Congruency sequence effect without feature integration and contingency learning ☆

Sanga Kim, Yang Seok Cho *

Department of Psychology, Korea University, Seoul, South Korea

ABSTRACT

The magnitude of congruency effects, such as the flanker-compatibility effects, has been found to vary as a function of the congruency of the previous trial. Some studies have suggested that this congruency sequence effect is attributable to stimulus and/or response priming, and/or contingency learning, whereas other studies have suggested that the control process triggered by conflict modulates the congruency effect. The present study examined whether sequential modulation can occur without stimulus and response repetitions and contingency learning. Participants were asked to perform two color flanker-compatibility tasks alternately in a trial-by-trial manner, with four fingers of one hand in Experiment 1 and with the index and middle fingers of two hands in Experiment 2, to avoid stimulus and response repetitions and contingency learning. A significant congruency sequence effect was obtained between the congruencies of the two tasks in Experiment 1 but not in Experiment 2. These results provide evidence for the idea that the sequential modulation is, at least in part, an outcome of the top-down control process triggered by conflict, which is specific to response mode.

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1. Introduction

Human task performance is continuously influenced by the context in which it occurs. For example, past experience modulates all aspects of human information processing, including perception, attention, memory, and many other higher cognitive activities. Most interesting, the influence of task-irrelevant distractors on the task performance at hand is modulated by the amount of conflict the performer has just experienced (e.g., Gratton, Coles, & Donchin, 1992). That is, the congruency effect is smaller when the previous trial was incongruent than when it was congruent. This *congruency sequence effect* (Gratton effect or conflict-adaptation effect) has been found across a variety of versions of conflict tasks, including the Simon task, the Stroop task, and the flanker-compatibility task.

Many researchers attribute this reduced congruency effect after an incongruent trial to conflict adaptation, which refers to conflict being regulated by biasing the processing of a task-relevant stimulus feature

or that of task-irrelevant conflicting stimulus features (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000). Botvinick and colleagues developed the *conflict monitoring* model which describes how conflicts are detected and regulated. According to this model, conflicts between the correct response and the response triggered by task-irrelevant conflicting stimulus features are detected by a conflict monitoring system, which is located in the dorsal anterior cingulate cortex (dACC). Then, the dACC projects signals to dorsolateral prefrontal cortex (DLPFC) to regulate the detected conflicts. The DLPFC reduces conflicts on the following trial by allocating different attentional weights to the task-relevant dimension and the task-irrelevant conflicting stimulus dimension. For example, the task-relevant dimension is weighted more after experiencing conflict to focus more on the task demand, and/or the weighting on the task-irrelevant conflicting stimulus dimension is reduced to ignore the distractors.

However, other researchers have argued that the congruency sequence effect is attributed to a bottom-up memory-related process rather than a top-down control process (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). Hommel et al. suggested that the feature-integration is the major source of the congruency sequence effect. Once a stimulus is presented and its response is executed, an event-file, which binds the stimulus and response features, is formed. If one of the stimulus features in the event-file is presented on the

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following trial, the other features in the event file, including the bound response, are retrieved automatically. If the retrieved response is different from the correct response, it takes longer time to execute the correct response, because the bound response has to be inhibited before the execution of an overt response. When the stimulus and response of a given trial are the same as the previous trial, a fast response is possible. A fast response is also possible when the stimulus and response of a given trial are completely different from those of the previous trial, because any stimulus feature on the current trial was not integrated into an event file in the previous trial, so that no response would be automatically activated.

Hommel et al. (2004) pointed out that the effects of conflict adaptation and feature integration are completely confounded in many experiments. Specifically, the sequences of previously congruent and currently congruent trials (cC) and the sequences of previously incongruent and currently incongruent trials (iI), which consist of only the complete repetition trials and the complete alternation trials in a two-choice task, are faster to respond to than the sequences of previously congruent and currently incongruent trials (cI) and the sequences of previously incongruent and currently congruent trials (iC), all of which are partial repetition trials. Hommel et al.'s finding of a congruence sequence effect without conflict is inconsistent with the idea that the reduced congruency effect after an incongruent trial is due solely to the allocation of different attentional weights on the task-relevant dimension and the task-irrelevant conflicting stimulus dimension after detecting conflict.

One way to avoid confounding the top-down adjustment modulation with the bottom-up priming is to increase the number of stimulus (and response) alternatives. Akçay and Hazeltine (2007) had participants perform a four-choice reaction task and analyzed only completely alternated trials which were the only subset that includes all types of sequence. Although they also removed negative priming trials, which make iI trials additionally slower, Akçay and Hazeltine found a significant congruence sequence effect. Kerns et al. (2004) also showed a congruency sequence effect in the color–word Stroop task after removing the trials on which the target color or distractor word was repeated from their analysis. Ullsperger, Bylsma, and Botivinck (2005) Experiment 2 demonstrated that significant sequential modulation occurred in the flanker-compatibility task with a larger stimulus set when they analyzed only the trials on which all stimulus features were completely different from the previous trial. Notebaert, Gevers, Verbruggen, and Liefooghe (2006) found the evidence of both top-down and bottom-up sources of the congruency sequence effect using two different response stimulus intervals (RSI) using a flanker compatibility task with larger stimulus and response sets. When the RSI was extremely short (50 ms), the sequential modulation was found only in the trials with feature repetition. However, when the RSI was relatively long (200 ms), significant sequential modulation was found in both completely alternated trials and completely repeated trials. These results indicate that the congruency sequence effect can occur without the contribution of the process of binding.

