



Determining the scope of control underlying the congruency sequence effect: roles of stimulus-response mapping and response mode[☆]

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ABSTRACT

Sequential modulation between two task congruencies has been examined to investigate the nature of the cognitive control mechanism underlying the congruency sequence effect (CSE). Previous results regarding what consecutive tasks must have in common to engender the cross-task CSE are inconsistent. The present study examined the roles of stimulus-response (S-R) mappings and response mode as critical factors in determining the scope of control. Two flanker-compatibility tasks having different stimulus and response sets alternated in turn, and the arbitrariness of S-R mappings alone (Experiment 1) or the arbitrariness of stimulus set and the distinctiveness of response modes (Experiment 2) were manipulated. Experiment 1 showed that non-arbitrary S-R mappings engendered a cross-task CSE even when the response modes were different. However, when S-R mappings were arbitrary in Experiment 2, sequential modulation was evident across two tasks only when their response modes were same, irrespective of the arbitrariness of the stimulus set. These results suggest that the arbitrariness of S-R mappings and response mode are salient task features that reconfigure task representation and consequently determine the scope of the control underlying the CSE.

1. Introduction

When the response activated by task-relevant information conflicts with the response activated by task-irrelevant information, response times or error rates increase, which is referred to as the *congruency effect*. The congruency effect, such as the flanker-compatibility effect (Eriksen & Eriksen, 1974), Simon effect (Simon & Rudell, 1967) and Stroop effect (Stroop, 1935), is modulated by previous-trial congruency, as the congruency effect is smaller after incongruent trials than after congruent trials (Gratton, Coles, & Donchin, 1992). This sequential modulation is called the *congruency sequence effect* (CSE). It has been suggested that the CSE occurs because of a reactive control mechanism triggered by conflict, which adjusts the level of control depending on the occurrence of conflict in the previous trial. For example, Botvinick, Braver, Barch, Carter, and Cohen (2001) proposed a *conflict monitoring hypothesis*, according to which a conflict monitoring system located in the dorsal anterior cingulate cortex (dACC) detects conflict when task-relevant and task-irrelevant features activate different responses. This system then sends a signal to the dorsolateral prefrontal cortex (dlPFC) to enhance the regulation of conflict. This heightened control reduces the influence of conflict on the following trials, leading to the sequential modulation of the congruency effect.

One of the primary concerns regarding the nature of the CSE is the extent to which the same control mechanism is adjusted across task contexts. A wealth of studies provide evidence for domain-specific characteristics of the control process (e.g., Akçay & Hazeltine, 2008; Braem, Abrahamse, Duthoo, & Notebaert, 2014; Egner, 2008; Kim & Cho, 2014) by examining whether the CSE occurs between two different tasks, which involve different stimulus sets, response sets and/or conflict types. Those studies provide evidence that the scope of control is determined by specific task properties.

Egner, Delano, and Hirsch (2007) proposed that different control mechanisms are adopted depending on the type of conflict. The source of conflict is supposed to be mainly categorized by two types; the conflict between relevant and irrelevant stimulus dimensions (e.g., flanker-compatibility and Stroop tasks) and the conflict between the irrelevant stimulus dimension and the response dimension (e.g., Simon task). By using a modified Stroop task, which entailed both types of conflict, Egner et al. obtained a CSE between two successive trials only when they involved the same type of conflict. However, a number of other studies did not observe the CSE between two tasks having the same conflict type (Akçay & Hazeltine, 2008; Lee & Cho, 2013; Notebaert & Verguts, 2008). For example, Akçay and Hazeltine demonstrated no CSE between two Simon tasks that had different stimulus

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and response sets, while a significant CSE was found when the two tasks had an identical response set but different stimulus sets. Thus, some researchers argued that the way sequential modulation occurs between two tasks is more specific than what Egner et al. (2007) suggested.

Akçay and Hazeltine (2008) proposed that the scope of control is flexibly determined by task structure. That is, sequential modulation occurs between two tasks when they are represented as a single task, but not when they are represented as different tasks. More specifically, Verguts and Notebaert (2008, 2009) emphasized the importance of the stimulus dimension in determining the scope of control. According to them, the detection of conflict strengthens all currently activated associations, most of which involve task-relevant information and its correct response. In this way, conflict especially allows a facilitated process of task-relevant information within the boundary of the associations that are presently activated. Meanwhile, other studies demonstrated that conflict, at least in Simon-type tasks, is resolved mainly by suppressing the task-irrelevant stimulus dimension (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Thus, two tasks are required to have a common task-irrelevant stimulus dimension to be regulated by the same control mechanism (Kim, Lee, & Cho, 2015; Lee & Cho, 2013).

Recently, Kim and Cho (2014) suggested that *response mode* plays a critical role in the cross-task CSE. They examined the CSE between two color flanker-compatibility tasks performed by the same hand (Experiment 1) or different hands (Experiment 2), which were assumed to represent the same response mode and different response modes, respectively. Response mode is a representational group of related motor responses, which is flexibly determined by salient features, such as relative location of responses, spatial cues, or even the conceptualization of a task (Adam, 1994; Adam, Hommel, & Umiltà, 2003; Ansorge & Wühr, 2004; Freedberg, Wagschal, & Hazeltine, 2014; Hazeltine, 2005; Lippa, 1996; Proctor & Reeve, 1985, 1986; Reeve & Proctor, 1984). Due to hierarchical characteristics of response features (Rosenbaum, 1980), the distinction of response sets in terms of hands is supposed to be more salient than that of fingers (Miller, 1982; Rosenbaum, 1983). Thus, if two response sets are discriminated by the left and right hands, they are more likely to be represented as different response modes. However, two response sets comprised from four fingers of one hand – with the two left fingers (i.e., index and middle fingers) allocated to one task and two right fingers (i.e., ring and little fingers) to the other task – can be assumed to be represented as a single response mode. This is because the distinction between response sets is made in terms of fingers, which is assumed to be a less salient feature than hands. The results showed that the cross-task CSE was evident when the two tasks were performed with the same hand, but not with different hands. They provides evidence that the control mechanism recruited by conflict in the previous trial regulated conflict in the current trial only when responses in the two successive trials belonged to the same response mode.

Meanwhile, Weissman, Colter, Drake, and Morgan (2015) suggested that the scope of control triggered by conflict is independent of response mode. With a similar experimental design to that used in Kim and Cho's (2014) experiments, they found a significant CSE between the two tasks performed with different response modes (i.e., the two hands). However, one possibility for the contradictory results in the studies by Kim and Cho (2014) and Weissman, Colter, et al. (2015) is that the influence of response mode on the cross-task CSE is modulated by the arbitrariness of stimulus-response (S-R) mappings, as Weissman and his colleagues also suggested. In Weissman et al.'s experiments, the stimulus sets of the two tasks consisted of alphabet letters (A, B, C, and D) or digits (1, 2, 3, and 4), which had overlearned sequential relationships among the stimulus alternatives of the two tasks. Also, the spatial arrangements (from left to right) of the response alternatives were compatible with those sequential relationships, leading to non-arbitrary mappings between the stimulus and response alternatives. However, Kim and Cho employed arbitrary sets of colored stimuli (red, yellow, green, and blue), which did not have any semantic or sequential

relationships among the stimulus and response alternatives.

