



Congruency sequence effect in cross-task context: Evidence for dimension-specific modulation[☆]



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ABSTRACT

The congruency sequence effect refers to a reduced congruency effect after incongruent trials relative to congruent trials. This modulation is thought to be, at least in part, due to the control mechanisms resolving conflict. The present study examined the nature of the control mechanisms by having participants perform two different tasks in an alternating way. When participants performed horizontal and vertical Simon tasks in Experiment 1A, and horizontal and vertical spatial Stroop task in Experiment 1B, no congruency sequence effect was obtained between the task congruencies. When the Simon task and spatial Stroop task were performed with different response sets in Experiment 2, no congruency sequence effect was obtained. However, in Experiment 3, in which the participants performed the horizontal Simon and spatial Stroop tasks with an identical response set, a significant congruency sequence effect was obtained between the task congruencies. In Experiment 4, no congruency sequence effect was obtained when participants performed two tasks having different task-irrelevant dimensions with the identical response set. The findings suggest inhibitory processing between the task-irrelevant dimension and response mode after conflict.

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1. Introduction

Interference paradigms, such as the flanker-compatibility task, the Stroop task, and the Simon task, have been used to investigate the automatic aspect of the human cognitive system. In these paradigms, interference occurs when different stimulus features activate different responses. For example, in the Simon task, in which participants are to make a left or right response to the color of the target stimulus appearing at the left or the right side of fixation, responses are faster and more accurate when the color and the location of the target stimulus activate the same response than when they activate different responses. It has been thought that these congruency effects occur because of the automatic activation of a competing response by task-irrelevant information (e.g., Kornblum, Hasbroucq, & Osman, 1990).

Interestingly, the congruency effects have been reported to be modulated by the previous trial congruency (Gratton, Coles, & Donchin, 1992). Using the flanker-compatibility task, Gratton et al. found a smaller flanker-compatibility effect after incongruent trials than after congruent trials. Specifically, the congruent trials following a congruent trial (cC) were faster and more accurate than the trials following an incongruent trial (iC). Incongruent trials were faster and more accurate when the

preceding trials were incongruent (iI) than when the preceding trials were congruent (cI). Such finding was replicated in other interference paradigms, such as the Stroop task (Kerns et al., 2004; Notebaert, Gevers, Verbruggen, & Liefvooghe, 2006) and the Simon task (Hommel, Proctor, & Vu, 2004; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Wühr, 2005). To explain this congruency sequence effect, two classes of accounts have been proposed. One is based on the repetition of stimulus–response features (Mayr, Awh, & Laurey, 2003), and the other is based on the conflict-driven modulation by the cognitive control mechanism (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001).

Mayr et al. (2003) suggest that the congruency sequence effect is due to repetition priming. A repetition benefit occurs when stimuli are repeated (e.g., Altmann, 2011). Because 50% of the cC and iI trials, but none of the cI and iC trials, are stimulus repetitions (target and flanker repetition) in a two-forced choice task, the cC and iI trials are faster than the cI and iC trials, resulting in the congruency sequence effect. In their experiment, in which participants were to perform vertical and horizontal arrow flanker tasks alternately in a trial-by-trial manner to eliminate immediate stimulus–response repetition, the flanker compatibility effect was modulated by n-2 congruency but not by n-1 congruency. According to Mayr et al., the congruency sequence effect disappears when the lower-level repetition priming effect is removed.

However, other researchers suggested that the congruency sequence effect is the consequence of cognitive control processes (e.g., Botvinick et al., 2001; Gratton et al., 1992). According to the conflict monitoring theory (Botvinick et al., 2001), the congruency sequence effect is due to the heightened level of control induced by the conflict of the preceding trial. That is, after an incongruent trial the cognitive system

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adaptively biases information processes to improve performance. In an fMRI study, Botvinick, Nystrom, Fissell, Carter, and Cohen (1999) showed that the peak activation of the dorsal anterior cingulate cortex (dACC) was greater during incongruent than congruent trials. Most importantly, the enhanced dACC activation of incongruent trials interacted with the previous congruency, being greater following congruent than incongruent trials. Based on these results, they suggested that the conflict is detected by a conflict-monitoring mechanism, located in dACC, which then triggers the lateral prefrontal cortex (LPFC), known to be specialized in resolving conflicts (e.g., Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000).

Empirical findings suggest that both the repetition priming and the control mechanism triggered by conflict contribute to the congruency sequence effect (e.g., Akçay & Hazeltine, 2007; Davelaar & Stevens, 2009; Egner, 2007; Verguts & Notebaert, 2008). For example, the congruency sequence effect was obtained after trials which did not have any conflict (Hommel et al., 2004; Liepelt, Wenke, Fischer, & Prinz, 2011). However, other studies have reported a robust sequential effect while controlling the effect of repetition priming (Akçay & Hazeltine, 2007; Hazeltine, Akçay, & Mordkoff, 2011; Kerns et al., 2004; Notebaert et al., 2006; Ullsperger, Bylsma, & Botvinick, 2005). For example, when multiple target and distractor features were used to control for the repetition priming effect, a significant congruency sequence effect was obtained (Akçay & Hazeltine, 2007; Kerns et al., 2004; Notebaert et al., 2006).

Recently, many researchers were interested in the nature of the control mechanisms. Some argue that conflict is modulated by a single global control mechanism (e.g., Kunde & Wühr, 2006), but many others suggest that conflict is thought to be resolved by independent local control mechanisms based on conflict types or task structures (Akçay & Hazeltine, 2008; Egner, Delano, & Hirsch, 2007; Funes, Lupiáñez, & Humphreys, 2010). Egner et al. (2007) reported that modulation that comes from previous trial conflict does not produce crosstalk between tasks of different conflict types. In a combined Stroop–Simon color naming task, in which participants responded to the color of the target word while ignoring the word meaning (Stroop conflict) and the word location (Simon conflict), the congruency sequence effect was found only between the identical conflict types but not between different conflict types. The Stroop conflict was defined as a *stimulus-based conflict* because the conflict arises between the task-relevant stimulus feature (ink color) and task-irrelevant stimulus feature (color word) at the stimulus level. On the other hand, the Simon conflict was defined as a *response-based conflict* because the conflict arises between the task-relevant stimulus feature (ink color) and the task-irrelevant stimulus feature (location) only after the task-relevant stimulus feature is processed at the response selection stage. Egner and his colleagues suggested that the absence of crosstalk between the Stroop and Simon conflicts is due to independent control mechanisms which resolve a specific type of conflict. More specifically, they claimed that the stimulus-based conflict is resolved by enhancing the processing of task-relevant information, whereas the response-based conflict is resolved by suppressing the output of automatic route processing. The absence of the crosstalk between different conflict types was replicated in a combined Simon–flanker compatibility task. The congruency sequence effect was obtained within a same conflict type (e.g., Simon; Flanker; Stroop) but not across different conflict types (e.g., Akçay & Hazeltine, 2011; Egner et al., 2007; Funes et al., 2010).

Funes et al. (2010) also found that the crosstalk occurred only between the same type of conflicts but not between different types of conflict. In their Experiment 2, participants were to make left–right responses to the direction of an up–down pointing arrow appearing in left, right, above or below a fixation point. That is, spatial Stroop conflict was assumed to occur when the arrow was presented above or below the fixation point, whereas Simon conflict when the arrow was presented to the left or right side of it. This allowed the manipulation of conflict type to switch or repeat between trials while keeping the task-relevant

dimension and response mode constant. The congruency sequence effect was obtained when the two types of conflict were common but not when they were switched.

However, other studies show that tasks with the same source of conflict do not yield crosstalk in certain settings (Akçay & Hazeltine, 2008; Mayr et al., 2003). Akçay and Hazeltine (2008) reported that two different Simon tasks which had independent sets of stimuli–responses did not show crosstalk. When participants were to perform two Simon tasks with different task-relevant dimension but a common response set, the congruency sequence effect occurred between the two task congruencies. Akçay and Hazeltine suggested that the scope of control is determined by the task structure, rather than the source of conflict, and that if the stimulus–response sets overlap between the two tasks, conflicts are resolved by a single control mechanism. Otherwise, conflicts are resolved by task-specific control mechanism recruited by each task set. Thus, when two tasks are conceptualized into a single task, the control mechanisms triggered by the conflict of one task modulate the congruency effect of the other.