On the other hand, it has been suggested that increasing the numbers of stimulus and response alternatives to avoid the confounding effects of the top-down control and the stimulus or response repetition causes a confounding effect of the contingency between the distractor and correct response because researchers tended to present congruent trials equally frequently with incongruent trials (Mordkoff, 2012; Schmidt, Crump, Cheesman, & Besner, 2007; Schmidt & De Houwer, 2011). For example, when performing a 4-choice color naming Stroop task, the congruent color word is presented more frequently (50%) than any incongruent color word. Because the congruent word is presented higher than the chance level (25%), participants learn these contingencies, resulting in faster and more accurate responses on the congruent trials than incongruent trials (e.g., Schmidt et al., 2007). Moreover, the contingency effect is modulated by previous contingency (Schmidt et al., 2007). The effect of the contingency

was more evident following a high contingency trial than a low contingency trial. According to Schmidt et al., if the distractor predicts the correct response in the previous trial (high contingency trials), participants are more likely to use the contingency information. On the other hand, if the distractor is paired with an unusual target, they are unlikely to use that information. Therefore, there would be a larger contingency effect after high contingency trials than the effect after the low contingency trials.

Mayr et al. (2003) separated repetition and alternation trials in their first experiment, and made their task without stimulus and response repetitions and the contingency of the distractor with the correct response in their second experiment. According to them, performance for the cC sequence trials and the iI sequence trials is better than performance for the cI sequence trials and the iC sequence trials because the half of these trials are the exact stimulus and response repetition trials in the flanker-compatibility task which has only two stimulus alternatives and two corresponding response alternatives. In their first experiment, they replicated the congruency sequence effect using the arrow version of the flanker-compatibility task, and they also showed that this effect was present only in the stimulus repetition trials and was completely absent in the stimulus alternation trials. They demonstrated no significant sequential modulation when a horizontal arrow flanker task and vertical arrow flanker task were presented alternately in a trial-by trial manner in their second experiment to exclude the effects of the stimulus repetition and the contingency learning. Based on these results, Mayr et al. suggested that the congruency sequence effect is due to bottom-up priming rather than top-down adjustment modulation.

However, Ullsperger et al. (2005) suggested that the lack of the congruency sequence effect in Mayr et al.'s (2003) second experiment, in which every trial was a switching trial, was possibly due to a task switch affecting the control process. Another possibility for the lack of sequential modulation in the Mayr et al.'s experiment is that different task-specific control mechanisms may have been employed for each of the arrow flanker-compatibility tasks. There is ample evidence that cognitive control process is specific to domains (Akçay & Hazeltine, 2008; Egner, 2007; Kiesel, Kunde, & Hoffmann, 2006; Notebaert & Verguts, 2008). To account for these findings, Verguts and Notebaert (2008, 2009) proposed a model to account for the congruency sequence effect. They emphasized the role of a Hebbian learning mechanism in their cognitive control model. According to them, when conflict is detected on incongruent trials, a neuromodulatory system increases the level of arousal, resulting in strengthening the associations between task-relevant stimulus feature and response via a Hebbian learning process, based on the currently activated task rule. Because the Hebbian learning rule is local, no congruency sequence effect between two tasks is expected to occur when they have different stimulus or response dimensions.

Akçay and Hazeltine (2008) suggested that participant's task representation might determine the scope of the control process. In their Experiment 1, the congruency sequence effect between two different response sets was obtained when the stimulus sets for the two response sets overlapped but not when they were separated. According to them, the task was represented as a single task when there was overlap in the stimulus dimension, while it was represented as separated subtasks when there was no overlap in stimulus–response pairs. When participants represent a task as several different subtasks, local control mechanisms were recruited for each subtask.

Recently, Lee and Cho (2013) suggested that the control process is specific to the response mode as well as the task-irrelevant conflicting stimulus feature. When they had participants perform a horizontal Simon task, in which a left or right keypress response was made to the color of a target presented to the left or right of fixation, and a vertical Simon task, in which an above or below keypress response was made to the color of a target presented above or below fixation, no sequential effects was obtained between the horizontal and vertical Simon

congruencies in their Experiment 1. They also obtained no sequential modulation between the horizontal and vertical spatial Stroop congruencies in Experiment 2. However, they found significant sequential modulation of the congruency effect between the horizontal Simon task and the horizontal spatial Stroop task which shared the same task-irrelevant dimension, when the participants used a shared response set in their Experiment 3, but not when they responded to one task with the right hand and to the other with the left hand in their Experiment 2. From these findings, they concluded that the congruency sequence effect is due, in part, to the control process inhibiting the link between the stage processing the task-irrelevant conflicting stimulus features and the stage processing the response.

Thus, according to the previous studies (Akçay & Hazeltine, 2008; Lee & Cho, 2013; Verguts & Notebaert, 2008, 2009), the lack of the congruency sequence effect in Mayr et al.'s (2003) second experiment was possibly due to the different dimensions of the stimulus feature (either task-relevant or irrelevant) and response mode of the two arrow flanker-compatibility tasks, which were horizontal and vertical. It is important to note that the horizontal and vertical dimensions are processed separately in the human information-processing system (e.g., Nicoletti & Umiltà, 1984; Rubichi, Vu, Nicoletti, & Proctor, 2006; Wiegand & Wascher, 2007). Consequently, the control triggered by conflict in the horizontal dimension was possibly unable to modulate the amount of the conflict in the vertical dimension and vice versa.

The aim of the present study was to examine whether stimulus and response repetitions and/or contingency learning are the only factors causing the congruency sequence effect. For these aims, two experiments were conducted. In both experiments, participants performed two color flanker-compatibility tasks in an alternating way. To avoid stimulus repetition, red or yellow circles were presented as a target and flankers in one task and blue or green circles were presented in the other task. To avoid response repetition, participants were to respond to one color flanker-compatibility task with the index and middle fingers of their dominant hand and to the other task with the ring and small fingers of their dominant hand in Experiment 1. In addition, these experiments effectively avoided having participant learn the contingencies of distractors with responses because each task had only two different stimulus and response alternatives, resulting in each target being associated with each distractor at chance level.