Considering that S-R mappings designate the association between stimulus and response alternatives, the task sets are likely to be re-configured following the S-R mapping rule (Dreisbach, Goschke, & Haider, 2007; Hazeltine, 2005; Proctor & Reeve, 1985). When overlearned sequential relationships exist among the S-R mappings of two tasks, it is possible that they are bound by a single S-R mapping rule, rather than being processed as four individual associations between stimulus and response alternatives (Dreisbach, 2012; Dreisbach et al., 2007). In this way, the distinction between two task sets would not be salient enough to form separate task representations, even when their response sets are allocated to different hands. That is, when two tasks share a common task feature (e.g., S-R mapping rule), which is more salient than response mode, the representation of the two tasks would not be distinguished and so are subject to the same control mechanism, as Akçay and Hazeltine (2008) suggested.

The aim of the present study was to investigate whether the arbitrariness of S-R mappings, as well as response mode, are crucial factors in determining the scope of control. For this purpose, two flanker-compatibility tasks involving a string of non-arbitrary letter stimuli (A, B, C, and D) or arbitrary letter stimuli (T, L, H, and N) were used. In Experiment 1, the arbitrariness of S-R mappings was manipulated and the two tasks were always performed with different response modes. If the arbitrariness of S-R mappings modulates the influence of response mode on the cross-task CSE, sequential modulation would be observed when the non-arbitrary S-R mappings were used, but not when the arbitrary stimulus S-R mappings were used. In Experiment 2, the role of the response mode was examined when S-R mappings remained arbitrary, while the confounding effect of the arbitrariness of stimulus sets themselves was dissociated from that of S-R mappings. If the boundary of control varies depending on the sequential relationship among stimulus alternatives themselves, rather than the S-R mappings, the cross-task CSE would be more evident when the non-arbitrary stimulus sets were used than when the arbitrary stimulus sets were used. At the same time, if response mode is one of the salient task features constraining the scope of control, the cross-task CSE is supposed to be engendered only when the two tasks were performed with the same response mode.

2. Experiment 1

Experiment 1 was conducted to investigate whether the CSE between two different tasks is modulated by the arbitrariness of S-R mappings when they are performed with different response modes. Participants performed two letter flanker-compatibility tasks alternately in a trial-by-trial manner with non-arbitrary or arbitrary S-R mappings. For non-arbitrary S-R mappings, the stimulus sets of the two tasks consisted of capital letters A, B, C, and D that had an overlearned sequential relationship with each other. Since each stimulus alternative was mapped to each response alternative in a manner that was spatially (from left to right) compatible with its alphabetical order, S-R mappings also had an overlearned sequential relationship. Hence, S-R mappings of the two tasks were expected to be linked, along with the sequential relationships among them. In contrast, for arbitrary S-R mappings, stimulus sets of the two tasks consisted of capital letters T, L, H, and N, which were sequentially unrelated to each other. The response sets of the two tasks were always clearly distinguished by making responses to one flanker-compatibility task with the left index and middle fingers, and the other flanker-compatibility task with the right index and middle fingers. Thus, the two tasks were assumed to have different response modes (see Fig. 1).

Because each participant performed the two tasks having the identical task-relevant and task-irrelevant stimulus dimensions, and the same source of conflict, three possible results were expected in terms of the arbitrariness of S-R mappings and response mode. If a common control mechanism is adjusted to the two tasks independently of response mode, the CSE would occur with both types of S-R mappings.

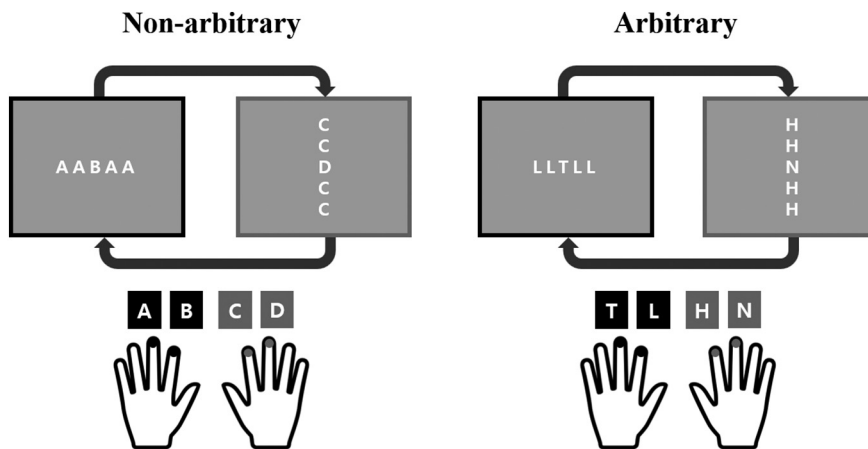


Fig. 1. Example of stimulus sets and response sets in Experiment 1. Two tasks consisted of the non-arbitrary (left) or the arbitrary (right) S-R mappings. The shade denotes each task, so for the non-arbitrary S-R mappings, letter 'A' and 'B' belonged to one task and letter 'C' and 'D' belonged to the other task. For the arbitrary S-R mappings, letter 'T' and 'L' composed one task and letter 'H' and 'N' composed the other task.

However, if the arbitrariness of S-R mappings modulates the influence of response mode on the scope of control, a significant cross-task CSE would be found when S-R mappings were non-arbitrary, but not when they were arbitrary. Finally, if the two tasks having different response modes do not share the same control mechanism regardless of the arbitrariness of S-R mappings, sequential modulation between the two tasks would not occur, either with the arbitrary or non-arbitrary S-R mappings.

2.1. Method

2.1.1. Participants

A total of 32 undergraduate students (13 male, mean age = 21.88) were recruited from Korea University. A group of 16 participants was to perform the task with arbitrary S-R mappings, and the other participants were to perform the task with non-arbitrary S-R mappings. All participants had normal or corrected-to-normal visual acuity and were right-handed. The participants gave informed consent and received KRW 6000 (about five US dollars) for their participation. The current and following experiment were approved by the Institutional Review Board at Korea University (KU-IRB-16-142-A-1).

2.1.2. Stimulus and apparatus

Stimuli and responses were controlled by MATLAB 2008a or MATLAB 2014b, using Psychtoolbox3, and presented on a 17-in. CRT personal computer monitor. Responses were made using four keys of a standard computer keyboard with the left and right index and middle fingers. The two flanker-compatibility tasks consisted of different stimulus and response sets, which were alternated in a trial-by-trial manner to prevent the stimulus and response features from being repeated, and to control the repetition priming effect (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). For the non-arbitrary S-R mappings, the letter A or B was presented as a target and distractor in one flanker-compatibility task, and the letter C or D in the other flanker-compatibility task. For one task, participants were instructed to press adjacent keys to the left side of the keyboard, the 'd' key to the target 'A' and the 'f' key to 'B,' using the middle and index fingers of their left hand, respectively. For the other task, participants were to press keys located to the right side of the keyboard, the 'j' key to the target 'C' and the 'k' key to the 'D,' with the index and middle fingers of their right hand, respectively. For the arbitrary S-R mappings, letters T, L, H, and N were used instead of letters A, B, C, and D (see Fig. 1).

