A carry-over task rule in task switching: An ERP investigation using a Go/Nogo paradigm

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ABSTRACT

Investigations of executive control using a task-switching paradigm have consistently found longer reaction times for task-switch trials than task-repetition trials. This switch cost may result from interference by a stimulus-response (SR) rule carried over from the preceding alternative task. We examined event-related brain potential (ERP) evidence for such carry-over effects using a combined paradigm of task switching with Go/Nogo; Nogo trials, which require no response execution, should expose carry-over effects from preceding trials. On Go trials, twelve participants performed a button-pressing task in compatible (hand and signal direction consistent) and incompatible conditions, which switched predictably every three trials. Reaction times were longer on switch than on repetition trials. On compatible switch trials, a stimulus-locked lateralized readiness potential (sLRP) for Nogo stimuli revealed a positive dip, suggesting incorrect response activation in the early automatic process that was induced by a SR rule carried over from the preceding task.

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1. Introduction

The task-switching paradigm has been used to investigate executive control since the 1990s. In this paradigm, participants are required to switch between different stimulus-response (SR) task rules. A consistent finding is that reaction times (RTs) are longer for task-switch trials than for task-repetition trials, which indicates a *switch cost* (e.g., Kiesel et al., 2010; Monsell, 2003; Vandierendonck et al., 2010). The switch cost cannot be eliminated completely, even if participants are able to predict the upcoming task (*residual switch cost*; Rogers and Monsell, 1995). One of the prevailing assumptions is that the residual switch cost results from interference of a SR rule carried over from the preceding alternative task (e.g., Allport et al., 1994: Meiran, 2000; Meiran et al., 2000; Wylie and Allport, 2000). Another hypothesis is that an additional control process is involved in reconfiguring the task set (e.g., Rogers and Monsell, 1995; Rubinstein et al., 2001). In other words, the former hypothesis indicates that the switch cost is caused by the prolongation of task-specific processes (e.g., response selection), whereas the latter hypothesis suggests that it originates from the control process inserted into the task-processing stream on switch trials.

The switch cost has been explored by using event-related brain potential (ERP) measures with high temporal resolution, especially latencies of the P3 (or P300, P3b), stimulus-locked lateralized readiness potential (sLRP), and response-locked LRP (LRPr). P3 latency was used an index of the time required for stimulus encoding and identification, sLRP as an index of time elapsed until the completion of response selection, and LRPr as an index of the duration of final response execution (Hsieh and Liu, 2005; Hsieh and Yu, 2003). These studies found that sLRP latency was longer on switch trials than on repetition trials, with no task-switching effect on P3 latency and LRPr duration. This supported the aforementioned hypothesis that switch cost in RTs is induced by a carry-over SR rule prolonging the response-selection process.

Recent task-switching studies using the Eriksen flanker task, however, have found no prolongation of sLRP latency for switch trials (Umebayashi and Okita, 2010, 2011). In Umebayashi and Okita (2010), participants were shown a five-letter array consisting of the letters "H" and "S" and were asked to make a choice in response to the central target letter. The four flankers were either identical to the target (a congruent stimulus, e.g., HHHHH) or different from the target and associated with the alternative response (an incongruent stimulus, e.g., SSHSS). In addition, participants had to switch between different SR rules indicated by a pre-cue (e.g., left-hand response to "H" and right-hand response to "S", and vice versa). Replicating the previous findings, switch costs in RT were obtained for both congruent and incongruent stimuli on switch trials. However, the onset latency of sLRP on switch trials was shorter

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for incongruent stimuli than for repetition trials, although it was longer for congruent stimuli. The shortened sLRP onset latency on incongruent switch trials was interpreted as being indicative of automatic response activation. This activation was inferred as being dependent upon a SR rule carried over from a preceding trial and induced by early transmission of flanker-related information from stimulus-evaluation processes (see Coles et al., 1988). In other words, the task-irrelevant flanker information of incongruent stimuli in the current switch trial was considered to activate the correct response according to the SR rule of the preceding trial, whereas that of congruent stimuli was considered to activate the incorrect response. The sLRP reflection of the automatic response activation was evidenced by the earlier onset compared to the fronto-central N2 associated with stimulus identification. Thus, the finding that RT switch costs were incurred irrespective of the congruency of the trials implied that switch costs are not attributable simply to the interference of a carry-over SR rule in response selection, but rather derive from an additional process of active control inserted into the task processing stream.

Contrary to expectations, however, Umebayashi and Okita (2010) obtained no obvious ERP evidence of incorrect response activation in the early portion of sLRP. Incorrect response activation has been generally observed as a small positive deflection of sLRP (a so-called positive dip), that precedes the negative-going development of sLRP associated with correct response activation (see Coles et al., 1995, 1988). However, as sLRP reflects the balance (or difference) in activation of the two motor cortices, the positive dip that occurs with activation of an incorrect response (e.g., left-hand response preparation) decreases and disappears with the concurrent activation of a correct response (e.g., right-hand response preparation). A similar decrement of a positive dip could occur when equivalent activations of correct and incorrect responses overlap across trials over time. Therefore, Umebayashi and Okita (2010) suggested that the overlapping of correct response activation with shorter latencies due to temporal jitter across trials had made it difficult to observe the positive dip in the averaged waveforms. In fact, an additional median-RT split analysis revealed a positive dip in the sLRP with slow RTs (or longer latencies), which is consistent with results from other studies (e.g., Gratton et al., 1988), though this dip was not statistically significant. If incorrect response activation is in fact induced by a preceding alternative SR rule carried over to the current switch trials, but obscured by the concurrent activation of a correct response, it may be visible as a positive dip when execution of an overt response is not required and correct response activation is therefore not present. The present study tests this possibility by means of a Go/Nogo procedure in a task-switching situation, since Nogo stimuli do not require the execution of overt responses. The presence of a positive dip on Nogo task-switch trials could suggest that early incorrect response activation on the current switch trials is indeed induced by a preceding alternative SR rule.