In Experiment 2, participants were to respond to one task with the index and middle fingers of their right hand and to the other task with the index and middle fingers of their left hand. Because the distinction of the two response sets was made in terms of finger, which is not a salient dimension, in Experiment 1, the response sets for the two tasks are assumed to be processed as a single response mode. However, because the distinction of the two response sets was made in terms of hand, which is a salient dimension, in Experiment 2, the two sets are assumed to be processed as different response modes.

If the congruency sequence effect is due to response repetition or contingency learning, no congruency sequence effect would be obtained between the two tasks regardless of whether the two response sets were processed as a single response mode or not. However, if the absence of a congruency sequence effect in Mayr et al.'s (2003) second experiment was due to the two tasks having different task-relevant and/or irrelevant conflicting stimulus features and response dimensions, then the congruency sequence effect should be obtained between the two tasks in Experiment 1 because the tasks share the task-irrelevant conflicting stimulus features and response dimension, but not in Experiment 2 because the two tasks had different response modes. Moreover, if the contingency learning is the only explanation for the congruency sequence effect, no sequential modulation would be observed in Experiment 1 because there were no contingencies between each distractor and a specific correct response.

2. Experiment 1

Experiment 1 was aimed at testing whether the congruency sequence effect occurs even when there is no stimulus or response repetition and no contingency, as in Mayr et al.'s (2003) second experiment. Participants were asked to perform two color flanker-compatibility tasks alternating on a trial-by-trial manner. To eliminate the repetitions of stimulus and response, different sets of color stimuli and responses were used for each task. Only red and yellow colors were used as a target and flankers in one flanker-compatibility task and only blue and green colors were used in the other task to avoid the contingency learning. Because the target color (for example, red) was always the paired color of a distractor color (yellow) on incongruent trials, the distractor color was not predictive of the congruent response although the frequencies of congruent and incongruent trials were 50% each. To make the two tasks separate, the target and flankers were arrayed horizontally in the former task and vertically in the latter task (see Fig. 1). Participants were to respond to the color of the target using the four fingers of the dominant hand. Even though different response sets were used for each task, the two tasks shared the response mode because the distinction of the two response sets was not salient (e.g., Proctor & Reeve, 1985).

If the congruency sequence effect is attributed to the repetitions of stimulus and response, as Mayr et al. (2003) suggested, or the contingency learning, as Schmidt and De Houwer (2011) suggested, no sequential modulation would be obtained because neither stimulus or response repetition nor contingency was allowed. However, if the control mechanism triggered by conflict is specific to the task-relevant or task-irrelevant stimulus dimension and response mode, significant sequential modulation of the flanker compatibility effect would be found between the two task, because the two tasks shared the task-relevant and task-irrelevant conflicting stimulus dimensions and the response mode.

2.1. Method

2.1.1. Participants

Sixteen undergraduate students (mean age = 22.0, 7 males) at Korea University participated in partial fulfillment of a course requirement. All participants had normal or corrected-to normal visual acuity and color vision and were right-handed, determined by self-report.

2.1.2. Stimuli and apparatus

Stimuli were controlled by Psychtoolbox 3 (Brainard, 1997; Pelli, 1997) implemented in MATLAB 2008a (The MathWorks, Natick, MA). Responses were made by using four keys of a standard computer keyboard with the four fingers of the dominant hand. Participants were instructed to press the 'f' key of the keyboard to the red target circle with the index finger of their right hand, the 'g' key to the yellow with the middle finger, the 'h' key to green with the ring finger, and the 'j' key to blue with the small finger when their dominant hand was right (see Fig. 2) and with small finger, ring finger, middle finger and index finger of their left hand, respectively, when their dominant hand was left.

A white cross (0.43° × 0.43°) presented at the center of the display was used for the fixation point. A target circle (0.67° in diameter) was presented at the center of the screen. For horizontal trials, flanker circles (0.67° in diameter) were presented 1.05° left and right from the target. For vertical trials, flanker circles were presented 1.05° above and below the target. Red (R = 255, G = 0, B = 0) and yellow (R = 255, G = 255, B = 0) circles were used as the target and flankers only in the horizontal flanker-compatibility trials, and green (R = 0, G = 255, B = 0) and blue (R = 0, G = 0, B = 255) circles were used only in the vertical flanker-compatibility trials. All stimuli were presented on the gray (R = 128, G = 128, B = 128) background on a 17-inch
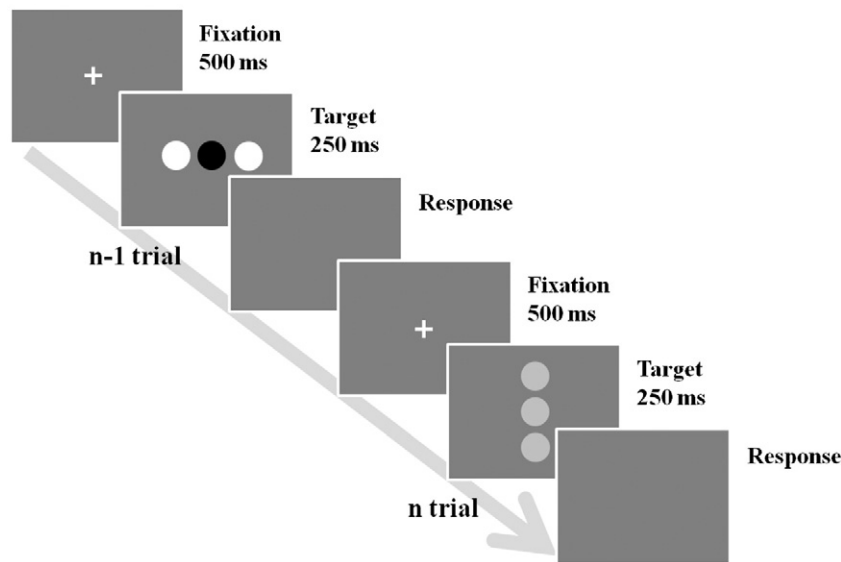
Fig. 1. Example of the trial sequences in Experiments 1 and 2. The horizontal and vertical trials alternated in a trial-by trial manner. Participants were instructed to respond to the color of the target (the center circle) as quickly and accurately as possible.