As a fixation point, a white cross (approximately $0.3^\circ \times 0.3^\circ$) was presented at the center of the display. The target stimulus (approximately $0.6^\circ \times 0.66^\circ$) appeared at the center of the display, and two flanker stimuli (approximately $0.6^\circ \times 0.66^\circ$) at left and right sides of the target in odd trials, and above and below the target in even trials. Letter stimuli were spaced at an equal distance (approximately 0.09°)

from each other. All stimuli were presented in white on a gray ($R = 128, G = 128, B = 128$) background, and viewed from a distance of 60 cm.

2.1.3. Procedure

After the informed consent, participants were instructed in the experimental procedure in a soundproof chamber with dim light. The midlines of the participants and keyboard were aligned with the center of the monitor. Each trial began with the fixation cross for 500 ms, then the target and flankers were presented at the same time for 250 ms, followed by a blank display for 1750 ms. The two flanker-compatibility tasks were performed in turn. For the non-arbitrary S-R mappings, letter A and/or B appeared in one flanker-compatibility task, which participants responded to using their left hands, while letter C and/or D appeared in the other flanker-compatibility task, which participants responded to using their right hands. For the arbitrary S-R mappings, the letters T, L, H, and N were used, instead of A, B, C, and D.

Participants were instructed to respond to the target letter as rapidly and accurately as possible. As soon as the response was made, the display became blank, and auditory feedback (a beep sound) was presented for 150 ms for incorrect responses or late responses for which the reaction time (RT) was longer than 2000 ms. This was followed by another blank display for 1000 ms. All stimuli were presented in a pseudorandom order to equate the four sequence types, taking the congruency of the previous trial and the current trial into account: previously congruent and currently congruent (cC), previously congruent and currently incongruent (cI), previously incongruent and currently congruent (iC), and previously incongruent and currently incongruent (iI) sequences. Aside from the 30 practice trials, the main experiment consisted of eight blocks of 82 trials. A 60-s break period was provided between blocks.

2.2. Results

The first and second trials of each block were removed from analyses. Trials with RTs shorter than 150 ms or longer than 2.5 standard deviations from the individual's mean RT for each sequence type (cC, cI, iC, and iI) were defined as outliers. RT outliers and the trials following RT outlier or incorrect responses were excluded from the analyses (approximately 8.72% of the total trials). Mean correct RTs and percent errors (PEs) were calculated for each participant as a function of previous-trial congruency (n-1 congruent vs. n-1 incongruent) and current-trial congruency (congruent vs. incongruent). Three-way mixed-measures ANOVAs were conducted on the mean correct RTs and PEs with the above factors as within-subject variables and S-R mapping (arbitrary vs. non-arbitrary) as a between-subjects variable (Table 1).

Table 1

Mean and standard deviation of reaction time (in milliseconds) and percentage error in Experiment 1, as a function of S-R mapping, previous-trial congruency, and current-trial congruency.

S-R mapping	Previous congruency	Current congruency	RT		PE	
			Mean	SD	Mean	SD
Non-arbitrary	Congruent	Congruent (cC)	470	43.26	2.75	3.25
		Incongruent (cI)	505	42.12	4.30	4.99
	Incongruent	Congruent (iC)	478	47.48	3.22	3.47
		Incongruent (iI)	502	43.96	4.65	4.85
Arbitrary	Congruent	Congruent (cC)	541	80.97	2.75	2.87
		Incongruent (cI)	563	68.55	4.13	3.30
	Incongruent	Congruent (iC)	543	77.27	3.34	3.85
		Incongruent (iI)	569	70.27	4.31	3.33

2.2.1. RT

The main effect of current-trial congruency was significant, $F(1, 30) = 80.07$, $p < .001$, $MSE = 288$, $\eta_p^2 = 0.7274$. The mean RT was shorter for congruent trials ($M = 508$ ms) than incongruent trials ($M = 535$ ms). Also, the main effect of S-R mapping was significant, $F(1, 30) = 9.46$, $p = .0044$, $MSE = 14,500$, $\eta_p^2 = 0.2398$. Responses were faster when the S-R mappings were non-arbitrary ($M = 489$ ms) than when they were arbitrary ($M = 554$ ms). The interaction between previous-trial congruency and current-trial congruency was not significant, $F(1, 30) = 1.11$, $p = .3007$, $MSE = 96$, $\eta_p^2 = 0.0356$, indicating no overall CSE. However, the three-way interaction of S-R mapping, previous-trial congruency, and current-trial congruency was significant, $F(1, 30) = 5.43$, $p = .0268$, $MSE = 96$, $\eta_p^2 = 0.1532$. For further examination of this interaction, separate analyses for each S-R mapping were performed as a function of previous-trial congruency and current-trial congruency. When the non-arbitrary S-R mappings were presented, previous-trial congruency interacted with current-trial congruency, $F(1, 15) = 10.41$, $p = .0056$, $MSE = 53$, $\eta_p^2 = 0.4097$, indicating a smaller congruency effect following incongruent trials (24 ms), $F(1, 15) = 67.16$, $p < .001$, $MSE = 67$, $\eta_p^2 = 0.8174$, than following congruent trials (35 ms), $F(1, 15) = 49.28$, $p < .001$, $MSE = 204$, $\eta_p^2 = 0.7666$. However, for the arbitrary S-R mappings, no CSE was obtained, $F(1, 15) = 0.56$, $p = .4652$, $MSE = 140$, $\eta_p^2 = 0.0361$ (see Fig. 2).

2.2.2. PE

The overall PE was 3.68%. The main effect of current-trial congruency was significant, $F(1, 30) = 13.14$, $p = .0011$, $MSE = 4.32$, $\eta_p^2 = 0.3045$, indicating a typical congruency effect (1.33%). The main effect of S-R mapping and previous-trial congruency, and any interactions between factors, were not significant.