Verguts and Notebaert (2008, 2009) proposed an associative learning model to explain sequential modulation of the congruency effect parsimoniously. According to this account, the congruency sequence effect is due to arousal leading to strengthening the associations of task-relevant information with its corresponding response after conflict. In Braem, Verguts, and Notebaert's (2011) experiments, in which participants performed two different Simon tasks in a random order, a congruency sequence effect was obtained between two different congruencies when the two tasks were performed with the same response effectors. Based on this result, they suggested that the influence of the task-irrelevant information is reduced because the association of task-relevant information with its corresponding response is strengthened after conflict.

In sum, many studies have shown that conflict is modulated in a domain-specific fashion (Akçay & Hazeltine, 2008; Funes et al., 2010; Schlaghecken, Refaat, & Maylor, 2011; Verguts & Notebaert, 2008), but the factors determining the scope of control are still unclear. That is, the findings that no crosstalk was obtained between two congruencies having the same type of conflict (Akçay & Hazeltine, 2008; Mayr et al., 2003) indicate that the source of conflict does not determine the scope of control. Also, the findings that no crosstalk was obtained between two different types of conflict when the task-relevant dimension and response mode were constant (e.g., Funes et al., 2010) indicate that conflict is not modulated by independent local control mechanisms based on task structures.

The present study examines the nature of the control mechanisms by manipulating the conflict type, the target dimension, the distractor dimension, and/or the response set of two different tasks. If independent control mechanisms modulate stimulus-based conflict and response-based conflict, as Egner et al. (2007) suggested, the congruency sequence effect should be evident when the tasks share the source of conflict. Counter to this hypothesis, Mayr et al. (2003) have demonstrated that horizontal and vertical flanker congruencies, both stimulus-based conflicts, did not crosstalk if the tasks had no repetitions. Experiments 1A and 1B were conducted in order to expand this finding to other task types. In Experiment 1A, participants performed vertical and horizontal Simon tasks in an alternating fashion. According to the account of Egner et al., the congruency sequence effect should be evident between the horizontal and vertical Simon tasks which have response-based conflicts. In Experiment 1B, participants performed horizontal and vertical spatial Stroop tasks in an alternating fashion. Again, if a single control mechanism resolves stimulus-based conflicts a crosstalk should be obtained between horizontal and vertical spatial Stroop tasks.

A second possible strategy to overcome conflict is to suppress the processing of the task-irrelevant information (Stoffels, 1996; Stürmer et al., 2002). Stoffels suggested that the congruency effect disappears after incongruent trials because of the suppression of the unconditional

route, in which task-irrelevant information is processed. To expand on this type of account, it is possible that task-irrelevant information processing is reduced or gated by the control mechanisms. If the control mechanism resolves conflict by suppressing task-irrelevant information in a constrained way, the congruency sequence effect would be obtained between two different tasks which share the task-irrelevant dimension. To test this possibility, in Experiment 2, participants were to perform the horizontal Simon and horizontal spatial Stroop tasks alternatingly with different response sets while having the distractor dimension constant at the horizontal dimension. If the cognitive control mechanism works globally to all conflicts which share the same task-irrelevant dimension, a significant congruency sequence effect would be observed between the two tasks.

A third possibility is that conflict is resolved by suppressing the automatic link between the task-irrelevant information processing stage and the response-mode specific response execution stages. That is, task-irrelevant information is automatically processed but does not activate the response-mode specific response code after an incongruent trial because the control mechanism suppresses the link between them. In Experiment 3, participants were to perform the Simon and spatial Stroop tasks in an alternating fashion. While participants performed two tasks with different response sets in Experiments 1A, 1B, and 2, they performed the tasks with the same response set in Experiment 3. Accordingly, the task-relevant dimension was alternated between the two tasks in a trial-by-trial manner, but the distractor dimension and the response set were constant across the two tasks. In Experiment 4, participants performed a horizontal Simon task and an orthogonal Simon task in an alternating fashion with the same response set. That is, the task-irrelevant dimension was alternated between horizontal and vertical dimensions but the task-relevant dimension and response set were held constant. If the control mechanism is specific to the response set, a significant congruency sequence effect would be evident in Experiments 3 and 4.

2. Experiments 1A and 1B: Horizontal and vertical congruency tasks

Experiments 1A and 1B investigated whether the control mechanism resolves conflict by enhancing the task-relevant information. If the congruency sequence effect results from the modulation of the task-relevant information, a significant congruency sequence effect should be obtained when two tasks share the task-relevant dimension.

It had also been suggested that the control mechanisms act general to a specific type of conflict but local to different types of conflicts. In Experiment 1A, participants performed horizontal and vertical Simon tasks on alternating trials. In this particular set of tasks, the task-relevant feature of both tasks was color, whereas the distractor dimension was either horizontal or vertical. In the two tasks, response-based conflict would occur between the response code activated by the task-relevant information and the one activated by the task-irrelevant information. Similarly, in Experiment 1B, participants performed horizontal and vertical spatial Stroop tasks, which the task relevant features were directional words, on alternating trials. If conflict is resolved by a conflict-specific control mechanism which is general to a conflict type, a significant congruency sequence effect would be obtained between the two tasks which have the same source of conflict.

2.1. Method

2.1.1. Participants

Sixteen undergraduate students (mean age = 22, 11 females) at Korea University participated to their course requirements for Experiment 1A. All were native Korean speakers who had self-reported to have corrected-to-normal vision and were free of color blindness. Sixteen more participants (mean age = 21.5) were recruited from the same pool for Experiment 1B.

2.1.2. Stimuli and apparatus

The stimuli were presented against a black background on a CRT monitor (17 in.) of a personal computer. The viewing distance was approximately 60 cm. The stimuli were controlled by E-Prime software (Version 1.2). In Experiment 1A, participants performed horizontal and vertical Simon tasks. For the vertical Simon task, responses were made to the target square ($1.5^\circ \times 1.5^\circ$) colored in yellow or green presented above or below the central fixation ($0.57^\circ \times 0.57^\circ$) by pressing the {a} or {z} key of the standard computer keyboard with the middle and the index finger of the left hand. Distance of the target stimulus from fixation was 6.5° . For the horizontal Simon task, responses were made to the red or blue target square presented on the left or the right side of the central fixation by pressing the {;} or {/} key with the index or the middle finger of the right hand. In Experiment 1B, all were identical except for the target features. For the vertical Stroop task, up or down responses were made with the left hand according to the directional word, “ ” (up) or “ ” (down), written inside a white target square ($1.5^\circ \times 1.5^\circ$), presented above or below the central fixation. For the horizontal Stroop task, left or right responses were made with the right hand according to the words “ ” (left) or “ ” (right) written inside a white target square presented on the left or the right side of the central fixation (see Fig. 1).

2.1.3. Procedure

Participants performed the experiment individually in a dimly lit soundproof chamber. They were instructed to press either the {a} or {z} button for the vertical task and {;} or {/} button for the horizontal task accordingly to the pre-assigned colors. The two colors assigned to the up or down response were always presented on the vertical task, and the other two colors assigned to the right or left response were always presented on the horizontal task in Experiment 1A. The color to response mappings were counterbalanced across participants. In Experiment 1B, colors were replaced to corresponding directional words. Each participant performed a practice block of 40 trials and two test blocks of 258 trials each. Between the blocks a rest period of 20 s was given.

Each trial started with a fixation cross. After 250 ms, the target stimulus was presented for 250 ms. Response was collected for the maximum of 1750 ms. An auditory warning signal was given when the response exceeded the limited time or whenever an error was made. After the response, a blank display was presented for 1500 ms. The horizontal and vertical Simon trials were alternated in a trial-by-trial manner (see Fig. 1). Consequently, the task dimension was always orthogonal to that of n-1 trial and identical to that of n-2 trial.