CRT monitor of a personal computer and viewed at a distance of 60 cm.

2.1.3. Procedure

Participants performed the experiment individually in a dimly lit soundproof chamber. The body midline of the participant and the keyboard were aligned to the center of the monitor.

At the beginning of each trial, a white cross was presented as fixation for 500 ms following a 1000-ms blank display. An imperative stimulus was presented for 250 ms, followed by a blank display until a response. The horizontal and vertical trials alternated in a trial-by trial manner. Participants were instructed to respond to the color of the target (the center circle) with their dominant hand as quickly and accurately as possible. If the response was incorrect, a feedback tone was presented for 500 ms. The experiment consisted of one 41-trial practice block and ten 81-trial test blocks. All trials were presented in a pseudorandom order to equate the number of the four types of trials (cC, cI, iC, and iI) as a function of current-trial congruency and n-1 trial congruency, and four types of trials as a function of current-trial congruency and n-2 trial congruency. A 60-s resting period was given between test blocks.

Fig. 2. Response modes used in Experiments 1 and 2. Responses were made by using the four keys of a standard computer keyboard with the four fingers of the dominant hand in Experiment 1 (left) and with the index and middle fingers of both hands in Experiment 2 (right).
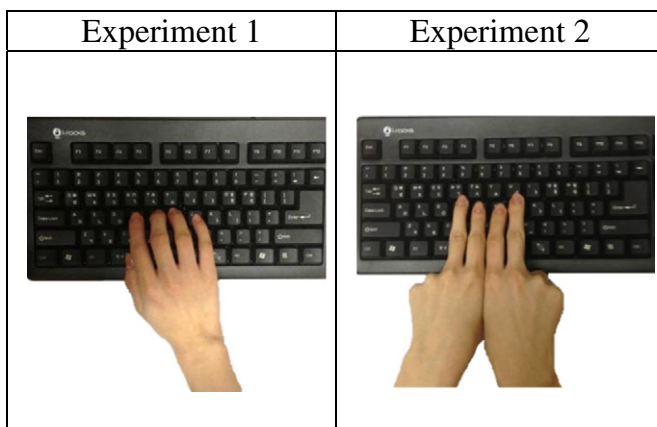
2.2. Results

The first two trials of each block and two trials following error trials and the trials on which RT were faster than 150 or slower than 1250 were removed from the analysis (18.48%). Mean reaction times (RTs) and percentage of errors (PEs) were calculated for each participant as a function of n-2 trial congruency (congruent or incongruent), n-1 trial congruency (congruent or incongruent), and current-trial congruency (congruent or incongruent). Three-way repeated measure analyses of variance (ANOVAs) were conducted on the mean correct RT and PE data (see Table 1) with those variables as within-subject variables.

2.2.1. RT

The main effect of current-trial congruency was significant, $F(1, 15) = 34.90, p < .0001, MSE = 663, \eta_p^2 = .70$. The mean RT for congruent trials (539 ms) was shorter than incongruent trials (566 ms). There was a significant interaction between n-2 trial congruency and current-trial congruency, $F(1, 15) = 7.72, p = .0141, MSE = 114, \eta_p^2 = .34$, indicating a smaller congruency effect when the n-2 trial was incongruent (22 ms), $F(1, 15) = 35.94, p < .0001, MSE = 209, \eta_p^2 = .43$, than when the n-2 trial was congruent (32 ms), $F(1, 15) = 56.07, p < .0001, MSE = 294, \eta_p^2 = .54$. The interaction of current-trial congruency and n-1 trial congruency was also significant, $F(1, 15) = 6.77, p = .0201, MSE = 224, \eta_p^2 = .31$ (see Fig. 3). The magnitude of the current-trial congruency effect was smaller when the n-1 trial was incongruent (20 ms), $F(1, 15) = 34.80, p < .0001, MSE = 184, \eta_p^2 = .43$, than when it was congruent (34 ms), $F(1, 15) = 58.22, p < .0001, MSE = 313, \eta_p^2 = .55$.

A significant three-way interaction of current-trial congruency, n-1 trial congruency, and n-2 trial congruency was also obtained, $F(1, 15) = 4.60, p = .0488, MSE = 170, \eta_p^2 = .23$. To further explore this interaction, separate comparisons were performed at each level of n-2 trial congruency. The separate comparison analysis revealed that there was no significant interaction of n-1 trial congruency and current-trial congruency when the n-2 trial was incongruent, $F(1, 15) < 1$. However, when the n-2 trial was congruent, there was a significant interaction, $F(1, 15) = 8.48, p = .0107, MSE = 264, \eta_p^2 = .36$, indicating a smaller congruency effect after an n-1 incongruent trial (20 ms), $F(1, 15) = 13.36, p = .0023, MSE = 247, \eta_p^2 = .47$, than after an n-1 congruent trial (44 ms), $F(1, 15) = 43.51, p < .0001, MSE = 355, \eta_p^2 = .74$. There was no other significant main effect or interaction.

Table 1
Mean reaction time (in milliseconds) and percent error in Experiment 1 as a function of current-trial congruency, n-1 trial congruency, and n-2 trial congruency.

	Previous trial							
	n-2 trial congruent				n-2 trial incongruent			
	n-1 trial congruent		n-1 trial incongruent		n-1 trial congruent		n-1 trial incongruent	
	RT	PE	RT	PE	RT	PE	RT	PE
Current trial								
Congruent	531	3.16	540	3.72	542	4.15	543	5.00
Incongruent	575	4.72	560	4.95	566	3.38	563	4.96
Congruency effect	44	1.56	20	1.23	24	−.77	20	−.04

2.2.2. PE

A significant interaction effect of current-trial congruency and n-2 trial congruency was found, $F(1, 15) = 4.75$, $p = .0475$, $MSE = 5.48$, $\eta_p^2 = .24$. The congruency effect was not significant after an incongruent n-2 trial, $F(1, 15) < 1$, but it was significant after a congruent n-2 trial (1.40%), $F(1, 15) = 7.54$, $p = .0085$, $MSE = 4.15$, $\eta_p^2 = .14$. No other term was significant.