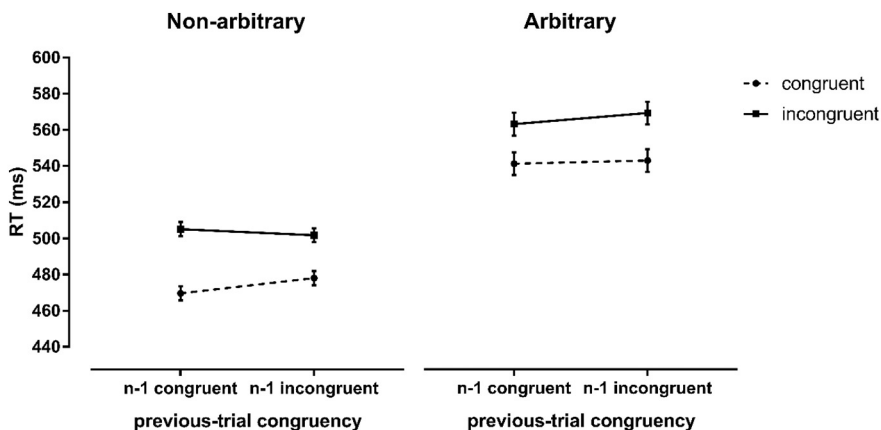


Fig. 2. Mean RTs as a function of previous-trial congruency and current-trial congruency (dashed vs. solid lines) for the non-arbitrary S-R mappings (left) and for the arbitrary S-R mappings (right) in Experiment 1. The results demonstrate that the cross-task CSE was significant only when S-R mappings were non-arbitrary but not when they were arbitrary. Error bars indicate the 95% confidence interval around the mean (Loftus & Masson, 1994).

2.3. Discussion

Even though participants responded to one task with one hand, and the other task with the other hand, as Weissman, Colter, et al. (2015) suggested, a significant CSE was obtained between the two task congruencies when S-R mappings of the two tasks had an overlearned sequential relationship in common. The flanker-compatibility effect was significantly smaller after incongruent trials (24 ms) than after congruent trials (35 ms). However, consistent with Kim and Cho's (2014) view, sequential modulation between the two task congruencies was not obtained when there was no sequential relationship among S-R mappings of the two tasks. Similar magnitudes of the flanker-compatibility effect were obtained after congruent (22 ms) and incongruent trials (26 ms). These results provide evidence that two tasks are required to share either a common response mode or mapping rule that links their S-R mappings, in order to recruit the same control mechanism. The results suggest that the arbitrariness of S-R mappings modulates the role of response mode in determining the scope of control.

However, note that the arbitrariness of S-R mappings was confounded with that of stimulus sets in the current experiment. When the non-arbitrary S-R mappings were used, the stimulus alternatives used in the two tasks were related to each other, conforming to their alphabetical order. In contrast, there was no sequential relationship among stimulus sets themselves when the S-R mappings were arbitrary. Therefore, it is necessary to verify that the cross-task CSE obtained in Experiment 1 was exclusively due to the non-arbitrary S-R mappings, rather than to the non-arbitrary stimulus sets themselves.

3. Experiment 2

The aim of Experiment 2 was to dissociate the influence of non-arbitrary stimulus sets on the cross-task CSE from that of non-arbitrary S-R mappings and examine whether the cross-task CSE varies depending on the arbitrariness of the stimulus set and/or response mode. While keeping S-R mappings arbitrary throughout the experiment, two key factors were manipulated in a factorial manner: (a) arbitrariness of stimulus sets and (b) distinctiveness of response modes. If the arbitrariness of stimulus sets determines the scope of control, the cross-task CSE would be found only with non-arbitrary stimulus sets, regardless of response mode. In contrast, if response mode plays a critical role in determining the boundary of control, the cross-task CSE would emerge across tasks sharing a common response mode, irrespective of the arbitrariness of stimulus sets.

To keep S-R mappings arbitrary, even in tasks involving non-arbitrary stimulus sets, the spatial arrangement (from left to right) of response alternatives assigned to letter stimuli did not correspond to their alphabetical order. For example, the target 'A' was allocated to the second, 'B' to the fourth, 'C' to the first, and 'D' to the third response

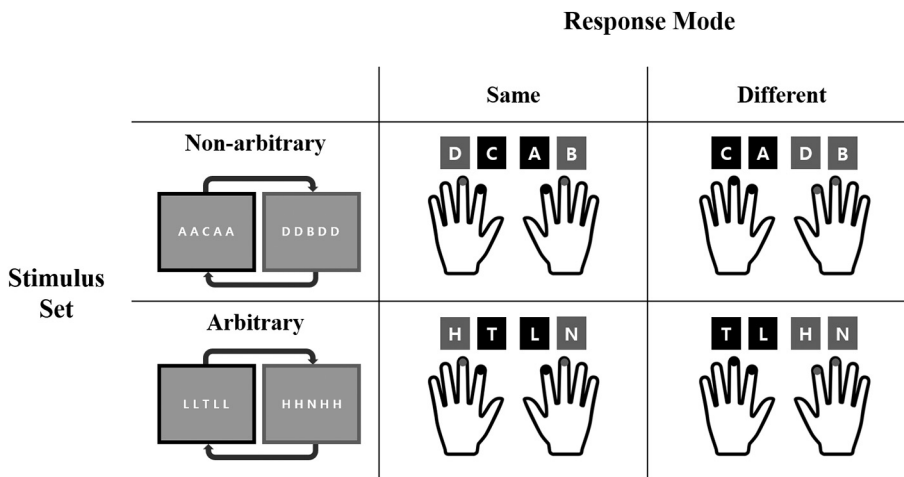


Fig. 3. Example of stimulus sets and response sets in Experiment 2. The non-arbitrary stimulus sets (upper) and the arbitrary stimulus sets (lower) were allocated to either the same (left) or different (right) response modes. The shade denotes each task, so for the non-arbitrary stimulus sets, letter ‘C’ and ‘A’ were presented in one task and letter ‘D’ and ‘B’ in the other task. For the arbitrary stimulus sets, letter ‘T’ and ‘L’ belonged to one task and letter ‘H’ and ‘N’ belonged to the other task.

alternatives, respectively (see Fig. 3). In this way, even though stimulus sets consisted of non-arbitrary sets of letters, S-R mappings remained arbitrary, just as in tasks involving arbitrary stimulus sets. Therefore, it was possible to verify whether the non-arbitrary stimulus sets themselves, rather than non-arbitrary S-R mappings, engendered the cross-task CSE.

The response sets were expected to be separately represented as two different response modes when one task was performed with the left hand and the other task with the right hand, as in Experiment 1. However, the distinction between the response sets was supposed to be obscure when one task was performed with the index fingers and the other task with the middle fingers of the left and right hands. Since the distinction in terms of fingers is less salient than in terms of hands, the response sets of the two tasks were assumed to be represented as the same response mode (Kim & Cho, 2014; Proctor & Vu, 2010; Reeve & Proctor, 1984).

3.1. Method

3.1.1. Participants

A total of 64 new undergraduate students (33 male, mean age = 23.09) from the same pool as Experiment 1 participated with informed consent. They were randomly assigned to one of four experiment groups, which differed in terms of stimulus set (arbitrary vs. non-arbitrary) and response mode (different vs. same). One group of 16 participants performed tasks with arbitrary stimulus sets and different response modes, the next with arbitrary stimulus sets and the same response mode, the next with non-arbitrary stimulus sets and different response modes, and the final group of 16 participants with non-arbitrary stimulus sets and the same response mode. All participants had normal or corrected-to-normal visual acuity and were right-handed by self-report. They received KRW 6000 (about five US dollars) for their participation following the experiment.

