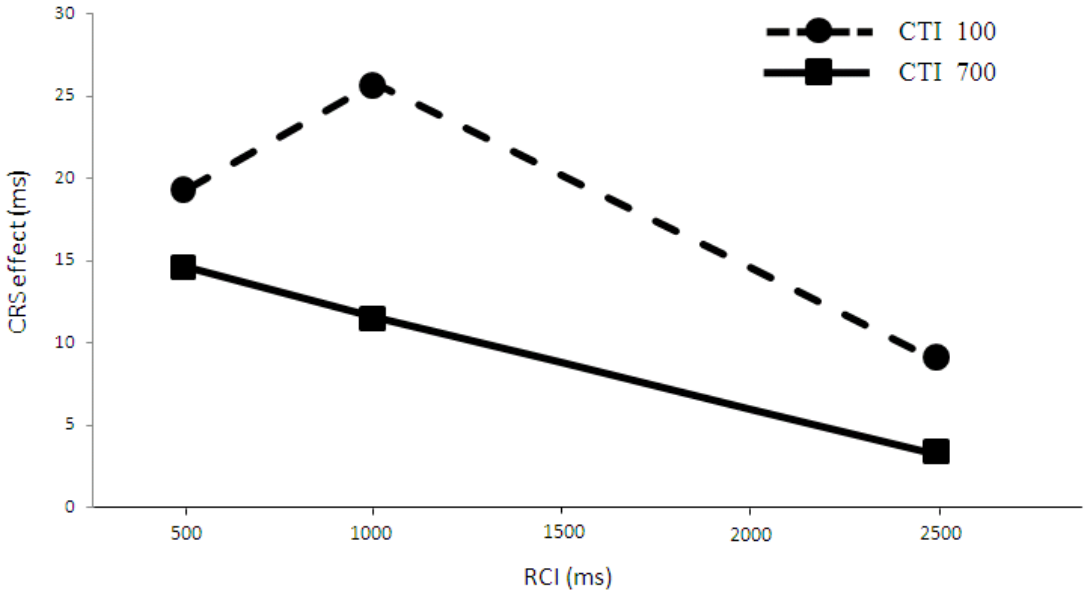

Figure 2: The CRS effect as a function of the Response-Cue Interval (RCI) and Cue-Target Interval (CTI). The figure shows that the CRS effect decreases with increasing RCI (17, 19 and 6 ms for RCI=500, 1000 and 2500 ms, resectively).

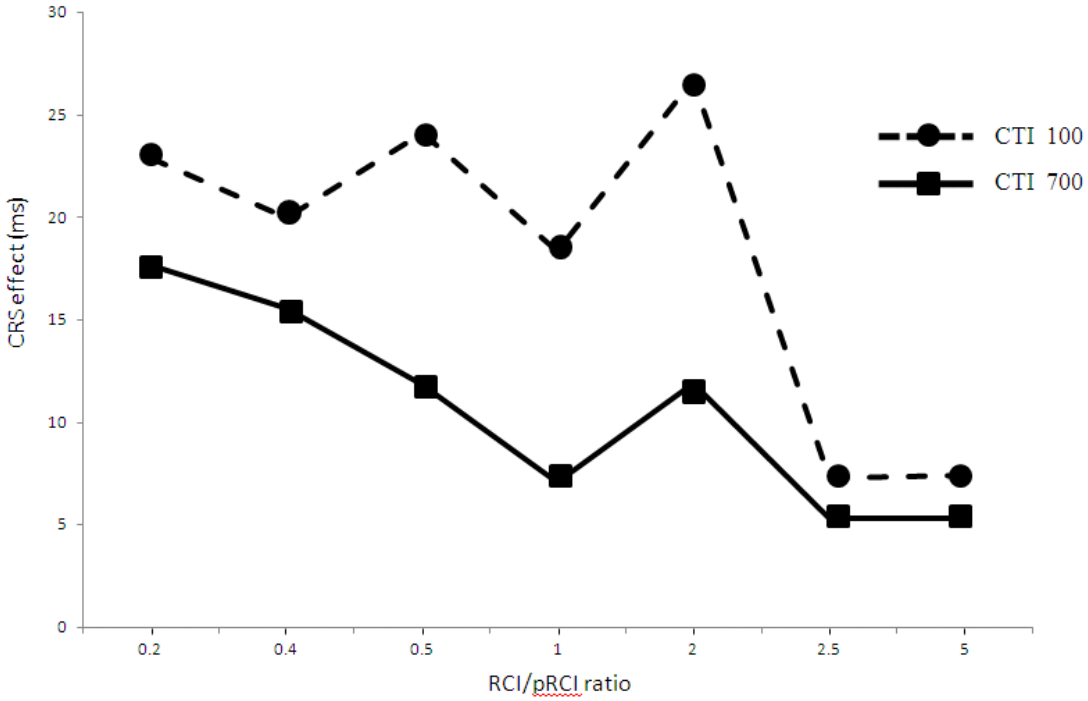

Figure 3: The CRS effect as a function of the RCI/pRCI Ratio and CTI. The figure shows that the CRS effect decreases with increasing RCI/pRCI ratio. (pRCI=Response-Cue Interval between Trials N-2 and N-1; RCI=Response-Cue Interval between Trials N-1 and N).