2.3. Discussion

Unlike the findings of Mayr et al.'s (2003) second experiment, the interaction of n-1 trial congruency and current-trial congruency was found when the participants performed two color flanker-compatibility tasks alternatively in a trial-by-trial manner, and the dominant hand was used to respond for the both tasks, even though neither stimulus or response repetition between two successive trials nor contingency learning was allowed. This result indicates that a single cognitive control mechanism triggered by conflict of one flanker-compatibility task modulated the amount of conflict of the other flanker-compatibility task when the two tasks share the dimensions of stimulus and response. Moreover, the findings that this sequential modulation was significant only when the n-2 trial was congruent but not when it was incongruent provides additional evidence for the idea that the modulation is due to the top-down adjustment mechanism triggered by conflict. That is, when the n-2 trial was incongruent, the conflict of the n-1 trial was not strong enough, resulting in small amount of the top-down sequential modulation between n-1 and current trials. However, when the n-2 trial was congruent, the conflict of the n-1 trial was great enough, resulting in great amount of the sequential modulation between them. These results imply that the magnitude of the congruency sequence effect was determined by the amount of conflict on the previous trial.

As in other experiments in which participants performed two conflict tasks alternatively in a trial-by-trial manner (e.g., Fernandez-Duque & Knight, 2008; Mayr et al., 2003), the interaction of current

Fig. 3. Mean RTs depicted as a function of n-1 trial congruency (left) and as a function of n-2 trial congruency (right) in Experiment 1.

trial and n-2 trial congruency was significant, indicating that the congruency sequence effect was obtained within the same flanker-compatibility task. When additional ANOVAs were conducted on the RT and PE data without response repetition trials to see whether this sequential effect was due to top-down control or bottom-up response priming, the interaction of n-2 trial congruency and n trial congruency was not significant, $Fs(1, 15) < 1.0$. This result suggests that bottom-up response repetition priming was, at least in part, responsible for the congruency sequence effect when response repetition was allowed, as Mayr et al. (2003) suggested.

3. Experiment 2

In Experiment 1, a significant congruency sequence effect was obtained between two congruencies when no stimulus or response repetition was allowed between the two tasks. These findings suggest that the congruency sequence effect is, at least in part, due to the cognitive control mechanism rather than stimulus and response priming or contingency learning. It has been found that the congruency sequence effect between two different tasks was evident when the two tasks shared the identical response set (Hazeltine, Lightman, Schwarb, & Schumacher, 2011) or when there was overlap between the two response sets (Braem, Verguts, & Notebaert, 2011). However, in Experiment 1, the two tasks did not share the response set. This might have been due to the control mechanism specific to response mode because the distinction between the two response sets was made in terms of a less salient dimension (index and middle fingers for one task and ring and small fingers for the other task). Thus, if two response sets are discriminated in terms of a more salient feature, they are probably processed as different response modes.

The present experiment was conducted to test this possibility. As in Experiment 1, participants were asked to perform the two color flanker-compatibility tasks alternatively in a trial-by-trial manner in Experiment 2. However, they responded to the target with their left index and middle fingers in one task and their right index and middle fingers in the other task. Because the two response sets were discriminated in terms of a salient feature, which is response hand, the two response sets were processed as different response modes. The stimulus dimension was shared for the two color flanker-compatibility tasks, but the response mode was not in Experiment 2. If the control process is dependent on the response mode, no sequential modulation between the two congruencies would be obtained.

3.1. Method

3.1.1. Participants

Sixteen new undergraduate students (mean age = 22.7, 6 males) from the same participant pool as that in Experiment 1 participated.

3.1.2. Stimuli and apparatus

Experimental stimuli, apparatus, and procedure were identical to those of Experiment 1, with the following exceptions. Participants were instructed to respond to press the 'f' key of keyboard to the red
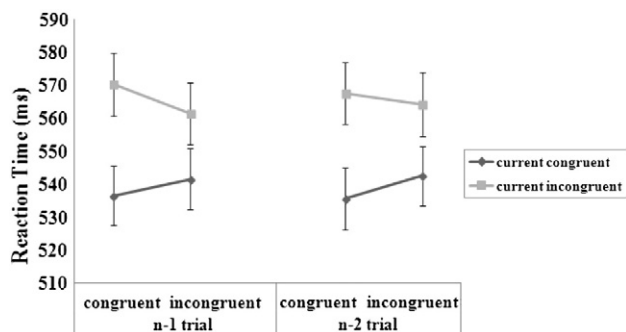
Table 2

Mean reaction time (in milliseconds) and percent error in Experiment 2 as a function of current-trial congruency, n-1 trial congruency, and n-2 trial congruency.

	Previous trial							
	n-2 trial congruent				n-2 trial incongruent			
	n-1 trial congruent		n-1 trial incongruent		n-1 trial congruent		n-1 trial incongruent	
	RT	PE	RT	PE	RT	PE	RT	PE
Current trial								
Congruent	542	2.95	546	2.57	551	3.48	555	4.51
Incongruent	574	3.99	569	3.49	559	3.58	569	3.79
Congruency effect	32	1.03	23	.92	8	.10	14	−.72

target circle with the left middle finger, the 'g' key to the yellow with the left index finger, the 'h' key to the green with the right index finger, and the 'j' key to the blue with the right middle finger (see Fig. 2).