In the present combined paradigm of task switching with a Go/Nogo manipulation, participants responded to Go stimuli with either their left or right hand. To avoid the complexity of tasks with flanker stimuli, arrows with a well-established response tendency were used as task stimuli. The hand corresponded either to the direction of an arrow stimulus that pointed to the left or right (SR compatible, dominant task) or to the direction opposite that indicated by the arrow (SR incompatible, non-dominant task). This setup using arrows was also expected to induce stronger effects on automatic response activation, as compared to the flanker-related information in a standard Eriksen task, and enable us to observe the positive dip reflecting a preceding alternative SR rule on the current switch trials. Furthermore, Allport et al. (1994) found that switching to a dominant task incurred larger costs than switching to a non-dominant task. This asymmetrical switch cost was assumed to derive from carry-over of the inhibition for the dominant-task

rule, which had occurred on the preceding non-dominant task, and reflect the time required to reactivate the current dominant rule. In the present experiment, if the inhibition for the dominant rule were carried over from incompatible (non-dominant task) to compatible trials (dominant task), then the delay of correct response activation on switch compatible trials should allow us to observe the positive dip even for Go stimuli.

Thus, the current study examined whether a positive dip could be observed that would reveal carry-over of a preceding alternative task rule in a task-switch situation. The ERP measures of the fronto-central N2 and the parieto-central P3 were employed as indexes of stimulus identification and stimulus categorization, respectively (Dien et al., 2004). The sLRP was used to analyze early response activation and response selection and the LRPr to analyze the response execution process (Coles et al., 1995, 1988).

2. Methods

2.1. Participants

The participants were 13 females, 22–33 years old (mean age = 25.6 years). All participants were right-handed and had normal or corrected-to-normal vision. They gave written informed consent and received payment for their participation. Data from one participant were excluded from analysis because 34% of her responses were errors and the numbers of averaging ERP responses decreased.

2.2. Stimuli and behavioral tasks

Fig. 1 shows an example of the stimulus presentation sequence and SR task rules in the current study. In the combined paradigm of task switching with a Go/Nogo manipulation, the task stimuli were arrows, pointing to the left or right, which subtended 5.5° width by 1.5° height of visual angle. The arrows were randomly presented in green or red on a white background; the green arrow was assigned to Go stimuli and the red arrow to Nogo stimuli for half of the participants, and vice versa for the remaining half. The proportion of Go and Nogo trials was equal (Falkenstein et al., 1995, 1999). For Go stimuli, participants were required to respond by pressing a left or right button with an index finger as quickly and accurately as possible. The response hand corresponded to the arrow direction for the compatible task and was reversed for the incompatible task. For example, a green right-pointing arrow should elicit a button press with the right hand for the compatible task, and a response with the left hand for the incompatible task.

The two compatible and incompatible tasks were switched every three trials in a predictable pattern. Thus, a switch trial was followed by two repetition trials, a first repetition and a second repetition. Participants were also predictably informed about the nature of each task by pre-cues. The pre-cues were either an upward (▲) or inverted triangle (▼) drawn in black, indicating a compatible or incompatible task, respectively. The number of triangles increased from one to three following switch, first repetition, and second repetition trials, and the number was reset when the task was switched. Each triangle had a visual angle of 1.9° width by 1.6° height and the center-to-center distance between triangles was 0.3°. The assignment (compatible or incompatible) of each cue (▲ or ▼) was also counterbalanced across participants. All stimuli were presented at the center of a computer display, using a PC5100 (DEC Co) computer with SuperLab Pro for Windows Version ver. 2.0.4 (Cedrus Co) software.

2.3. Procedure

The entire experimental session lasted 2–2.5 h. The session started with the attachment of electrodes. The experiment was conducted with participants seated in an electrically shielded room facing a computer display at a distance of 60 cm, which was maintained using a chin rest. At the beginning of each trial, the task cue was presented at the center of the monitor for 800 ms, and was then replaced by the task stimulus for 200 ms. Following a blank screen for 1500 ms, the next trial started.

The first block of 51 trials was used to familiarize participants with the process. Following the practice phase, participants performed 16 experimental blocks of 51 trials. The first three trials of each block served as a warm up. Participants were asked to try to minimize eye movements or blinks in order to minimize ocular artifacts.

2.4. Recording and processing

Responses to Go stimuli occurring within a 150–1000 ms time window after stimulus onset were classified as correct or incorrect, depending on the SR mapping. Correct and incorrect responses occurring outside of this time window were recorded as premature or delayed responses.

EEG activity was recorded from 16 scalp sites (Fpz, Fz, Cz, Pz, F3, F4, C3, C4, O1, O2, F7, F8, T3, T4, T5 and T6) using Ag–AgCl electrodes positioned according to the