2.1.4. Data analysis

The first two trials of each block, two trials following an error trial, and trials with response times (RT) less than 150 ms or greater than 1500 ms were excluded from the analysis as outliers (11.63% in Experiment 1A, 10.67% in Experiment 1B). Mean RT and percentage of error (PE) were calculated for each participant as a function of task type (horizontal Simon task or vertical Simon task), current trial congruency (congruent or incongruent), n-1 trial congruency, and n-2 trial congruency. Analyses of variance (ANOVAs) with all variables within-subjects were conducted on the mean RT and PE data. The α -level for all statistical analysis in this study was .05.

2.2. Results

2.2.1. Experiment 1A

2.2.1.1. RT analysis. The main effect of congruency was significant, $F(1, 15) = 9.31, p = .0081, \eta_p^2 = .383, MSE = 1401$. Responses were faster when the target location was congruent with the response location (601 ms) than when it was not (615 ms), resulting in a 14 ms Simon effect. However, the Simon effect did not interact with n-1 trial

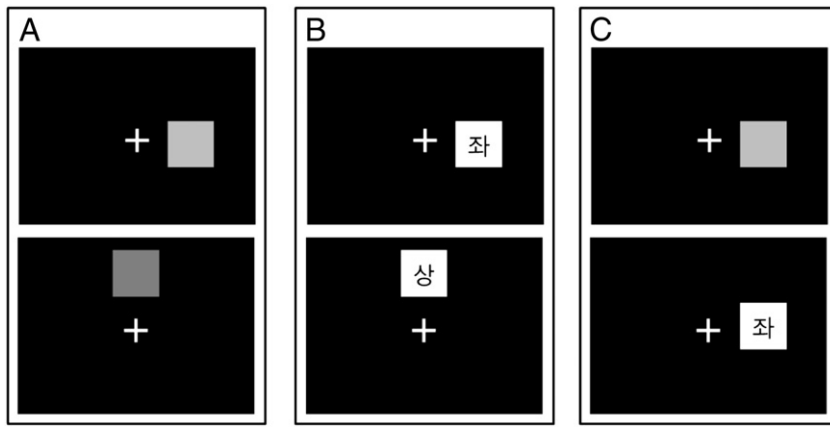


Fig. 1. Example of the trial sequences. A) Horizontal and vertical Simon tasks were alternated in a trial-by-trial manner in Experiment 1A. For the horizontal Simon task, a red or blue square was presented to the left or right of fixation. For the vertical Simon task, a yellow or green square was presented above or below fixation. B) Horizontal and vertical spatial Stroop tasks were alternated in a trial-by-trial manner in Experiment 1B. For the horizontal Stroop task, a directional word, 좌 ("left") or 우 ("right"), appeared in the inside of a white square presented to the left or right of fixation. For the vertical Stroop task, a directional word, 상 ("up") or 하 ("down"), appeared in the inside of a white square presented above or below fixation. C) Horizontal spatial Stroop and Simon tasks were alternated in a trial-by-trial manner in Experiments 2 and 3. For the horizontal Stroop task, a directional word, 좌 ("left") or 우 ("right") appeared in the inside of a white square presented to the left or right of fixation. For the horizontal Simon task, a red or blue square was presented to the left or right of fixation.

congruency, $F(1, 15) < 1.0$, while it was modulated by n-2 trial congruency, $F(1, 15) = 13.62$, $p = .0022$, $\eta_p^2 = .476$, $MSE = 982$ (see Fig. 2). When the n-2 trial was congruent, congruent trials ($M = 590$ ms) were faster than incongruent trials ($M = 619$ ms). This effect of congruency was removed when the n-2 trials were incongruent, by congruent trials ($M = 612$ ms) being same as incongruent trials ($M = 611$ ms). The horizontal trials ($M = 655$ ms) were slower than the vertical trials ($M = 561$ ms), $F(1, 15) = 45.05$, $p < .0001$, $\eta_p^2 = .75$, $MSE = 12,541$. No other interaction was significant.

2.2.1.2. Error analysis. The overall PE was 5.65%. Although the congruency effect did not reach significance, $F(1, 15) = 1.99$, $p = .1785$, $\eta_p^2 = .117$, $MSE = 38.30$, PE of the congruent trials (5.04%) was lower than that of non-congruent trials (6.14%). The current trial congruency did not interact with n-1 trial congruency, $F(1, 15) < 1.0$. However, the current trial congruency interacted with n-2 trial congruency, $F(1, 15) = 7.74$, $p < .0139$, $\eta_p^2 = .340$, $MSE = 10.77$. As in the RT data, a 2.21% Simon effect was obtained when the n-2 trial was congruent, while a -0.05% Simon effect when the n-2 trial was incongruent.

2.2.2. Experiment 1B

2.2.2.1. RT analysis. Congruent trials ($M = 645$ ms) were faster than incongruent trials ($M = 670$ ms), $F(1, 15) = 45.44$, $p < .0001$, $\eta_p^2 = .752$, $MSE = 894$, resulting in a 25 ms spatial Stroop effect. The main effect of n-1 trial congruency, $F(1, 15) = 2.26$, $p = .1532$, $\eta_p^2 = .131$, $MSE =$

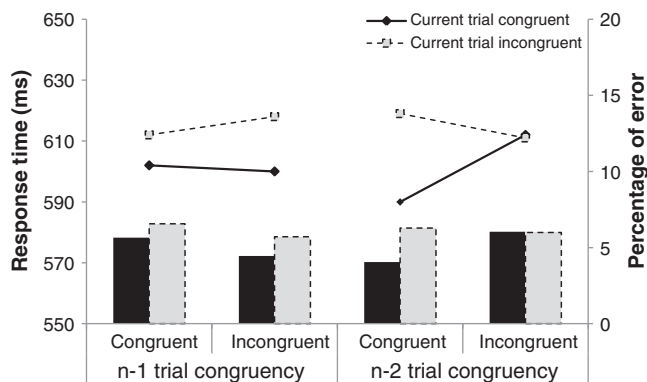


Fig. 2. Mean reaction time and percentage of error as a function of n-1 trial congruency and current trial congruency (left) and as a function of n-2 trial congruency and current trial congruency (right) in Experiment 1A.

695, and n-2 trial congruency, $F(1, 15) < 1.0$, were not significant. As in Experiment 1A, the congruency sequence effect was not found between current trial congruency and n-1 trial congruency, $F(1, 15) = 1.87$, $p = .1917$, $\eta_p^2 = .111$, $MSE = 661$, but was between current trial congruency and n-2 trial congruency, $F(1, 15) = 17.18$, $p = .0009$, $\eta_p^2 = .534$, $MSE = 650$ (see Fig. 3). The Stroop effect was larger when the n-2 trial was congruent (38 ms) rather than incongruent (12 ms).

The main effect of stimulus dimension was not significant, $F(1, 15) < 1.0$, but the interaction between stimulus dimension and current trial congruency was, $F(1, 15) = 19.35$, $p = .0005$, $\eta_p^2 = .563$, $MSE = 678$. The vertical spatial Stroop effect was larger (39 ms) than the horizontal spatial Stroop effect (11 ms).

2.2.2.2. Error analysis. The overall PE was 4.73%. PE for congruent trials (3.60%) was lower than incongruent trials (5.86%), $F(1, 15) = 7.24$, $p = .0167$, $\eta_p^2 = .326$, $MSE = 45.07$. This congruency effect was influenced neither by n-1 trial congruency, $F(1, 15) < 1$, nor n-2 trial congruency, $F(1, 15) = 1.64$, $p = 0.22$, $\eta_p^2 = .267$, $MSE = 21.60$.