3.2. Results

With the same exclusion criteria as in Experiment 1, 17.23% of the trials were removed from analysis. Mean RT and PE were calculated for each participant as a function of n-2 trial congruency (congruent or incongruent), n-1 trial congruency (congruent or incongruent), and current-trial congruency (congruent or incongruent). ANOVAs were conducted on the mean RT and PE data (see Table 2) with those as within-subject variables.

3.2.1. RT

The main effect of current trial congruency was significant, $F(1, 15) = 49.05$, $p < .0001$, $MSE = 238$, $\eta_p^2 = .77$. The mean RT for the congruent trials (549 ms) was shorter than the mean RT for the incongruent trials (568 ms). As in Experiment 1, the interaction of current-trial congruency and n-2 trial congruency was significant, $F(1, 15) = 7.21$, $p = .0170$, $MSE = 300$, $\eta_p^2 = .32$. The congruency effect was smaller when the n-2 trial was incongruent (11 ms), $F(1, 15) = 9.63$, $p = .0032$, $MSE = 197$, $\eta_p^2 = .17$, than when it was congruent (27 ms), $F(1, 15) = 57.42$, $p < .0001$, $MSE = 208$, $\eta_p^2 = .55$ (see Fig. 4). Importantly, the interaction of current-trial congruency and n-1 trial congruency was not significant, $F(1, 15) < 1$. No other main effect or interaction was significant, including the 3-way interaction, $F(1, 15) = 1.98$, $p = .1802$, that was significant in Experiment 1.

3.2.2. PE

There was a significant interaction of n-2 trial congruency and n-1 trial congruency, $F(1, 15) = 4.57$, $p = .0493$, $MSE = 1.98$, $\eta_p^2 = .23$. For congruent n-2 trials PE of the current trial was higher when the n-1 trial was congruent (3.47%), than when it was incongruent (3.03%), but for incongruent n-2 trials PE of the current trial was higher when then n-1 trial was incongruent (4.15%) than when it was congruent
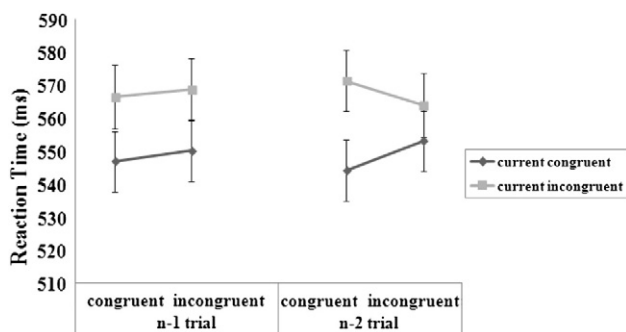
(3.53%). However, these n-1 congruency effects were not significant, $F(1, 15) < 1$, and $F(1, 15) = 1.22$, $p = .2751$, $MSE = 5.05$, $\eta_p^2 = .03$, respectively. No other main effect or interaction was significant.

3.3. Discussion

The results of Experiment 2, unlike Experiment 1, showed no congruency sequence effect between the two color flanker-compatibility tasks, even though a significant 19-ms flanker compatibility effect was obtained in RT. The magnitude of the flanker-compatibility task was the same 19 ms regardless of whether trial n-1 was incongruent or congruent. These findings suggest that the control mechanism triggered by conflict was response mode-specific, which is consistent with recent findings (Braem et al., 2011; Hazeltine et al., 2011; Lee & Cho, 2013). That is, control triggered by conflict of one flanker-compatibility task exerts on the link between the stages processing a stimulus dimension of color and its response mode of the left (right) hand response set, did not modulate conflict of the other flanker-compatibility task on the next trial, because the response modes of the two tasks were different.

4. General discussion

Two experiments were conducted to investigate whether the congruency sequence effect is obtained between two flanker-compatibility tasks without stimulus or response repetition in a context in which a distractor has no information about the response on a given trial. Experiment 1 showed a congruency sequence effect between different tasks when participants performed two color flanker-compatibility tasks with the same response mode but different response set. Even when neither stimulus nor response was allowed to repeat and distractors had no information for the correct response, the congruency of one task modulated the magnitude of the congruency effect of the other task on the following trial. However, when participants were asked to respond for one color flanker-compatibility task with one hand and the other task with the other hand in Experiment 2, no congruency sequence effect was obtained between the two different congruencies. These results indicate that the congruency sequence effect is due, at least in part, to conflict-induced cognitive control mechanism, which is sensitive to response mode.

As mentioned earlier, Mayr et al. (2003) and Hommel et al. (2004) suggested that performance is impaired when some stimulus or response features of the previous trial are repeated but the others are alternated in the current trial. Because this partial repetition trial exists on the iC and Ci trial sequences in a 2-choice conflict task, the cC and iI trial sequences are faster than iC and cI trial sequences. To discriminate the effect of the cognitive control process from the effect of the stimulus or response repetition priming, many researchers have conducted tasks with more than two stimulus and response alternatives. When the data of only complete alternation trials (e.g., Akçay & Hazeltine, 2007; Notebaert et al., 2006) or the data without stimulus-repetition trials (e.g., Kerns et al., 2004; Ullsperger et al., 2005) were analyzed, a significant congruency sequence effect was obtained,

Fig. 4. Mean RTs depicted as a function of n-1 trial congruency (left) and as a function of n-2 trial congruency (right) in Experiment 2.

indicating that the sequential modulation is not entirely due to bottom-up priming. However, Spapé, Band, and Hommel (2011) have suggested that it is impossible to eliminate confounds of repetition-priming with the effect of the top-down control in principle because the performance of complete alternation trials can be facilitated by binding of stimulus and response features formed on the previous trial. Yet, even though this confound could not have been completely avoidable, as Spapé et al. suggested, the effect of binding was minimized in the present experiments because the two successive tasks had different sets of stimulus and response alternatives. That is, the benefit from the binding of stimulus and response features should be smaller when response competition occurs between alternative codes of different tasks than when it occurs between alternative codes of the same task (Hommel, Müsseler, Aschersleben, & Prinz, 2001).

