

# Comparison of Neural Responses between Exogenous and Endogenous Rule Shifting in Cued Switching Task; an ERPs study

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## Abstract

Task switching is a well-known cognitive paradigm to explore task-set reconfiguration processes such as rule shifting. In particular, endogenous task switching is thought to differ qualitatively from stimulus-triggered exogenous task switching. However, no previous study has examined the neural substrate of endogenous task switching. The purpose of the present study is to explore the differences between event-related potential responses to exogenous and endogenous rule switching at cue stimulus. We modified two patterns of cued switching tasks: exogenous (bottom-up) rule switching and endogenous (top-down) rule switching. In each task cue stimulus was configured in order to induce switching or maintaining rule. In Exogenous switching tasks, late positive deflection was larger in the switch rule condition than in the maintain rule condition. However, in endogenous switching tasks late positive deflection was unexpectedly larger in the maintain rule condition than in the switch rule condition. These results indicate that exogenous rule switching is explicit stimulus-driven processes whereas endogenous rule switching is implicitly parallel processes independent of external stimulus.

**Keywords:** Switching task; Event related potentials; rule shifting

## Introduction

Executive function is thought to be one of most important cognitive functions, and it is conceptualized as having four components: volition, planning, purposive action, and effective performance (Lezak, 1995). There are several neuropsychological tests that assess executive function, such as the Wisconsin Card Sorting Test (WCST), the Trail Making Test, and the Tower of London task. In WCST, the subject suppresses a no-longer-relevant task-set and replaces it with an appropriate new task-set; this process is called set shifting (Anderson, Damasio, Jones, & Tranel, 1991; Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997; Goldberg & Weinberger, 1994; Milner, 1963).

The task switching paradigm is a well-known and sophisticated paradigm that engages these cognitive processes and requires predictable or random alternation between two response selection tasks (Jersild, 1927; Rogers & Monsell, 1995). For example, participants have previously been instructed to switch between a letter classification task

(Task A) and a digit classification task (Task B) in a predictable sequence (e.g., AABB) or in a random sequence. Many studies using the task switching paradigm have observed that reaction time (RT) was reliably greater in switching trials than in maintain trials (no-switching trials) (Rogers & Monsell, 1995). Switch cost is estimated by subtracting the RTs in trials requiring no switch from those in trials requiring a switch; switch cost is thought to be an index of the extra difficulty associated with reconfiguring the active task-set.

Previous Event-related potential (ERP) and fMRI studies have identified the neural substrates of task switching processes. Some previous studies have implicated the lateral prefrontal cortex and the parietal cortex as being centrally involved in preparatory processing during task switching (Johnston, Levin, Koval, & Everling, 2007; Kamigaki, Fukushima, & Miyashita, 2009; Rowe J, 2008; Ruge, 2007). Savine and Braver (Adam C. Savine, 2010) reported that using incentives to modulate cognitive control specifically enhanced task-cue-related activation of the left dorsolateral prefrontal cortex. In an ERP study, Karayanidis et al. (Karayanidis, Coltheart, Michie, & Murphy, 2003) indicated that switch-related positivity and switch-related negativity were elicited by a target stimulus in switching trials. These ERP data reflected that switch-related positivity was unaffected by irrelevant task-cueing, whereas the amplitude and latency of switch-related negativity were modulated by the response-stimulus interval.

Many studies have used task switching, in which stimulus-triggered, bottom-up processes to shift between rules operate via external stimuli such as contextual stimuli, but few studies have focused directly on endogenous, voluntary rule shifting. Rogers and Monsell (Rogers & Monsell, 1995) used an endogenous task switching paradigm that required task-set alternation between trials; this paradigm places high demands on working memory. Participants were told to switch between "Task A" and "Task B" in a predictable sequence (AABB). Target stimuli were presented in one of four boxes continuously displayed on a computer screen, and stimulus position was rotated in a clockwise direction. Thus, on a given trial, the active task was cued by the position of the displayed stimulus. This paradigm seems to require a certain form of endogenous rule switching, because participants change tasks in a predictable sequence.