2.3. Discussion

The results of Experiments 1A and 1B are inconsistent with Egner et al.'s (2007) conflict-specific multiple control account. In line with Akçay and Hazeltine's (2008) findings of no congruency sequence effect between different tasks of the same source of conflict, no effect was

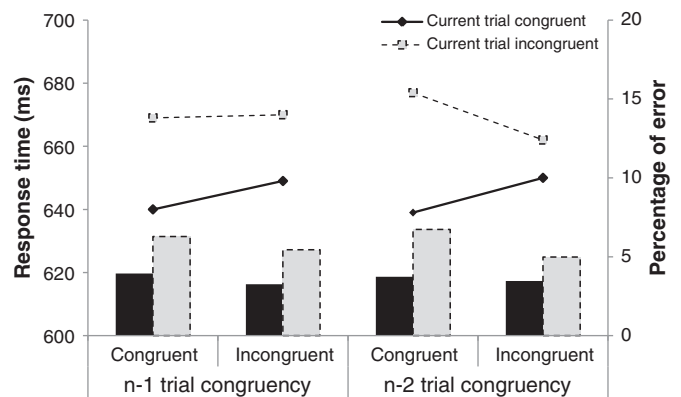


Fig. 3. Mean reaction time and percentage of error as a function of n-1 trial congruency and current trial congruency (left) and as a function of n-2 trial congruency and current trial congruency (right) in Experiment 1B.

obtained between the horizontal and vertical congruencies for the Simon (Experiment 1A) and spatial Stroop (Experiment 1B) tasks. That is, even though significant congruency effects (14 ms in Experiment 1A & 25 ms in Experiment 1B) were obtained, the congruency was not modulated by the previous congruency of the different task. These findings suggest that there is no general control mechanism resolving any type of conflict. The control mechanisms recruited by the conflict in one type of task is not responsible for the resolution of the conflict in another type of task. However, each control mechanism is not sensitive to the source of conflict. Because there was no stimulus-repetition in any two successive trials, the null effects obtained in Experiments 1A and 1B are consistent with Mayr et al.'s (2003) and Hommel et al.'s (2004) ideas. Also, if conflict is resolved by enhancing the processing of the target dimension, there should have been a significant congruency sequence effect because the task-relevant information was color in both tasks.

It should be noted that in Experiment 1B, the spatial Stroop effect is induced by both the response-based conflict and stimulus-based conflict (Egner, 2007; Kornblum et al., 1990). If there are any control mechanisms specific to the source of conflict, the two spatial Stroop tasks have every reason to show crosstalk. However, there was no congruency sequence effect observed between the two tasks. There is no evidence to support that the stimulus-based control mechanism (or response-based control mechanism) resolved the stimulus-based conflict (response-based conflict) of following trial by enhancing the processing of the task-relevant information.

On the other hand, the congruency effect was modulated by the congruency of the $n-2$ trials, as in the previous studies (Mayr et al., 2003; Wendt, Kluwe, & Peters, 2006, but also see Stürmer et al., 2002). The congruency sequence effect between the current and the penultimate trials can be thought as a consequence of the priming effect under the assumption that features of a trial are retained in the episodic memory system for several trials (Mayr et al., 2003). This is quite plausible because none of the task-relevant and task-irrelevant features and response codes between n and $n-1$ trials overlap. Another possibility is that the $n-2$ congruency sequence effect is due to local control mechanisms which work independently for distinct task components (Akçay & Hazeltine, 2008). If separate mechanisms modulated the congruencies of current (e.g., horizontal congruency task) and $n-1$ trials (e.g., vertical congruency task), introduction of the $n-1$ trial conflict would not have affected the control setting induced by the $n-2$ trial conflict. However, this issue will not be discussed any further because such issue is not at the center of interest of the current study and the design of the two-choice tasks in the current study confounds conflict induced effects with the binding effects for the $n-2$ congruency sequence effects.

3. Experiment 2: Horizontal Simon and horizontal spatial Stroop tasks with different response sets for each task

In Experiments 1A and 1B, no congruency sequence effect was obtained between two different tasks sharing the same source of conflict and the task-relevant information dimension. In the previous studies, no congruency sequence effect was obtained between the Stroop and Simon tasks (Egner et al., 2007) and between the flanker compatibility tasks with horizontal pointing target arrow and distracting flanker arrows and with vertical pointing target arrow and flanker arrows (Mayr et al., 2003). It should be noted that participants performed two tasks with different task-irrelevant dimensions in both studies and in Experiments 1A and 1B of the present study. However, if conflict is controlled by inhibiting the task-irrelevant information in a dimension specific way, modulation should be evident only when participants perform two different tasks sharing the same task-irrelevant information dimension.

To investigate the possibility that processing of the task-irrelevant information is inhibited by a control mechanism recruited by conflict, participants performed the horizontal Simon and horizontal spatial Stroop tasks in an alternating order in Experiment 2. They were to respond to the color of a colored square presented to the left or right of fixation in

the Simon task trial and to the meaning of a directional word presented to the left or right of fixation in the spatial Stroop task trial. The task-relevant dimension switched between color (Simon) and directional word (spatial Stroop), whereas the task-irrelevant dimension remained constant (horizontal spatial dimension). If the control mechanism recruited by conflict is a distractor dimension-specific system, both the Simon and the spatial Stroop task congruencies would be modulated by the congruency of the other task in the previous trial.

3.1. Method

3.1.1. Participants

Sixteen new undergraduate students (mean age = 23.4, 8 females) at Korea University participated to their course requirements. All were native Korean speaker who had self-reported to have corrected-to-normal vision and were free of color blindness.

3.1.2. Stimuli, apparatus, and procedure

The stimuli, apparatus, and procedure were identical to those used in Experiments 1A and 1B with the following exceptions. A square colored in red or blue was presented as a target in the Simon task, or a word “ ” (left) or “ ” (right) inked in black on a white square in the spatial Stroop task. The target was presented on the left or the right side of fixation. Participants were to press either the {z} or the {x} button of the keyboard with their left hand for the color target of the Simon task and either the { } or the { / } button with their right hand for the spatial word target of the spatial Stroop task. The Simon and Stroop tasks were alternated in a trial-by-trial manner (see Fig. 1). Consequently, the task was always different to $n-1$ trial and identical to $n-2$ trial.

3.1.3. Data analysis

The first two trials of each block, two trials following an error trial, and trials with RTs less than 150 ms or greater than 1500 ms were excluded from the analysis as outliers, which resulted in 12.46%. Mean RT and percent of error (PE) were calculated for each participant as a function of task type (Simon task or Stroop task), current trial congruency (congruent or incongruent), $n-1$ trial congruency, $n-2$ trial congruency, and distractor repetition. ANOVAs with all variables within-subjects were conducted on the mean RT and PE data.

3.2. Results

3.2.1. RT analysis

The main effect of congruency was significant, $F(1, 15) = 12.75, p = .0028, \eta_p^2 = .46, MSE = 952$, indicating a 14 ms congruency effect. However, this congruency effect was not modulated by $n-1$ trial congruency, $F(1, 15) < 1.0$. The congruency effect was modulated only by $n-2$ trial congruency, $F(1, 15) = 31.82, p < .0001, \eta_p^2 = .68, MSE = 307$ (see Fig. 4). A 26 ms congruency effect obtained after $n-2$ congruent trials was reduced to a 1 ms effect after $n-2$ incongruent trials. All interactions between other factors were not significant.

3.2.2. Error analysis

The overall PE was 4.87%. There was not any significant effect.

3.3. Discussion

A significant congruency effect of 16 ms was obtained. Most importantly, however, the magnitude of the congruency effect was not modulated by previous trial congruency, indicating that the control mechanisms recruited by Simon conflict did not modulate spatial Stroop conflict and vice versa when participants performed the two tasks sharing the task-irrelevant information dimension with different response sets. That is, the result is inconsistent with the idea that the control mechanisms recruited by conflict suppress the processing stage dealing with the task-irrelevant information.