3.1.2. Stimulus and apparatus

The stimuli and apparatuses were identical to those of Experiment 1 with the following exceptions. Since it is possible that switching the axis of stimulus alignments (horizontal and vertical) may have partially contributed to the disappearance of the cross-task CSE (Lee & Cho, 2013; Mayr et al., 2003; Rubichi, Vu, Nicoletti, & Proctor, 2006; Wiegand & Wascher, 2007) in Experiment 1, flanker stimuli were always presented to the left and right sides of the target stimulus.

Different response modes were separated by the left and right hands, whereas the same response mode was distinguished by the index and middle fingers of both hands. As non-arbitrary stimulus sets, the letters A, B, C, and D were used, while letters T, L, H, and N were used for arbitrary stimulus sets. However, to keep the S-R mappings

arbitrary, stimulus alternatives of non-arbitrary stimulus sets were assigned to response alternatives in an order that was not compatible with their alphabetical order. The letters C and A, presented in odd trials, were mapped to one response set, and the letters D and B, presented in even trials, were mapped to the other response set. For different response modes, the participants were instructed to press the ‘d’ key to the target ‘C’ and the ‘f’ key to ‘A,’ using the middle and index fingers of their left hands, respectively, and the ‘j’ key to the target ‘D’ and the ‘k’ key to the ‘B’ with the index and middle fingers of their right hands, respectively. In contrast, for the same response mode, the target ‘C’ was responded by pressing the ‘f’ key and the target ‘A’ by pressing the ‘j’ key with the index fingers of the left and right hands, respectively, and the target ‘D’ by pressing the ‘d’ key and the target ‘B’ by pressing the ‘k’ key with the middle fingers of the left and right hands, respectively. In this way, S-R mappings defined by the task rule were never in line with the overlearned sequential relationships. That is, regardless of response mode, S-R mappings associated with the non-arbitrary stimulus sets became totally arbitrary, like those associated with the arbitrary stimulus sets, even though stimulus sets still consisted of non-arbitrary strings of letter stimuli. For the arbitrary stimulus sets, the targets ‘T,’ ‘L,’ ‘H,’ and ‘N’ were responded in the same way as for the targets ‘C,’ ‘A,’ ‘D,’ and ‘B,’ respectively (see Fig. 3).

3.1.3. Procedures

The procedures were identical to those of Experiment 1 with the following exceptions. Participants performed two flanker-compatibility tasks alternating on a trial-by-trial basis. Letters C, A, D and B were presented as non-arbitrary stimulus sets, and letters T, L, H and N were presented as arbitrary stimulus sets. For different response modes, one flanker-compatibility task response was performed with the left hand, while the other flanker-compatibility task was performed with the right hand. For the same response mode, participants were instructed to perform one flanker-compatibility task with the index fingers, and the other flanker-compatibility task with the middle fingers of both hands.

3.2. Results

The first and second trials of each block were removed from analyses. RT outliers were defined as in Experiment 1; they and the trials following the RT outliers or incorrect responses were excluded from the analyses (approximately 9.5% of the total trials). Mean correct RTs and PEs were calculated for each participant as a function of previous-trial congruency (n-1 congruent vs. n-1 incongruent) and current-trial congruency (congruent vs. incongruent). Four-way mixed-measures ANOVAs were conducted on the mean correct RTs and PEs with the above factors as within-subject variables, and stimulus set (arbitrary vs.

Table 2

Mean and standard deviation of reaction time (in milliseconds) and percentage error in Experiment 2, as a function of stimulus set, response mode, previous-trial congruency, and current-trial congruency.

Stimulus set, response mode	Previous congruency	Current congruency	RT		PE	
			Mean	SD	Mean	SD
Non-arbitrary, Same mode	Congruent	Congruent (cC)	489	50.33	2.98	2.73
		Incongruent (cI)	533	62.57	4.91	3.16
	Incongruent	Congruent (iC)	501	56.70	3.49	2.40
		Incongruent (iI)	527	59.86	4.43	3.30
Non-arbitrary, Different mode	Congruent	Congruent (cC)	581	101.13	4.26	3.64
		Incongruent (cI)	598	80.18	4.63	3.85
	Incongruent	Congruent (iC)	574	85.40	3.17	2.47
		Incongruent (iI)	595	91.24	5.19	4.64
Arbitrary, same mode	Congruent	Congruent (cC)	580	60.82	5.60	3.26
		Incongruent (cI)	633	69.08	7.29	4.11
	Incongruent	Congruent (iC)	593	61.40	4.14	2.37
		Incongruent (iI)	628	70.55	6.31	4.19
Arbitrary, different mode	Congruent	Congruent (cC)	560	102.86	2.78	2.28
		Incongruent (cI)	599	96.75	5.83	4.32
	Incongruent	Congruent (iC)	566	102.37	2.81	1.59
		Incongruent (iI)	599	96.50	4.58	3.37

non-arbitrary) and response mode (different vs. same) as between-subjects variables (Table 2).

3.2.1. RT

The main effect of stimulus set was significant, $F(1, 60) = 5.19$, $p = .0263$, $MSE = 24,769$, $\eta_p^2 = 0.0796$, as the mean RT was greater for arbitrary stimulus sets ($M = 595$ ms) than non-arbitrary stimulus sets ($M = 550$ ms). The interaction between stimulus set and response mode was significant, $F(1, 60) = 6.74$, $p = .0119$, $MSE = 24,769$, $\eta_p^2 = 0.1009$. When the same response mode was used, the responses for non-arbitrary stimulus sets were 96 ms faster than arbitrary stimulus sets, $F(1, 30) = 20.51$, $p < .001$, $MSE = 14,338$, $\eta_p^2 = 0.406$, but when different response modes were used, the effect of stimulus set did not reach significance, $F(1, 30) = 0.04$, $p = .8516$, $MSE = 35,201$, $\eta_p^2 = 0.0012$.

The main effect of current-trial congruency was evident, $F(1, 60) = 162.3$, $p < .001$, $MSE = 442$, $\eta_p^2 = 0.7301$, as the mean RT was shorter on congruent trials ($M = 555$ ms) than on incongruent trials ($M = 589$ ms). This congruency effect was modulated by stimulus set, $F(1, 60) = 6.32$, $p = .0146$, $MSE = 442$, $\eta_p^2 = 0.0953$, since a smaller congruency effect was found for non-arbitrary stimulus sets (27 ms), $F(1, 30) = 75.24$, $p < .001$, $MSE = 307$, $\eta_p^2 = 0.7149$, than arbitrary stimulus sets (40 ms), $F(1, 30) = 89.14$, $p < .001$, $MSE = 577$, $\eta_p^2 = 0.7482$. In addition, current-trial congruency interacted with response mode, $F(1, 60) = 5.43$, $p = .0231$, $MSE = 442$, $\eta_p^2 = 0.083$. The congruency effect was found to be smaller for different response modes (27 ms), $F(1, 30) = 64.45$, $p < .001$, $MSE = 372$, $\eta_p^2 = 0.6824$, than for the same response mode (40 ms), $F(1, 30) = 97.94$, $p < .001$, $MSE = 513$, $\eta_p^2 = 0.7655$.