We believed that cognitive control of endogenous rule shifting is more difficult than control of exogenous rule shifting. For example, perseveration, which is a contextually inappropriate and unintentional repetition of response, is attributed to defective set shifting caused by frontal lobe lesion or cognitive dysfunction, and is often observed in patients with psychiatric disorders. Thus, people who display perseveration find it more difficult to move on from one idea to the next voluntarily than to follow instructions from others. It is likely that the neural substrates characterizing exogenous and endogenous rule shifting are different from one another.

No previous study has examined the neural substrate of endogenous rule shifting using tasks such as those reported by Rogers and Monsell. Their above-mentioned paradigm is simple, but the time point when participants switch rule voluntary is unclear. Because contextual stimuli (four small squares occupying quadrants of the screen) are displayed continuously in their task and then there is no explicit cue which requires participants to switch rule endogenously. Therefore it seems to be difficult to measure neural responses to endogenous rule switching. It is worthwhile to examine differences in the neural activity elicited by exogenous and endogenous rule shifting in detail. We modified an existing cued switching task and configured the cue stimuli to induce two patterns of rule switching: exogenous (bottom-up) rule switching and endogenous (top-down) rule switching. Furthermore, we compared the neural responses elicited by exogenous rule shifting to those elicited by endogenous rule shifting using ERPs.

## Materials and methods

### Participants

Twelve right-handed student volunteers (12 male, aged 20–34 years, mean age 24.8 years) served as participants. All participants had normal or corrected-to-normal vision. None had a history of neurological or psychiatric disorders. All participants gave written informed consent, and the study was approved by the local research ethics committee.

### Procedure

We made novel cued switching tasks and configured cue stimuli in order to induce two patterns of rule switching: exogenous (bottom-up) rule shifting and endogenous (top-down) rule shifting. In practice trials, the participant learned to perform a two-choice response task accurately according to each of two response rules (see Figure 1). The first was an even vs. odd number classification rule, in which the participant was required to press a button with the left hand in response to an odd number or to press a button with the right hand in response to an even number. The second rule was a small vs. large number classification rule, in which the participant was required to press a button with the left hand in response to a number below five or to press a button with the right hand in response to a number above five. Figure 2 shows a schematic diagram of the cued switching task in

present study. In each trial, a cue stimulus was presented for 1000 ms and was followed by a target stimulus. The target stimulus remained on the screen until the participant pressed one of the two buttons. In the exogenous rule switching task, a white cue stimulus indicated that the subject should maintain the same rule as the previous trial; the white cue stimulus was presented in two or three consecutive trials, and then its color changed to red, indicating that the subject should switch to the other response rule. In the endogenous rule switching task, the cue stimulus was always white, and the participant was instructed to switch the response rule voluntarily every other trial, maintaining each response rule for two consecutive trials. Infrequently, an instruction stimulus showing another rule was presented instead of the cue stimulus; the instruction stimulus dictated that the participant had to switch the response rule immediately. This manipulation requires the participant to attend to the cue stimulus in every trial. If the participant sees the cue stimulus after two consecutive trials during which the same response rule was used, this means that the participant should switch to the other response rule endogenously. We thought that this procedure enables to measure neural response to endogenous rule switching effectively.

rule	response	
	left	right
	odd/even	odd even
	small/large	below 5 above 5

Fig. 1: Response rule in present task

### EEG recording and analysis

An electroencephalogram (EEG) (bandpass 0.16–30 Hz, digitized at 500 Hz) was recorded from 55 electrodes according to the international 10-10 system. Ag/AgCl electrodes were used, and impedance was kept below 10 kΩ. All electrodes were referenced to linked earlobes. An electrooculogram (EOG) was recorded from electrodes lateral to and below the left eye. The signals were digitized for an epoch of 800 ms starting 200 ms prior to the presentation of the cue and target stimulus respectively. During the present study, we recorded large volumes of ERP data, but we conducted a conventional ERP analysis using only a small number of channels and achieved satisfactory findings. We measured the mean amplitude of the ERP's late positive component (LPC) over 250–300 ms to cue stimulus and LPC over 400–700 ms to target stimulus. A three-way repeated measures ANOVA with Greenhouse-Geisser correction was performed to compare mean LPC amplitudes on the basis of cue modality factor (exogenous vs. endogenous), response rule switching factor (maintain vs. switch), and electrode site factor (Fz, Cz and Pz).