According to the conflict-based accounts, the control process triggered by conflict modulate the influence of the conflict inducing stimulus features by enhancing the process of the task-relevant stimulus features (e.g., Egner, 2007; Egner & Hirsch, 2005) or suppressing the process of the task-irrelevant stimulus features (e.g., Lee & Cho, 2013; Stürmer, Leuthold, Soetens, Schrter, & Sommer, 2002). Because the horizontal and vertical dimensions are processed independently (Nicoletti & Umiltà, 1984; Rubichi et al., 2006; Wiegand & Wascher, 2007) in Mayr et al.'s (2003) second experiment, the dimension-specific control process triggered by the conflict in one spatial dimension was not able to modulate the conflict in the other dimension. However, in the present Experiment 1, the two flanker-compatibility tasks had the same task-relevant (and task-irrelevant) stimulus dimension, which was color, even though they had different sets of colors, so that the control process triggered by the conflict of the one color flanker-compatibility task was able to modulate the conflict in the other flanker-compatibility task.

Another problem of using a larger stimulus set to control the effect of repetitions between trials is that researchers usually equated the proportions of congruency within a block, resulting in participants learning the contingency between a specific distractor and a specific response (Mordkoff, 2012; Schmidt et al., 2007). It has been shown that this contingency learning contributes to the congruency sequence effect or, at least, it contaminates the effect, as well as the stimulus and response repetitions do (Schmidt & De Houwer, 2011; Schmidt et al., 2007). For example, Schmidt and De Houwer found no congruency sequence effect after removing all repetition trials when they had participants perform a four-choice flanker-compatibility task in which all stimuli were presented equally often as a distractor in their Experiment 2. However, a significant congruency sequence effect was obtained in the present Experiment 1, in which the effects of the contingency learning and the stimulus and response repetition priming were controlled by having participant perform two 2-choice flanker-compatibility tasks alternatively with different response sets. Moreover, in Schmidt and De Houwer's Experiment 1, in which participants performed a 4-choice Stroop task, a significant congruency sequence effect was obtained in the error data. The findings of the congruency sequence effect occurring without the contributions of the contingency learning and the bottom-up repetition priming indicate that the top-down control process triggered by conflict plays a great role in the sequential modulation.

One critical question regarding the conflict-based control mechanism is whether the top-down trial-to-trial adjustments are due to an enhanced process of the task-relevant stimulus features or suppressive process of the task-irrelevant conflicting stimulus features. Egner and Hirsch (2005) reported that the activation of the fusiform face area (FFA) was amplified after incongruent trials relative to the activation after congruent trials when a face was presented as a target, but it was not affected by the previous congruency when the face was presented as a distractor, suggesting that the control process triggered by conflict on the previous trial amplifies processing of the task-relevant stimulus features. According to them, this enhanced processing of the target is possibly accomplished by enhancing baseline neural activity before the onset of the target. Notebaert and Verguts (2008) showed that the

congruency sequence effect was obtained between the SNARC (spatial numerical association of response code, Dehaene, Bossini, & Giraux, 1993) and spatial Simon congruencies only when the task-relevant dimensions of the two tasks were identical. However, no congruency sequence effect was obtained between horizontal and vertical Simon tasks sharing the task-relevant stimulus feature (Lee & Cho, 2013, Experiment 1). If the control process triggered by conflict of one task amplifies the task-relevant stimulus features, the congruency sequence effect should have been obtained between the two tasks sharing the task-relevant feature.

Rather, Lee and Cho (2013) found congruency modulation between the Simon and spatial Stroop tasks sharing the task-irrelevant conflicting stimulus features and response dimension, indicating a top-down suppressive control mechanism. These results are in agreement with Stürmer et al.'s (2002) finding that incorrect lateralized readiness potential (LRP) was present after congruent trials but not after incongruent trials, indicating that response priming activated by task-irrelevant conflicting stimulus feature was modulated by a control process after incongruent trials. Unfortunately, the present study does not provide an answer for the question about whether the control process is accomplished by enhancement of the task-relevant stimulus feature or suppression of the task-irrelevant conflicting stimulus features because the task-relevant and task-irrelevant dimensions are identical in the flanker-compatibility task. However, as many researchers have claimed that the core control mechanism is suppressive in nature in various situations (e.g., Aron, 2007; De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990; Logan, 1985; Mayr & Keele, 2000; Nee, Wager, & Jonides, 2007; Ridderinkhof, 2002), the trial-to-trial adjustment is possibly attributed to the suppression of the processing link through which task-irrelevant information activates a response, as well.

4.1. Response mode-specific control mechanism

The significant congruency sequence effects obtained without response repetition in Experiment 1 indicate that the sequential modulation between a horizontal Simon and spatial Stroop congruencies found by Lee and Cho (2013) was not due to response-repetition priming. However, no congruency sequence effect was obtained in Experiment 2, although all aspects of the experiment were identical to those of Experiment 1 with an exception that participants were asked to respond with one hand for one task and with the other hand for the other task. No congruency sequence effect was obtained between the Simon and spatial Stroop tasks (Lee & Cho, 2013) and two temporal flanker compatibility tasks (Hazeltine et al., 2011) when participants were to respond to one task with their left hand and the other task with their right hand. If the control mechanism is specific to task-relevant or task-irrelevant feature only, conflict of one task should have been modulated by conflict of the other task regardless of whether one hand was used to respond for the two tasks or different hands for different tasks. That is, whether the congruency sequence effect occurs between two different tasks depends on whether the response sets for the both tasks were represented as the same modality or different modalities (Braem et al., 2011; Hazeltine et al., 2011).