Also, current-trial congruency interacted with previous-trial congruency, $F(1, 60) = 8.68$, $p = .0046$, $MSE = 165$, $\eta_p^2 = 0.1264$, indicating an overall CSE. The congruency effect was smaller following incongruent trials (29 ms), $F(1, 60) = 78.16$, $p < .001$, $MSE = 339$, $\eta_p^2 = 0.5657$, than following congruent trials (38 ms), $F(1, 60) = 174.33$, $p < .001$, $MSE = 268$, $\eta_p^2 = 0.7439$. More importantly, it further interacted with response mode, $F(1, 60) = 6.51$, $p = .0133$, $MSE = 165$, $\eta_p^2 = 0.0979$.

To investigate this interaction, separate analyses for each response mode were conducted as a function of current-trial congruency, previous trial congruency and stimulus set. For the same response mode, a significant CSE was observed, $F(1, 30) = 18.17$, $p < .001$, $MSE = 137$, $\eta_p^2 = 0.3773$, indicating a 17-ms smaller congruency effect following incongruent trials (31 ms), $F(1, 30) = 36.73$, $p < .001$, $MSE = 413$, $\eta_p^2 = 0.5504$, than following congruent trials (48 ms), $F(1,$

$30) = 158.75$, $p < .001$, $MSE = 237$, $\eta_p^2 = 0.8411$. However, the CSE was not evident when different response modes were used, $F(1, 30) = 0.07$, $p = .7981$, $MSE = 192$, $\eta_p^2 = 0.0022$. Unlike response mode, stimulus set did not modulate the CSE, $F(1, 60) = 0.73$, $p = .3962$, $MSE = 165$, $\eta_p^2 = 0.012$. The main effects of response mode and previous trial congruency, as well as other interactions, such as the four-way interactions of current-trial congruency, previous-trial congruency, stimulus set, and response mode were not significant (see Fig. 4).

3.2.2. PE

The overall PE was 4.66%. The main effect of current-trial congruency was significant, $F(1, 60) = 37.68$, $p < .001$, $MSE = 5.25$, $\eta_p^2 = 0.3857$, indicating a 1.76% congruency effect. The main effect of previous-trial congruency was also significant, $F(1, 60) = 6.93$, $p = .0108$, $MSE = 2.54$, $\eta_p^2 = 0.1035$, as PE was higher after congruent trials (4.92%) than incongruent trials (4.4%). It further interacted with stimulus set, $F(1, 60) = 4.34$, $p = .0416$, $MSE = 2.54$, $\eta_p^2 = 0.0674$. The effect of previous trial congruency was significant with the arbitrary stimulus sets (0.94%), $F(1, 30) = 10.04$, $p = .0035$, $MSE = 2.81$, $\eta_p^2 = 0.2507$, but not with the non-arbitrary stimulus sets (0.11%), $F(1, 30) = 0.17$, $p = .6836$, $MSE = 2.27$, $\eta_p^2 = 0.0056$.

The overall CSE was not obtained in the error data, $F(1, 60) = 0.04$, $p = .8332$, $MSE = 3.3$, $\eta_p^2 = 0.0007$, but the four-way interaction of current-trial congruency, previous-trial congruency, stimulus set, and response mode was significant, $F(1, 60) = 4.94$, $p = .03$, $MSE = 3.3$, $\eta_p^2 = 0.0761$. For the same response mode, the pattern of the CSE was found only with the non-arbitrary stimulus sets (1.15%), even though it was not statistically significant, $F(1, 15) = 1.26$, $p = .2791$, $MSE = 4.21$, $\eta_p^2 = 0.0776$. In contrast, for different response modes, only the arbitrary stimulus sets engendered the pattern of the CSE (1.06%), despite the lack of statistical significance, $F(1, 15) = 2.47$, $p = .1371$, $MSE = 1.82$, $\eta_p^2 = 0.1412$. Other interactions were not significant.

3.3. Discussion

In Experiment 2, the arbitrariness of stimulus sets and response mode were manipulated, whereas S-R mappings were kept arbitrary. The overall congruency effect and CSE were both significant in the RT data. However, the CSE was not modulated by the arbitrariness of stimulus sets, which is inconsistent with the results of Experiment 1. Hence, we attribute the CSE found between the tasks performed with different response modes in Experiment 1 to the non-arbitrary S-R

