Acta Psychologica 162 (2015) 51–61

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Control processes through the suppression of the automatic response activation triggered by task-irrelevant information in the Simon-type tasks☆

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ARTICLE INFO

Article history:
Received 4 May 2014
Received in revised form 12 July 2015
Accepted 6 October 2015
Available online 31 October 2015

Keywords:
Congruency sequence effect
Cognitive control
Simon effect
Spatial Stroop effect

ABSTRACT

The congruency sequence effect, one of the indices of cognitive control, refers to a smaller congruency effect after an incongruent than congruent trial. Although the effect has been found across a variety of conflict tasks, there is not yet agreement on the underlying mechanism. The present study investigated the mechanism underlying cognitive control by using a cross-task paradigm. In Experiments 1, 2, and 3, participants performed a modified Simon task and a spatial Stroop task alternately in a trial-by-trial manner. The task-irrelevant dimension of the two tasks was perceptually and conceptually identical in Experiment 1, whereas it was perceptually different but conceptually identical in Experiment 2. The response sets for both tasks were different in Experiment 3. In Experiment 4, participants performed two Simon tasks with different task-relevant dimensions. In all experiments in which the task-irrelevant dimension and response mode were shared, significant congruency sequence effects were found between the two different congruencies, indicating that Simon-type conflicts were resolved by a control mechanism, which is specific to an abstract task-irrelevant stimulus spatial dimension.

1. Introduction

To successfully perform a given task, performers should select task-relevant information and ignore task-irrelevant information. However, it is impossible to avoid task performance degradation caused by task-irrelevant information. One approach to exploring this degradation is to use congruency tasks such as the Simon, Stroop, and flanker-compatibility tasks. In these tasks, a target display contains both task-relevant and conflicting task-irrelevant information, and task performance is worse when the two types of information activate different versus the same responses (e.g., Kornblum, Hasbroucq, & Osman, 1990; MacLeod, 1991).

Moreover, it has been found that the congruency effect of the current trial varies as a function of congruency in the previous trial (e.g., Gratton, Coles, & Donchin, 1992). For example, Gratton et al. found that the flanker-compatibility effect was smaller when the target was flanked by incongruent distractors in the previous trial than when it was flanked by congruent distractors. This *congruency sequence effect* (also known as the Gratton effect or conflict-adaptation effect) has been consistently observed in various experimental paradigms, including the Simon task and color and spatial Stroop tasks.

One of the most compelling theories for the congruency sequence effect is *conflict monitoring*, as suggested by Botvinick and colleagues (Botvinick, Braver, Barch, Carter, & Cohen, 2001). According to this theory, control mechanisms are recruited by a conflict monitoring module embedded in the dorsal anterior cingulate cortex (dACC), responding to the occurrence of response conflict, when the conflict monitoring module detects conflict between different responses, each of which is activated by task-relevant information and task-irrelevant information, respectively. It has been suggested that dorsal lateral prefrontal cortex (dLPFC) involves the regulation of the conflict by allocating differently weighted attention (Botvinick et al., 2001), resulting in enhanced processing of task-relevant information (Blais & Verguts, 2012; Egner & Hirsch, 2005; Funes, Lupiáñez, & Humphreys, 2010; Verguts & Notebaert, 2008; Verguts & Notebaert, 2009) and/or suppressed processing of task-irrelevant information (Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). Many lines of evidence for this type of the account have been reported (Durston et al., 2003; Egner & Hirsch, 2005; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000).

Egner and Hirsch (2005) conducted an fMRI study showing that conflict is regulated through cortical amplification of task-relevant information processing. They employed a facial Stroop task in which participants were asked to indicate whether the target stimulus was a politician or an actor. There was a significantly greater BOLD activity

☆ This research was supported by Korea Research Foundation Grant (NRF-2013R1A1A2058883).

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http://dx.doi.org/10.1016/j.actpsy.2015.10.001
0001-6918/

in the fusiform face area (FFA), which is specialized for face recognition processes (Kanwisher, McDermott, & Chun, 1997), on trials that followed an incongruent trial, but only when the face served as a target. When the face served as a distractor, there was no effect on BOLD activities in FFA. In contrast, Stürmer et al. (2002) found psychophysiological evidence suggesting that conflicts are regulated by suppression of task-irrelevant information in automatic route. They measured the lateralized readiness potential (LRP) when participants were performing a Simon task, and found that the initial incorrect activation on an incongruent trial was modulated by previous-trial congruency. Specifically, the initial incorrect activation on incongruent trial was evident when the previous trial was congruent, while it was reduced when the previous trial was incongruent. From these results, they concluded that automatic activation of task-irrelevant information induces an interference effect in the Simon task, and that this interference is reduced by suppressing the automatic route when conflict is detected in the previous trial.

However, Hommel, Proctor, and Vu (2004) noted that the congruency effect as a function of previous-trial congruency is completely confounded with the effect of feature integration in the conflict task in which both stimulus and response dimensions have only two alternatives. When a stimulus and a response occur in time, the features of the stimulus and response are integrated into a transient representation called *event file*. Because reactivating one feature of the event file activates the other features, performance on the subsequent trials is modulated by it. That is, responses are faster and more accurate when the features of the stimulus and response are either completely repeated or completely alternated in a trial sequence than when they are partial repeated. According to Hommel et al., because all congruent trials just after a congruent trial and all incongruent trials just after an incongruent trial are completely repeated or alternated but all congruent trials after an incongruent trial and all incongruent trials after a congruent trial are partial repeated, the congruency sequence effect occurs. In a similar vein, Mayr, Awh, and Laurey (2003) attributed the congruency sequence effect to the probability of stimulus repetition.