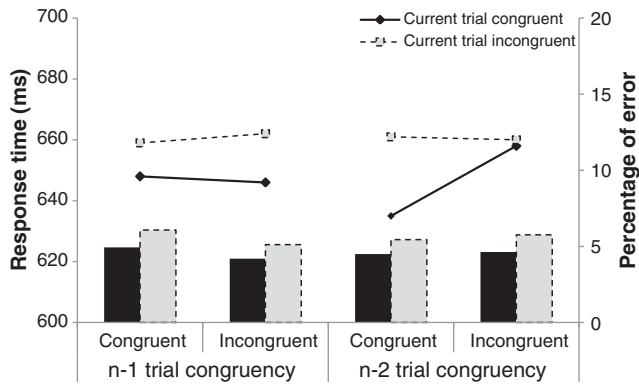


Fig. 4. Mean reaction time and percentage of error as a function of n-1 trial congruency and current trial congruency (left) and as a function of n-2 trial congruency and current trial congruency (right) in Experiment 2.

However, there is another possibility that control mechanisms recruited by conflict suppress the automatic route between the stage of the task-irrelevant attribute processing and the response execution stage specific to the response mode. It has been found that the congruency sequence effect is obtained between two congruencies only when participants performed two tasks with the same response mode (Braem et al., 2011; Hazeltine, Lightman, Schwarb, & Schumacher, 2011). If control is specific to response mode, no congruency sequence effect should be evident between the two tasks sharing the task-irrelevant dimension unless the tasks are performed with the same response set.

4. Experiment 3: Horizontal Simon and horizontal spatial Stroop tasks with an identical response set

Experiment 3 was conducted to examine whether the route between the processing stage of the task-irrelevant information and the response-execution stage which is specific to response set is inhibited by a control mechanism to resolve conflict. As in Experiment 2, participants were to perform the Simon and spatial Stroop tasks sharing the task-irrelevant dimension of the horizontal dimension. However, they made manual responses to both tasks with the same response set. When performing the Simon and spatial Stroop tasks, the task-irrelevant information, stimulus location, is processed and activates its corresponding response in both tasks. Thus, if the control mechanisms recruited by the Simon (or Stroop) conflict suppress the route between the processing stage of the spatial attribute and the response execution stage of the manual response mode, the spatial Stroop (or Simon) conflict should be modulated by the Simon (or Stroop) congruency of the previous trial.

As pointed out earlier, another interesting issue introduced in this experiment was whether the control mechanisms modulate conflict by biasing the entire dimension (e.g., the route between the horizontal spatial dimension and bimanual response-set) or a specific code (e.g., the route between the “right” stimulus code and “right” manual response code) activated from the previous trial. If the congruency sequence effect is a result of biasing the specific codes having been activated in the previous trial, the congruency sequence effect should be evident only on the trials on which the spatial code for the task-irrelevant information was repeated. On the other hand, if the cognitive control mechanism modulates performance by biasing the entire distractor dimension, the congruency sequence effect should be evident regardless of whether the distractor code was repeated or alternated.

4.1. Method

4.1.1. Participants

Sixteen undergraduate students (mean age = 23.5, 7 females) at Korea University participated to their course requirements. All were

native Korean speaker who had self-reported to have corrected-to-normal vision and were free of color blindness.

4.1.2. Stimuli, apparatus, and procedure

The stimuli, apparatus, and procedure were identical to those used in Experiment 2 except for the response modes. For both horizontal Simon and horizontal spatial Stroop tasks, participants were to press either the leftmost or the rightmost key according to pre-assigned color or target word with their index finger on a serial response box (Psychology Software Tools).

4.1.3. Data analysis

The first two trials of each block, two trials following an error trial, and trials with RTs less than 150 ms or greater than 1500 ms were excluded from the analysis as outliers, which resulted in 12.46%. Mean RT and PE were calculated for each participant as a function of task type (Simon task or Stroop task), current trial congruency (congruent or incongruent), n-1 trial congruency, n-2 trial congruency, and distractor repetition. ANOVAs with all variables within-subjects were conducted on the mean RT and PE data.

4.2. Results

4.2.1. RT analysis

The main effect of current trial congruency was not significant, $F(1, 15) < 1.0$. However, the congruency effect was modulated by n-1 trial congruency, $F(1, 15) = 24.78, p = .0002, \eta_p^2 = .623, MSE = 568$ (see Fig. 5). A 16 ms congruency effect was obtained after congruent trials but a -13 ms effect was obtained after incongruent trials. The two-way interaction of current trial congruency and n-2 trial congruency was significant, $F(1, 15) = 4.56, p = .0497, \eta_p^2 = .233, MSE = 712$, as in the previous experiments. The 8 ms congruency effect obtained after congruent trials was reversed to -6 ms after incongruent trials. The main effect of task type was significant, $F(1, 15) = 25.55, p < .0001, \eta_p^2 = .63, MSE = 7579$. All interactions between other factors were not significant.

To see the effect of the distractor repetition, separate analyses were conducted for trials which did not include distractor repetition and trials which did not include response repetition, respectively. When the distractor repetition trials were removed, the main effect of task type was significant, $F(1, 15) = 23.32, p = .0002, \eta_p^2 = .609, MSE = 8452$. Although the main effect of current trial congruency was not significant, $F(1, 15) = 1.47, p = .2449, \eta_p^2 = .089, MSE = 799$, the magnitude of the congruency effect was modulated by n-1 trial congruency, $F(1, 15) = 15.90, p = .0012, \eta_p^2 = .515, MSE = 1267$. The congruency effect of

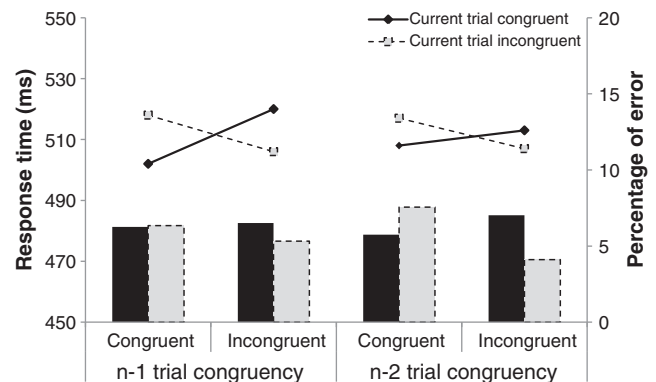


Fig. 5. Mean reaction time and percentage of error as a function of n-1 trial congruency and current trial congruency (left) and as a function of n-2 trial congruency and current trial congruency (right) in Experiment 3.

17 ms obtained after a congruent trial was reversed to -14 ms after an incongruent trial. No other interactions were significant.

The results were very similar to the trials in which the target repetition trials were removed. Responses were faster for the Simon task ($M = 482$ ms) than for the Stroop task ($M = 537$ ms), $F(1, 15) = 29.28$, $p < .0001$, $\eta_p^2 = .609$, $MSE = 6772$. The main effect of current trial congruency was not significant, $F(1, 15) < 1.0$, but was modulated by n-1 trial congruency, $F(1, 15) = 42.90$, $p < .0001$, $\eta_p^2 = .741$, $MSE = 780$. The congruency effect of 21 ms obtained after a congruent trial was reversed to -24 ms after an incongruent trial.

4.2.2. Error analysis

The main effect of current trial congruency was not significant, $F(1, 15) < 1.0$. No interaction between current trial congruency and n-1 trial congruency was found, $F(1, 15) < 1.0$. However, n-2 trial congruency was significant, $F(1, 15) = 6.73$, $\eta_p^2 = .31$, $p = .0203$, $MSE = 11.21$ with the incongruent trials (5.57%) being more accurate than the congruent trials (6.65%). There was a significant interaction between current trial congruency and n-2 trial congruency, $F(1, 15) = 26.56$, $p < .0001$, $\eta_p^2 = .639$, $MSE = 13.52$, with the congruency effect after n-2 congruent trials (1.82%) being reversed after n-2 incongruent trials (-2.92%). No other interaction was significant.