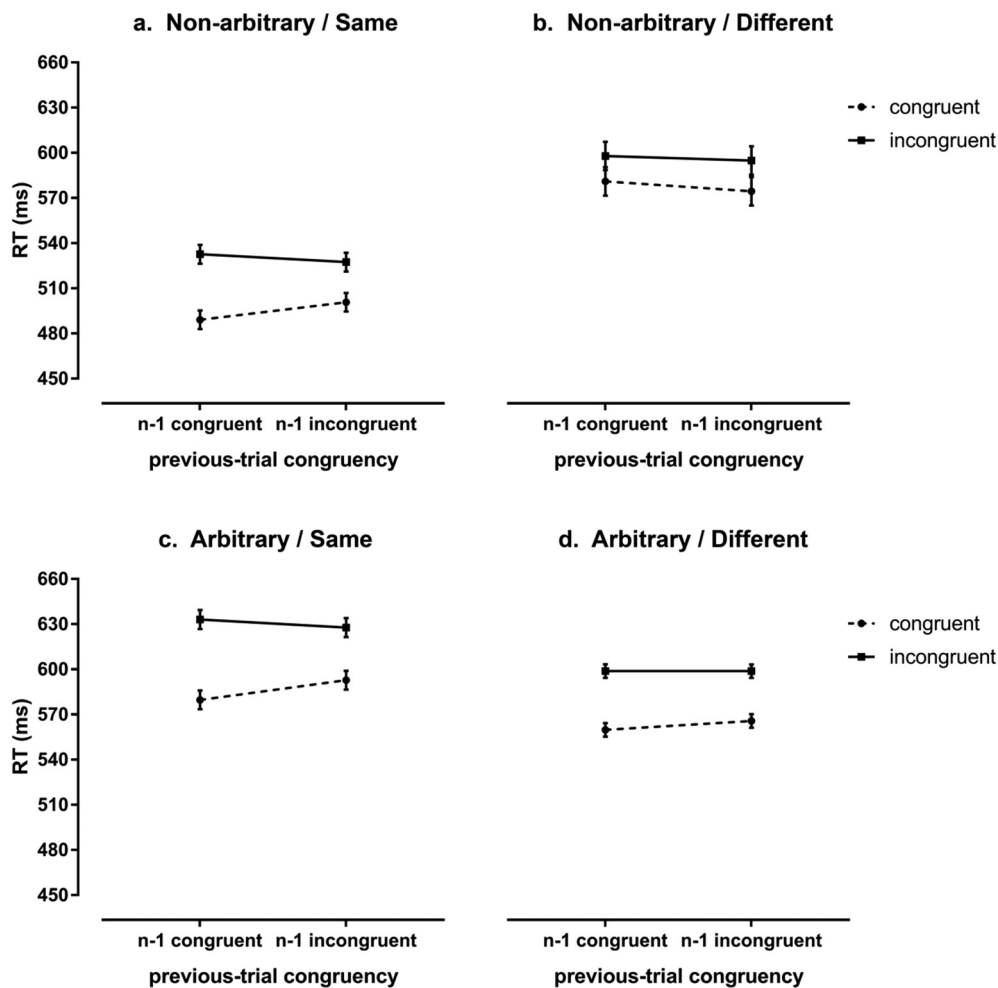


Fig. 4. Mean RTs as a function of previous-trial congruency and current-trial congruency (dashed vs. solid lines) in Experiment 2. Each panel demonstrates one of the four combinations of stimulus set (non-arbitrary vs. arbitrary), arranged in rows, and response mode (same vs. different), arranged in columns. The significant cross-task CSE was obtained only with the same response mode (a, c), but not with the different response modes (b, d). Error bars indicate the 95% confidence interval around the mean (Loftus & Masson, 1994).

mappings, rather than the non-arbitrary stimulus sets themselves. Meanwhile, the cross-task CSE was modulated depending on whether the two tasks were performed with the same or different response modes. The control mechanism recruited by conflict of one task decreased the congruency effect of the other task only when they shared the same response mode. However, for different response modes, the cross-task CSE was not found even when the two tasks were more similar than in Experiment 1 as their stimulus alignments were always horizontal. Therefore, the extent to which the same control mechanism was exerted varied depending on response mode, rather than on the arbitrariness of stimulus sets. That is, as far as S-R mappings were arbitrary, the control mechanism operated in a response mode-specific way, which was in line with Kim and Cho (2014)'s idea. Although the effect of current-trial congruency was smaller for different response modes than the same response mode, the congruency effect was still statistically significant and robust. Furthermore, it has been proposed that the magnitude of the CSE is not correlated to the amount of conflict (Weissman, Jiang, & Egner, 2014). Thus, the absence of the CSE in tasks involving different response modes likely was not entirely due to the reduced conflict.

While the arbitrariness of stimulus sets had no influence on the scope of control, it affected general task performance, as the non-arbitrary stimulus sets led to faster responses and a smaller congruency effect than the arbitrary stimulus sets did. However, the effect of stimulus sets was modulated by response mode, as the difference in the

congruency effect between the arbitrary and non-arbitrary stimulus sets disappeared when different response modes were used. Because letter stimuli from the non-arbitrary stimulus sets involved the alphabetical order, it might still have been of help to maintain task rules more effortlessly based on their overlearned sequential relationships, especially when the same response mode was used (Hazeltine, 2005). Hence, it is possible that the overall RT and the amount of conflict decreased, as the task difficulty was lower. However, when different response modes were used, it became much more difficult to remember the task rules based on the sequential order among non-arbitrary stimuli, because the spatial arrangements of their corresponding response alternatives were totally mixed. Therefore, the effect of stimulus set was much weaker when different response modes were used than when the same response mode was used.

4. General discussion

The present study examined whether the arbitrariness of S-R mappings influences the role of response mode in determining the boundary of cognitive control underlying the CSE. In Experiment 1, a significant CSE was found between two letter flanker-compatibility tasks performed by different response modes only when the stimulus sets and S-R mappings of the two tasks were non-arbitrary. In Experiment 2, to dissociate the effect of the arbitrariness of stimulus sets from that of the arbitrariness of S-R mappings, the S-R mappings were kept arbitrary,

while the arbitrariness of stimulus sets and response mode were systematically manipulated. The cross-task CSE was evident only when the two tasks were performed with the same response mode, but did not vary depending on the arbitrariness of stimulus sets. This outcome suggests that the response mode-independent CSE obtained in Experiment 1 was due to the non-arbitrary S-R mappings, rather than the non-arbitrary stimulus sets themselves. Furthermore, response mode was found to be the salient task feature determining the scope of control, at least, when S-R mappings were arbitrary.

4.1. The role of response mode and S-R mappings in the scope of control

The results of Experiment 2 show that the cross-task CSE depended on response mode. However, at the same time, the findings of the cross-task CSE with non-arbitrary S-R mappings even with different response modes in Experiment 1 provide further information about the role of response mode. One possibility is that the scope of control is determined by task representation (Braem et al., 2014; Hazeltine, Lightman, Schwarb, & Schumacher, 2011), which is largely dependent on response mode and S-R mapping (Akçay & Hazeltine, 2008). Because each stimulus and response alternative in a task has multiple physical features, only those of which are relevant or salient features comprise the task representation (Adam et al., 2003; Dreisbach, 2012; Hazeltine, 2005; Hommel, 1993, 1998; Reeve & Proctor, 1984; Schumacher & Hazeltine, 2016). Thus, various task representations can be developed depending on the current task situation. Considering that response mode and S-R mapping influence how stimulus and response features are coded, it is highly possible that the task representation is to depend on them. Previous findings suggested that tasks performed with different response modes are indeed represented as different tasks (Akçay & Hazeltine, 2008; Proctor & Vu, 2010; Hazeltine et al., 2011; Kim & Cho, 2014; Schumacher & Hazeltine, 2016). For example, Akçay and Hazeltine (2008) found that two tasks sharing a common response set are represented as a single task, resulting in a recruitment of the same control mechanism. Moreover, Kim and Cho (2014) observed a cross-task CSE even when the response sets of two tasks were not identical but grouped into the same response mode. These results indicate that response mode reflects how flexibly responses are coded, and finally has bearing on the formation of a task representation.

In the present study, considering the hierarchical organization of response features (Rosenbaum, 1980), response sets distinguished in terms of hands were likely to be represented as two different response modes, leading to a reconfiguration as two separate task representations. Meanwhile, when two response sets were distinguished in terms of fingers, they are supposed to be grouped into a common response mode and form a single task representation. This is in line with the findings of Kim and Cho (2014), which showed that sequential modulation occurred between two tasks for which the responses were made with the same response mode but not with different response modes.

Note that response mode is a representational group of related motor responses, which is closely linked but not identical to the anatomical distinction of effector systems. Thus, responses made by the same effector can be mentally coded differently depending on task situations (Ansorge & Wühr, 2004; Gaschler, Frensch, Cohen, & Wenke, 2012; Hazeltine, 2005; Miller, 1982; Proctor & Reeve, 1985, 1986; Wenke & Frensch, 2005). According to Adam et al.'s (2003) *grouping account*, a set of response alternatives sharing certain properties are grouped, rather than being individually coded. Basically, grouping of responses is established by physical properties, but it is malleable to be reconfigured in a way more compatible with the relevant task features. Adam et al. found that the representation of four spatially arranged responses were grouped into left and right subgroups in one context, and inner and outer subgroups in another context, depending on grouping factors. From these perspectives, it can be explained why some studies found a cross-task CSE performed by different effectors. For example, Weissman et al. (2014) found that a significant CSE

between horizontal and vertical Simon tasks performed with left and right hands, respectively. However, because the response keys for the horizontal and vertical Simon tasks were closely adjacent to each other, the placement of the two hands had to be overlapped to a substantial degree. In this way, each response alternatives involved multiple frames of reference for spatial coding and thus it is unlikely that the distinction between the left and right hands were salient enough to separately form two different response modes.

