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 reconfigured following the S-R mapping rule (Dreisbach, Goschke, & Haider, 2007; Hazeltine, 2005; Proctor & Reeve, 1985). When over-learned 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.