Response modality, which is closely related to anatomical effector systems (Huestegge & Hazeltine, 2011), is the representational categories of related actions, which are necessary for an overt response. It has been suggested that response modality is an important component of the task sets, which control cognitive and motor operations (e.g., Kleinsorge & Heuer, 1999; Philipp & Koch, 2011). Moreover, the task sets for two tasks differing in response modality are represented distinctively (Koch, Gade, & Philipp, 2004; Philipp & Koch, 2005). These imply that when two tasks have different response modes (different categories of the actions for responses to different tasks, such as left-hand keypressing responses for one task and right-hand keypressing responses for the other task) the control process of one task could not modulate the performance of the other task.

Response alternatives for a task are thought to be hierarchically organized (Rosenbaum, 1980), like task sets (Kleinsorge & Heuer, 1999; Kleinsorge, Heuer, & Schmidtke, 2004; Schneider & Logan, 2006). It has been suggested that the specification of hand takes place at a higher level than the specification of finger (Miller, 1982; Rosenbaum, 1983). However, Proctor and Reeve (1985, 1986, 1984) claimed that response alternatives are coded in terms of a salient feature, implying that whether two tasks share a common response mode is likely determined by whether the distinction of the response sets for the tasks is made in terms of a salient feature, such as effectors, spatial dimension of the response set, or stimulus dimension assigned to each response alternative (Adam, Hommel, & Umiltà, 2003). Proctor and Vu (2010) also suggested that two different tasks are represented separately when different hands are used to respond for different tasks.

Although the characteristics of the hierarchical structure for the response set are not clear yet, either way, the distinction between the two response sets is more evident between hands than different fingers on the same hand. Thus, when sets of response alternatives for two different tasks are separated between hands, as in Experiment 2, the two different response sets are represented separately because the distinction between them is made in terms of hand, which is a salient feature (Proctor & Reeve, 1985, 1986; Reeve & Proctor, 1984) or is specified at a higher level (Miller, 1982; Rosenbaum, 1983). However, when the two response sets are separated among fingers on the same hand, as in Experiments 1, the two different response sets are represented as a same response modality because distinction is made in terms of finger, which is a nonsalient feature or is specified at a lower level. It should be noted that the congruency sequence effect between two task congruencies was obtained when two tasks differed in terms of response hand (Akçay & Hazeltine, 2008, Experiment 1). However, because the task-relevant and task-irrelevant dimensions of the two tasks were same in Akçay and Hazeltine's Experiment 1, the response alternatives were probably represented in terms of the task-relevant dimension, as Adam et al. (2003) suggested. These results indicate that how response alternatives are represented can be flexibly determined depending on task situation.

4.2. Task structure-specific cognitive control mechanism?

According to Egner, Delano, and Hirsch (2007) and Funes, Lupiáñez, and Humphreys (2010), the cognitive control mechanism is specific to the source of conflict. In Egner et al.'s experiment, in which participants were to respond to the color of the target word presented to the left or right of fixation, no congruency sequence effect was obtained between the Stroop and Simon congruencies. Egner et al. suggested that the control mechanism recruited by the conflict caused by the color of the word and the meaning of the word did not modulate the conflict caused by the location of the color word and the response location, and vice versa. Akçay and Hazeltine (2008) agree that independent cognitive control mechanisms modulate different types of the congruency effect. However, as mentioned earlier, they suggested that the cognitive control mechanism is specific to the task structure, rather than the source of conflict. According to Akçay and Hazeltine's task structure account, whether two tasks are presented as an integrated one depends on the two tasks sharing stimulus and/or response set, and the stimulus–response mapping.

The findings that the presence of the congruency sequence effect between the congruencies of the two color flanker-compatibility tasks depended on whether or not the two tasks were responded with the same response mode imply that the task-structure specific control is responsible for the congruency sequence effect, as Akçay and Hazeltine (2008) suggested. However, the congruency sequence effect was evident between the congruencies of the Simon and spatial Stroop tasks having different task-relevant stimulus dimensions (and different stimulus–response mappings) but a common task-irrelevant conflicting stimulus dimension (Lee & Cho, 2013). Moreover,

top-down modulation between two tasks sharing the task-relevant stimulus dimension has been unreliable. For example, when two tasks shared the task-relevant dimension, a significant top-down modulation was obtained between two different congruencies in some experiments (e.g., Notebaert & Verguts, 2008, Experiment 1), but no sequential modulation in others (Lee & Cho, 2013, Experiment 4). Hazeltine et al. (2011) found a significant congruency sequence effect between two different congruencies even when neither task-relevant dimension nor task mapping was shared between the two tasks. To explain these results with respect to the structure-specific control mechanisms, an additional assumption should be necessary to define the task structure.

4.3. Conclusion

The present study showed significant congruency sequence effects between two different color flanker-compatibility tasks without stimulus or response repetition and contingency when the two tasks shared the response mode. That is, the lack of the top-down modulation between the vertical and horizontal arrow flanker compatibility tasks in Mayr et al. (2003) second experiment was due to the top-down trial-to-trial adjustment which is specific to stimulus and response dimensions. Even though stimulus and/or response repetitions reduce the congruency effect after an incongruent trial (Davelaar & Stevens, 2009; Hommel et al., 2004; Liepelt, Wenke, Fischer, & Prinz, 2011; Notebaert et al., 2006), the congruency sequence effect can occur without such repetitions. Moreover, the finding of the significant congruency sequence effect without the contingency of a distractor with the correct response indicates that the control mechanism triggered by conflict contributes to the effect. In sum, the present study demonstrated that the domain of control is determined depending on not only stimulus dimensions, but also response modality, as the task structure hypothesis (Akçay & Hazeltine, 2008; Hazeltine et al., 2011) and the Hebbian learning view (Braem et al., 2011; Verguts & Notebaert, 2008) suggested. However, the findings of the congruency sequence effect without stimulus or response repetition do not necessarily indicate that the congruency sequence effect is due entirely to the control mechanism triggered by conflict. Rather, both top-down trial-by-trial adjustment and bottom-up priming seem to operate together as the sources of the congruency sequence effect.

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