As another critical factor influencing how task representations are formed, S-R mappings are either individually maintained or categorized into a group of mappings that share a common feature (Dreisbach et al., 2007). Dreisbach et al. found that two separate task representations were formed when eight different S-R mappings were grouped into two sets of mappings by informing about the underlying task rule that discriminated those two mapping sets. A switch cost, which is a delay in RT after switching tasks, occurred when an S-R association from a different mapping set was followed, compared to when one from the same mapping set was followed. This result indicates that two separate task representations were developed according to the distinction between the two sets of S-R mappings, since the switch cost reflects additional time to reconfigure and readjust to a new task (Goschke, 2000; Monsell, 2003; Rogers & Monsell, 1995). However, when S-R mappings were merely represented as eight individual mappings, no switch cost was found, which indicates that all S-R mappings belonged to the same single task representation. Dreisbach et al.'s (2007) results suggest that if there are certain rules relating individual S-R mappings to each other, the task representations are reorganized based on those mapping rules (Dreisbach, 2012; Gaschler et al., 2012). Similarly, the manipulation of the sequential order underlying S-R mappings influenced the conceptualization of action coding, which is a fundamental component comprising task representations (Hazeltine, 2005; Kirsch & Hoffmann, 2011). Taken together, it seems that the consistent mapping rules organize individual S-R mappings into a meaningful structure and therefore reconstruct task representations (Akçay & Hazeltine, 2008).

In the present study, the representations of the two tasks were reconfigured based on the sequential relationship underlying S-R mappings of the two tasks. The four different S-R mappings having a sequential relationship seemed to develop a common task representation, even when their response sets were clearly distinguished as different response modes, because the sequential relationship worked as a common feature that reorganized individual S-R mappings into an integrated structure. In contrast, when the S-R mappings of two tasks do not have any features in common, response mode is possibly the most salient task feature that modulates task representation.

The response mode and the arbitrariness of S-R mappings are certainly not the sole factors determining the specificity of control. For example, Weissman et al. (2014, Experiment 3) found a significant CSE between two flanker-compatibility tasks which were discriminated by different response modes, but only when flanker stimuli temporally preceded the target stimulus. However, they did not observe the cross-task CSE when the target and flanker stimuli were presented simultaneously, which is consistent with the current findings. One possible explanation is that the two tasks are more likely to recruit the same control mechanism when the distracting stimulus activates the response ahead of the target stimulus, even though they do not share the same response mode or S-R mapping rules. It is possible that the temporal difference between the onsets of the target and distracting information is another important factor that modulates the scope of control. It can explain why the CSE is more robustly found when the distracting stimulus appears in advance of the target stimulus (Weissman, Egner, Hawks, & Link, 2015). However, at least when the target and distracting stimuli are presented at the same time, as in the traditional flanker-compatibility task, the Stroop task, or the Simon task, it seems necessary for two tasks to share a common response mode or S-R mapping rule to engender the cross-task CSE.

4.2. Does task representation determine the scope of control?

Akçay and Hazeltine (2008) proposed that the scope of control is flexibly determined by task representation. According to them, sequential modulation across two tasks is evident only when they are represented as a single task by sharing the task features, such as common stimulus or response sets. Furthermore, as there are multiple task features that could be used as references for setting the task representation boundary, the conceptualization of a task varies depending on the most salient task feature at hand. For example, when stimuli were either visually or aurally presented in every other trial, Hazeltine et al. (2011) found that the CSE was evident only when the stimulus modality repeated but not when it switched. However, when two tasks having different task-relevant stimulus dimensions alternated in every other trial, sequential modulation was observed even when the stimulus modality switched between two consecutive trials. This result indicates that stimulus modality constrained the scope of control only when it discriminated the tasks but not when the tasks were distinguished irrespective of stimulus modality. That is, the cognitive control mechanism is exerted not specifically to the hard-wired distinction but to the task representations for which boundaries are flexibly determined by the most salient or relevant task feature in a certain task situation (see also Dreisbach & Haider, 2008, 2009; Freedberg et al., 2014). Schmidt and Weissman (2015) also found that the CSE was evident only when distractors had a perceptual feature in common with target stimuli, which suggests that those distracting stimuli sharing target features were specifically included in the task representation and were consequently subjected to sequential modulation.

Dreisbach (2012) proposed that task representation is reconfigured in a way to reduce information that is not directly relevant to performing the current task. Schumacher and Hazeltine (2016) also introduced a new concept referred to as *task file*, which not only organizes and binds relevant stimuli and responses into meaningful groups but also encompasses higher-level task features, such as task goals, plans, or contexts. The components in task file are combined into multiple task representations and which task representation is most activated may vary depending on the current task situation in order to maximize performance efficiency. The ideal level of the task set boundary contains the association between stimulus and response features that are highly relevant to task performance and other advantageous contextual features, such as grouping factors dividing stimulus and/or response features into smaller subgroups or cue information predicting the correct responses (Dreisbach et al., 2007; Gaschler et al., 2012; Miller, 1982). In this regard, it is highly possible that the cognitive control system flexibly tunes the level of representation where control should be adjusted, depending on how the task representation is defined.

These integrative approaches offer a more convincing explanation for inconsistent results found in previous literature and provide insight on what determines the scope of control. It is possible that the absence of the cross-task CSE in the previous literature was attributable to salient task features that clearly distinguished task representations. For example, when two tasks were distinguished in terms of task-relevant stimulus dimensions (Notebaert & Verguts, 2008; Wühr, Duthoo, & Notebaert, 2015) or conflict types (Egner, 2008; Egner et al., 2007; Funes, Lupiáñez, & Humphreys, 2010), they could barely be reconfigured into a single task representation, resulting in no cross-task CSE.

4.3. Conclusion

The present study demonstrated that the same control mechanism operates across two tasks that possess either non-arbitrary S-R mappings or the same response mode. It suggests that non-arbitrary relationships among S-R mappings and response modes play important roles in determining the scope of control, as they reconfigure task

representation. However, the current findings do not necessarily imply that task representation is the sole determinant for the scope of control. Some studies demonstrated a cross-task CSE, even when two tasks were highly distinguishable (Braem et al., 2014; Lee & Cho, 2013; Weissman et al., 2014). Since task representation and the scope of control are supposed to vary flexibly depending on the most salient or relevant task features of the moment, the current findings imply that our cognitive system flexibly modifies processing strategies to maximize efficiency in a goal-directed behavior.

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