4.3. Discussion

The congruency effect of a task was modulated by the previous congruency of a different task. A 16 ms congruency effect was obtained after congruent trials and a reversed effect of -13 ms was obtained after incongruent trials. This congruency sequence effect was evident for both the Simon task trial to spatial Stroop task trial and the spatial Stroop task trial to Simon task trial sequences, indicating that the control recruited by the Simon conflict modulated the performance of the spatial Stroop task and vice versa by inhibiting the automatic route between the task-irrelevant information processing stage and the response execution stage specific to response set. Moreover, the congruency sequence effect was obtained for the RT and PE data, even when the distractor-repetition trials or response-repetition trials were removed. This finding indicates that the control mechanisms modulated conflict by biasing the automatic route of the whole distractor dimension to the dimension of the response set rather than the route of a specific stimulus code to specific response code activated from the previous trial.

Unlike the previous experiments, the same response mode was used for the two tasks. Thus, one could argue that the congruency sequence effect between Simon and spatial Stroop congruencies was due to the response-repetition priming (e.g., Altmann, 2011). However, the portions of response repetition did not differ across the types of trial transitions. Moreover, the congruency sequence effect was evident when distractor-repetition trials or response-repetition trials were removed. These findings indicate that conflict induced control mechanism other than low-level repetition priming, as Mayr et al. (2003) suggested, or feature integration, as Hommel et al. (2004) suggested, contributes to the congruency sequence effect.

5. Experiment 4: Simon and orthogonal Simon tasks with identical response mode

The congruency sequence effect was obtained between the Simon and spatial Stroop tasks when the two tasks shared the distractor dimension and response set (Experiment 3). However, no such effect was obtained when they shared the identical distractor dimension but different response sets (Experiment 2). However, it should be noted that, in Experiments 1 and 2, in which no congruency sequence effect was obtained between different congruencies, different response sets were used for each task, but in Experiment 3, in which a significant congruency sequence effect was obtained, the same response set was used.

Thus, it is still necessary to test whether the control mechanism modulates conflict by suppressing just the activation of a response set from any task-irrelevant information. To test this possibility, participants performed the Simon and orthogonal Simon tasks in an alternating way with the same response set. In the orthogonal Simon task, in which participants made left–right responses to the color of the target stimulus appearing above or below fixation, performance is better with up–right/down–left pairings than with up–left/down–right pairing (Cho, Proctor, & Yamaguchi, 2008; Nishimura & Yokosawa, 2006). Thus, the response set (left–right) and the target dimension (color) were repeated in the two tasks but the distractor dimensions were alternated between the horizontal and vertical dimensions in a trial-by-trial manner. If the control mechanisms recruited by conflict suppress the processing of the response dimension activated by any distractor dimension, a significant congruency sequence effect would be obtained between the congruencies of the tasks which have different task-irrelevant dimensions.

5.1. Method

5.1.1. Participants

Thirty undergraduate students (18 females) at Korea University participated to their course requirements. All were native Korean speaker who had self-reported to have corrected-to-normal vision and were free of color blindness.

5.1.2. Stimuli and apparatus

The stimuli and apparatus were identical to Experiment 3 with following exceptions. A target square ($0.7^\circ \times 0.7^\circ$) colored in red or blue was presented on the left or the right side of fixation ($0.6^\circ \times 0.6^\circ$) for the Simon task and above or below it for the orthogonal Simon task. The distance of the target from fixation was approximately 3° . For both Simon and orthogonal Simon tasks, participants were to press either the leftmost or the rightmost key according to pre-assigned color on a serial response box.

5.1.3. Procedure

Participants performed the experiment individually in a dimly lit soundproof room. They were instructed to press the left or the right button with their left or the right index finger according to the pre-assigned colors. Color to button relation was counter balanced among subjects. Each subject performed 24 practice trials and four test blocks each consisted of 129 trials.

At the beginning of each trial, a fixation was presented for 500 ms. Following the fixation, the target stimuli were presented in one of the four possible locations: above, below, left, or right. The stimulus and the fixation remained until the response was made. The next trial started 1500 ms after the response.

5.1.4. Data analysis

The first two trials of each block, two trials following an error trial, and trials with RTs less than 150 ms or greater than 1500 ms were excluded from the analysis as outliers, which resulted in 5.49%. Mean RT and PE were calculated for each participant as a function of task type (Simon task or orthogonal Simon task), current trial congruency (congruent or incongruent), n-1 trial congruency, and n-2 trial congruency. ANOVAs with all variables within-subjects were conducted on the mean RT and PE data.

5.2. Results

5.2.1. RT analysis

The main effect of congruency was significant $F(1,29) = 92.17$, $p < .0001$, $\eta_p^2 = .761$, $MSE = 409$, resulting in an 18 ms congruency effect. This congruency effect was modulated by task type, $F(1,29) = 24.34$, $p < .0001$, $\eta_p^2 = .456$, $MSE = 654$. The congruency effect was larger for

the Simon task (29 ms), $t(29) = 7.99$, $p < .0001$, than the orthogonal Simon task (6 ms), $t(29) = 2.92$, $p = .007$. The main effect of n-1 trial congruency was significant, $F(1,29) = 17.63$, $p = .0002$, $\eta_p^2 = .378$, $MSE = 321$. However, a two-way interaction of current trial congruency and n-1 trial congruency was not significant, $F(1,29) < 1.0$, (see Fig. 6). There was a significant interaction between the current trial congruency and n-2 trial congruency, $F(1,29) = 16.93$, $p = .0003$, $\eta_p^2 = .369$, $MSE = 552$. A 27 ms congruency effect was obtained after congruent trials, but 9 ms after incongruent trials. No other effects were significant.

5.2.2. Error analysis

Fewer errors were made for congruent trials (1.2%) than incongruent trials (2.5%), $F(1,29) = 15.73$, $p = .0004$, $\eta_p^2 = .352$, $MSE = 12.71$. This congruency effect was modulated by the n-2 trial congruency, $F(1,29) = 7.40$, $p = .0109$, $\eta_p^2 = .203$, $MSE = 3.80$. 1.78% of congruency effect after congruent trials was reduced to .8% after incongruent trials. The main effect of task type was significant, $F(1,29) = 9.6$, $p = .0043$, $\eta_p^2 = .249$, $MSE = 5.62$, the orthogonal Simon task (1.56%) being more accurate than the Simon task (2.23%). This task type interacted with the congruency, $F(1,29) = 8.36$, $p = .0072$, $\eta_p^2 = .224$, $MSE = 8.81$. The congruency effect was larger for the Simon task (2.08%) than the orthogonal Simon task (1.3%). Post hoc analyses indicated significant congruency effects for the Simon task, $t(29) = 3.67$, $p = .001$, but not for the orthogonal Simon task, $t(29) = 1.54$, $p = .134$. No other effects were significant.

5.3. Discussion

A significant congruency effect of 18 ms was obtained. However, this congruency effect was not modulated by the congruency of the other task in the previous trial. That is, the n-1 congruency of the Simon task did not modulate the orthogonal Simon effect or vice versa. If the control mechanisms recruited by conflict suppress the response dimension activated by task-irrelevant information, the congruency sequence effect should have been obtained between the tasks regardless of the distractor orientation. The lack of the congruency sequence effect between the Simon and the orthogonal Simon congruencies which shared the same response set indicates that the cross-task congruency sequence effect in Experiment 3 was due to the suppression of the automatic route between the processing stage for the task-irrelevant information and the response execution stage specific to the response set, rather than suppression of the response-set processing.