To avoid confounding feature integration or repetition priming and the correspondence between two successive trials, researchers have employed conflict tasks with a larger number of stimulus and response alternatives so that each trial type transition includes an equal proportion of the partial repetition and complete repetition trials (Akçay & Hazeltine, 2007). Other researchers removed exact repetition trials from their analyses (Kerns et al., 2004; Mayr et al., 2003; Ullsperger, Bylsma, & Botvinick, 2005). Although repetition priming clearly contributes to a sequential modulation of the congruency effect (Altmann, 2011), the findings that the congruency sequence effect has been obtained when feature integration or the repetition priming was controlled (Notebaert, Gevers, Verbruggen, & Liefooghe, 2006; Ullsperger et al., 2005; Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006; Wühr & Ansorge, 2005) indicates that control mechanisms play a great role in the congruency sequence effect.

When the numbers of stimulus and response alternatives increase in order to avoid the confounding effect of the stimulus or response repetition, however, the congruency sequence effect is often confounded with the contingency of a distractor and the correct response (Mordkoff, 2012; Schmidt & De Houwer, 2011). That is, because the numbers of congruent and incongruent trials are equated, a congruent distractor is more frequently associated with the correct response than any other response, resulting in contingency learning. Thus, responses are faster and more accurate on the congruent trials than incongruent trials. Furthermore, Schmidt, Crump, Cheesman, and Besner (2007) showed that the contingency effect is greater after a high contingency trial than a low contingency trial. However, Kim and Cho (2014) and Schmidt and Weissman (2014) found the congruency sequence effect when the confounding effects of feature integration or repetition priming and the contingency between the distractor and correct response were both controlled.

1.1. Characteristics of control mechanism

Recently, many researchers have tried to reveal the scope of control and its exact underlying mechanism. Some have reported evidence for a domain-general control mechanism that regulates all types of conflict once it is recruited. For example, Freitas, Bahar, Yang, and Banai (2007) had participants perform horizontal and vertical arrow flanker tasks alternatively in a trial-by-trial manner in Experiment 1, a horizontal or vertical arrow flanker task and a color Stroop task in Experiment 2, and a horizontal or vertical arrow flanker task and a spatial Stroop task in Experiment 3. Significant sequential interactions between the congruency levels of different tasks were found in all experiments, indicating that all conflict was regulated by one domain-general control process.

In contrast, other studies have shown that conflict is modulated by task-specific control mechanisms (Egner, 2007; Egner, Delano, & Hirsch, 2007; Funes et al., 2010; Kiesel, Kunde, & Hoffmann, 2006; Lee & Cho, 2013; Notebaert & Verguts, 2008). For example, a specific control mechanism might be recruited depending on the conflict type involved in the task (Egner et al., 2007; Funes et al., 2010). Egner et al. (2007) suggested that different sources of conflict are regulated by different control mechanisms because they must be regulated in different ways. The conflict of the Simon task is response-based conflict because conflict is induced by the overlap between the irrelevant stimulus dimension and the response dimension, whereas the conflict of the Stroop task is stimulus-based conflict because the conflict is induced by the overlap between the task-relevant and task-irrelevant stimulus information, as well as response-based conflict. In their experiment, participants were to respond to the color of a color word presented to the left or right of fixation, causing Simon conflict between the stimulus and response locations, and Stroop conflict between stimulus color and the meaning of it. They only found sequential modulation of the interference effect only between the same types of conflict but not between different congruencies.

Akçay and Hazeltine (2008) suggested that the domain of control might be determined by how the task is represented. They found sequential modulation of the congruency effect between two different Simon trials in which a red or green target stimulus was presented on the left or right box of either the left or right hemifield on n − 1 trial and in the other hemifield on n trial, and participants were asked to respond to the stimulus color in either hemifield with the corresponding hand. That is, the same control mechanism was recruited for conflict in both hemifields because the task was represented as a single task, regardless of whether the target was presented in the right or left hemifield. However, when a red or green target was presented in the left or right side of one hemifield and a yellow or blue stimulus was presented in the left or right of the other hemifield, no congruency sequence effect was found between the hemifields. The authors suggested that different local control mechanisms were recruited to resolve conflict occurring in different hemifields because the task was divided into two different subtasks.

However, Akçay and Hazeltine (2008) did not clarify how task representations are structured. In other words, it is difficult to determine whether two tasks are represented as two different subtasks or a single task in a given situation in terms of their task structure concept. A task representation could be defined by sets of stimulus and response alternatives and the rule that binds them together (Rogers & Monsell, 1995). Monsell (2003) also suggested that a task-set is formed based on task instructions. The task-relevant stimulus dimension is important for constructing the mental representation of the task. If the task-relevant stimulus dimension is not shared between any two successive trials, the task representations may be separate.

Notebaert and Verguts (2008) also showed the importance of the task-relevant dimension in control. In their experiment, sequential modulation was obtained between Simon and SNARC (spatial numerical association of response code; Dehaene, Bossini, & Giraux, 1993)