6. General discussion

6.1. Summary of finding

The purpose of this study was to examine how the control mechanism resolves conflict. The present study demonstrates two critical

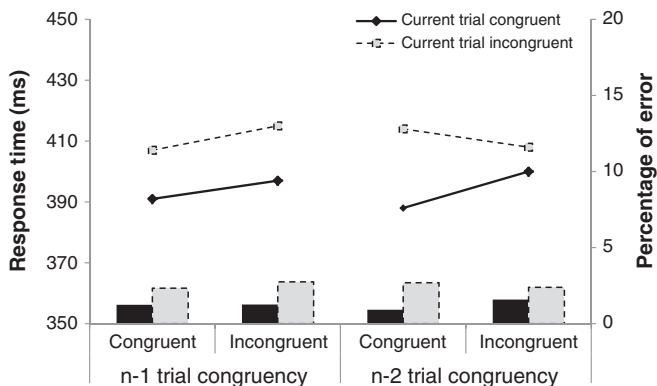


Fig. 6. Mean reaction time and percentage of error as a function of n-1 trial congruency and current trial congruency (left) and as a function of n-2 trial congruency and current trial congruency (right) in Experiment 4.

findings (see Table 1). First, as Akçay and Hazeltine (2008, 2011) and Egner et al. (2007) suggested, different types of conflict were resolved differently. In Experiment 1A, in which the horizontal and vertical Simon tasks shared a single dimension for the task-relevant information and an identical source of conflict, no congruency sequence effect was obtained. Similarly, in Experiment 1B, in which participants were to perform the horizontal and vertical spatial Stroop tasks sharing the same task-relevant dimension and source of conflict, no sign of the congruency sequence effect was found. It is important to note that the Simon tasks in Experiment 1A shared response-based conflict and the spatial Stroop tasks in Experiment 1B shared stimulus-based conflict.

It has been found that the control mechanisms recruited by the conflict in one task does not resolve the conflict in another task (Akçay & Hazeltine, 2008; Egner et al., 2007; Funes et al., 2010; Kiese, Kunde, & Hoffmann, 2006; Mayr et al., 2003; Schlaghecken et al., 2011; Wendt et al., 2006). For example, Wendt et al. (2006) found no congruency sequence effect between the flanker-compatibility and the Simon congruencies. Similarly, when participants performed a cross-task between a magnitude-judgment task and a parity task, the congruency sequence effect was observed between task repetition sequences but not between task alternation sequences (Kiese et al., 2006). That is, these results are consistent with the idea that no single global control mechanism can modulate conflict in a generalized way (Akçay & Hazeltine, 2008; Egner et al., 2007). The absence of congruency sequence effect between response-based conflicts in Experiment 1A and stimulus-based conflicts in Experiment 1B suggests that the scope of the control mechanisms is not determined solely by the source of conflict. There is a possibility that the significant congruency sequence effect between the spatial Stroop and the Simon congruencies was due to the spatial Stroop effect stemming from response-based conflict, as well as stimulus-based conflict (Egner, 2007). However, the findings of no congruency sequence effect between the Simon and orthogonal Simon congruencies, which stem from response-based conflict only, in Experiment 4, along with other findings, are inconsistent with the idea of global control mechanism sets by the source of conflict.

Second, the control mechanisms recruited by conflict resolve conflicts by suppressing the automatic route between the stage processing task-irrelevant information and the response execution stage which is specific to response sets. When participants performed two different tasks with independent response sets in Experiment 2, no congruency sequence effect was found between the two task-congruencies which shared a task-irrelevant dimension. However, when they performed the two tasks with the same response set in Experiment 3, the congruency effect was modulated by the congruency of the previous trial, regardless of the distractor- or response-repetition. To confirm the role of the response mode in the congruency sequence effect, an ANOVA was conducted on the combined RT data of Experiments 2 and 3. The analysis revealed a significant interaction of experiment, previous congruency and current congruency, $F(1, 30) = 7.33$, $p = .011$, $\eta_p^2 = .880$, $MSE = 874$. These results provide additional evidence for the idea that control processes are dependent on the response mode of the task (Braem et al., 2011; Hazeltine, Akçay, et al., 2011; Hazeltine, Lightman et al., 2011). In Braem et al.'s experiments, a significant congruency sequence effect was obtained only when two Simon tasks were performed with the same effector (hands) but not when one task was performed with one effector (hand) and the other task with another effector (foot). These results imply that control exerts on a basic common feature of the response alternatives defined within a task-set. Thus, only when two tasks share this feature crosstalk could occur between the two congruencies.

When participants performed the horizontal Simon task and the orthogonal Simon task, which share the source of conflict and task-relevant dimension but not the task-irrelevant dimension, with the

Table 1

Congruency sequence effect (in milliseconds) between current trial and n-1 trial and current trial and n-2 trial for Experiments 1 to 4. Significant congruency sequence effect is denoted with an asterisk.

	Task 1	Task 2	Overlap	n-1	n-2
Experiment 1A	Horizontal Simon	Vertical Simon	Target dimension (color)	-7	29*
Experiment 1B	Horizontal spatial Stroop	Vertical spatial Stroop	Target dimension (word)	9	26*
Experiment 2	Horizontal Simon	Horizontal spatial Stroop	Distractor dimension	-5	25*
Experiment 3	Horizontal Simon	Horizontal spatial Stroop	Distractor dimension, response set	30*	14*
Experiment 4	Horizontal Simon	Vertical Simon	Target dimension, response set	-2	18*

same response set in Experiment 4, no congruency sequence effect was obtained. That is, these results indicate that when the task-irrelevant information automatically activates its conceptually or physically corresponding response in a conflicting trial, the control mechanism suppresses the link between the task-irrelevant information processing stage and response execution stage to resolve conflict. Such suppression mechanism would thus modulate the influence of the task-irrelevant information in the subsequent trial resulting in a smaller congruency effect.

One could argue that the vertical and the horizontal Simon effects have different underlying mechanisms which induce different types of conflict (Vallesi, Mapelli, Schiff, Amodio, & Umiltà, 2005). Previous studies have shown that when RT distributions are analyzed using quintiles from fastest to slowest, the magnitude of the horizontal Simon effect decreases but that of the vertical Simon effect stays constant as a function of RT latency, suggesting that the horizontal Simon task could have an additional source of unconditional conflict due to the hemispheric nature of the stimulus–response arrangement. However, the tasks used in Experiment 1A should not show any differences in terms of fading because both tasks were responded with a single hand. When mean RTs were submitted to a three-way ANOVA with task type (horizontal vs. vertical Simon task), congruency (congruent vs. incongruent), and bins (first, second, third, and fourth) as independent variables to test this idea, the three-way interaction among the task type, congruency, and bin was not significant, $F(3,45) = 0.06, p = .9787, \eta_p^2 = .060, MSE = 382$. As depicted in Fig. 7, these results suggest that the horizontal and vertical Simon effects in Experiment 1A were relatively constant across bins.

7.2. Stimulus biasing and response biasing mechanisms

Two strategies have been proposed for the resolution of conflict by the cognitive control mechanism. One is based on biasing the task relevant information (Botvinick et al., 2001; Braem et al., 2011; Cohen, Dunbar, & McClelland, 1990; Egner & Hirsch, 2005; Notebaert & Verguts, 2008) and the other is based on biasing the task irrelevant information (Stoffels, 1996; Stürmer et al., 2002). Egner et al. (2007) suggested that the control mechanisms recruited by stimulus-based conflict enhance processing of task-relevant information and the mechanisms recruited by response-based conflict suppress the output of the task-irrelevant information processing in the automatic route. It is possible that these control mechanisms each modulate conflict in a

dimension specific fashion. It had been reported that when a Simon and a SNARC tasks (Spatial Numerical Association of Response Codes; Dehaene, Bossini, & Giraux, 1993) are performed alternately in a trial-by-trial manner, the congruency sequence effect was found between the two task congruencies only when the two tasks shared the task-relevant dimension (Notebaert & Verguts, 2008).

If the control mechanisms enhance task-relevant information processing after detecting conflict, as Egner et al. (2007) suggest, or the association of the task-relevant information with its corresponding response, as Verguts and Notebaert (2008, 2009) and Braem et al. (2011) suggested, the congruency sequence effect should be expected between any two tasks sharing the task-relevant dimension. However, when participants performed two spatial Stroop tasks in Experiment 1B the congruency of the previous trial in one task had no effect on the spatial Stroop effect in the other task even though the two tasks shared the task-relevant information. Even when two tasks shared the stimulus and response alternative in Experiment 4, no sequential modulation was obtained between the two congruencies. Moreover, the congruency of the stimulus-based conflict task in the previous trial modulated the congruency effect in the response-based conflict task and vice versa in Experiment 3. These findings are inconsistent with the ideas that the control mechanisms enhance the processing of the task-relevant information or strengthen the association of the task-relevant information and its corresponding response.

Contrast to the task-relevant information enhancing mechanism, Stoffels (1996) suggested the modulation of the task-irrelevant information. He suggested that the automatic route is suppressed as a default and it is available only when suppression is released after a congruent trial. Similarly, Stürmer et al. (2002) suggested that task-irrelevant information is biased by suppressing the automatic route after an incongruent trial in order to modulate conflict. They suggested that when the task-relevant information and task-irrelevant information activate different responses, the control mechanism blocks transmission of the output of the automatic (task-irrelevant) route to the motor execution system after an incongruent trial. More specifically, even though the sensorimotor information elicited by task-irrelevant information on the automatic route is available after an incongruent trial, the control mechanism suppresses this information from entering the response execution system. The findings of the present study are consistent with Stürmer et al.'s (2002) view. If the automatic route is suppressed after any conflict, as Stoffels (1996) suggested, the congruency sequence effect should have been obtained across any two tasks. The finding that

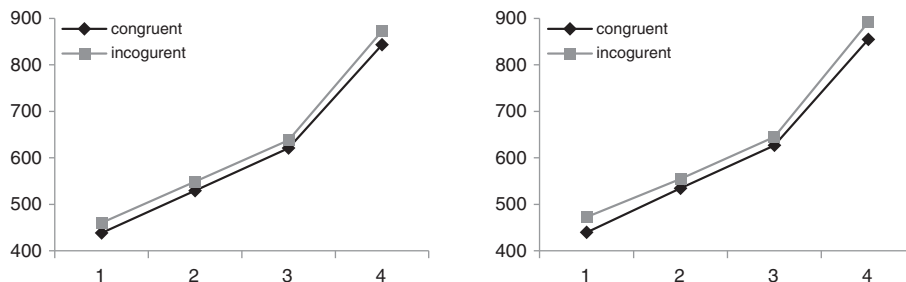


Fig. 7. Mean reaction time as a function of congruency and latency distribution for the horizontal (left) and vertical Simon tasks (right) of in Experiment 1A.

crosstalk was found only when the two tasks shared the task-irrelevant dimension and the response mode indicates that inhibition is specific to the combinations of the task-irrelevant dimension and response mode. It should be noted that in Notebaert and Verguts's (2008) experiment showing the congruency sequence effect between the Simon and SNARC congruencies, the two tasks were thought to also share the task-irrelevant dimension, which is a horizontal spatial dimension (e.g., Gevers, Caessens, & Fias, 2005), as well as the response mode in common. However, it should be noted that there is a possibility that the nature of the control mechanism is determined by the source of conflict (Egner et al., 2007; Soutschek, Müller, & Schubert, 2012). The obtained results indicate that the consequence of control processes triggered by, at least, Simon-like conflict is limited to specific combinations of the task-irrelevant dimension and response mode. Because the spatial Stroop task generated response-based conflict as well as stimulus-based conflict (e.g., Funes et al., 2010), the crosstalk could have occurred between the Simon and spatial Stroop congruencies.

Interestingly, the congruency sequence effect did not vary as a function of whether the distractor was repeated or alternated in Experiment 3. If the control mechanism modulates conflict by suppressing the link between a specific distractor code and a specific response of the previous trial, the congruency sequence effect should have been obtained only for the distractor repetition trials. Considering these results, the cognitive control mechanism seems to modulate performance not by suppressing the link to a specific response activated by task-irrelevant information in the previous trial but by suppressing the link between a specific task-irrelevant dimension and a specific response dimension. This idea is similar to Akçay and Hazeltine's (2008), Hazeltine, Akçay, et al.'s (2011), and Hazeltine, Lightman, et al.'s (2011) structural view that the boundaries of control stem from high-level aspect of the task representation. Akçay and Hazeltine stated that "control processes do not just modulate processing modules associated with different sources of irrelevant information. Rather, the system may assign processing modules flexibly so that each task is governed by more or less independent sets of processing modules" (p. 972). However, the findings in our Experiment 3 indicate that the control mechanism depends on specific properties of the task at hand rather than flexible task representation.

7.3. Context and cognitive control

Recently, it has been suggested that the magnitude of the congruency effect depends on the context of the previous trial rather than the conflict level of the previous trial (e.g., Fischer, Plessow, Kunde, & Kiesel, 2010). For example, Spapé and Hommel (2008) argued that the congruency sequence effect is evident only when two successive events are similar. In their experiment, in which participants were asked to say "high" or "low" to a high or low auditory tone simultaneously presented with a task-irrelevant auditory word "high" or "low", the sequential modulation was evident when the voice of two successive trials was the same, but not when they were different. Schlaghecken and Martini (2012) claimed that the dACC serves "the more general function of tracking the history of events and their outcomes" (p.278), rather than as a conflict detector. According to their account, a general context adaptation mechanism responds to conflict by continuously changing the activation gain and output threshold, which jointly determines the size of the congruency effect.

However, in their context adaptation model, Schlaghecken and Martini (2012) did not specify the scope of control. The findings that the congruency sequence effect is not always evident between two different congruencies (e.g., Akçay & Hazeltine, 2008; Funes et al., 2010; Schlaghecken et al., 2011) indicate that the changes in the activation gain and output threshold seem to occur in a domain-specific way. If this is the case, the present study implicates that the rate of the activation gain in the task-irrelevant dimension decreases after detecting conflict, whereas the output threshold of the response mode increases,

resulting in a decreased congruency effect in the subsequent trial only when the task-irrelevant dimension and response mode are repeated.

7.4. The repetition priming account and the feature integration account

The repetition priming account suggests that advantages of the trials in which the exact same stimulus–response features are repeated over the other types of trials yield the pattern of the congruency sequence effect (Mayr et al., 2003). Similar to the repetition priming account, Hommel et al. (2004) have suggested that the congruency sequence effect is due to the features related to a stimulus and its response in a trial integrated into a transient event file which is persistent enough to affect the performance of the following trials. The feature integration account predicts that complete match trials and complete alternation trials are better performed than partial repetition trials, because reactivating a single feature from the event file activates all features of the integrated event file. These had been a problem for the interpretation of the congruency sequence effect because such accounts predict the exact same pattern of results in two-choice task as the conflict monitoring account. For example, in Experiments 1A and 1B, none of the features were repeated because the alternating tasks had independent task-relevant and task-irrelevant dimensions and response modes. Due to the constant changes in the target and distractor features and the response modes, all trial sequences were complete mismatch trials in terms of the feature integration view. Thus, the lack of the congruency sequence effect could be in part due to the lack of the partial repetition trial, as the feature integration account suggests.

However, the significant congruency sequence effect obtained in Experiment 3 cannot be solely explained by the repetition priming account or the feature integration account. While the target features always changed between trials, the distractor and response dimensions were repeated on half the trials and alternated on the other half, respectively, regardless of the conflict level of the previous trial. Consequently, the proportions of the partial repetition and complete alternation trials were constant across all types of the trial sequence, introducing limited contribution for the congruency sequence effect.

8. Conclusion

The present study shows that the congruency sequence effect can be obtained between two different tasks only when they share the task-irrelevant dimension and the response mode. The obtained results indicate that the consequence of control processes triggered by conflict is limited to specific combinations of the task-irrelevant dimension and response mode. That is, the congruency sequence effect is due to the cognitive control processes suppressing the automatic activation link between the task-irrelevant dimension and response mode to resolve conflict. These findings add further evidence against the idea that general control processes are globally involved in the adjustment of attentional system in any congruency task. However, it should be noted that this does not necessarily indicate that multiple independent control processes operate with respect to the combinations of the task-irrelevant dimension and response mode. That is, it is possible that the congruency sequence effect is due to the carryover effect of inhibiting the automatic route to resolve the conflict of the current trial to the following trials, rather than the recruitment of different control mechanisms triggered by the conflict of the previous trial or the dissimilarity of the task context.

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