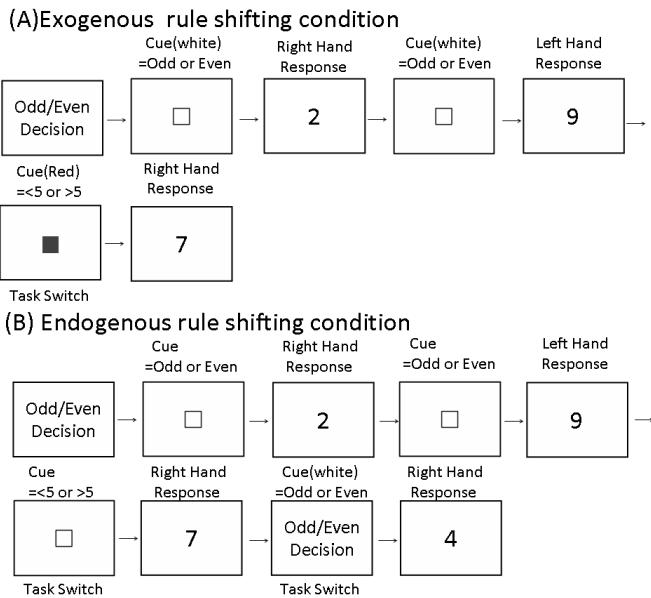


Fig. 2: Schematic diagram of cued switching task

## Result

### Behavioral data

We measured mean reaction times (RTs) and calculated switching costs (RT during trials in which the response rule switches minus RT during trials in which the response rule is maintained) for all conditions (see Figure 3). For RT data, the ANOVA revealed only one significant main effect, which was of switching,  $F(1, 11) = 35.25, p < .001$ . RTs in trials when the response rule was switched were significantly larger than RTs in trials when the response rule was maintained. A t-test on the switching cost results revealed no significant differences between the exogenous and endogenous switching conditions,  $T(11) = -0.76, p = .46$ .

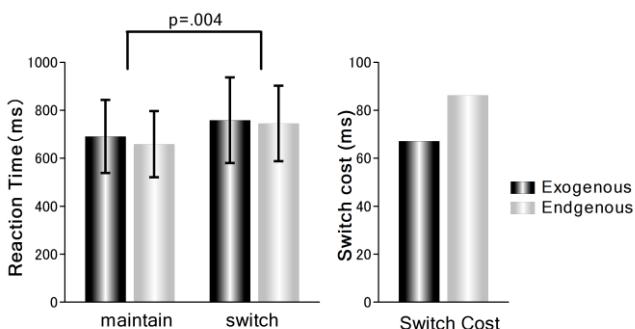


Fig. 3: Behavioral data

### ERPs data

Figure 4 shows the grand-averaged ERP waveforms elicited by the cue stimuli in our study. Figure 5 shows mean LPC amplitude by the cue stimuli at Pz. For the late positive component (LPC) mean amplitude data, the ANOVA revealed only one significant main effect, which was of electrode site factor,  $F(2, 11) = 5.43, p < .05$ . In addition, there was a significant interaction between cue modality factor and switching factor,  $F(1, 11) = 20.31, p < .01$ . LPC deflection in the exogenous task was larger in the switch condition than in the maintain condition, but this pattern was inverted in endogenous task; LPC amplitude in the endogenous task was larger in the maintain condition than in the switch condition.

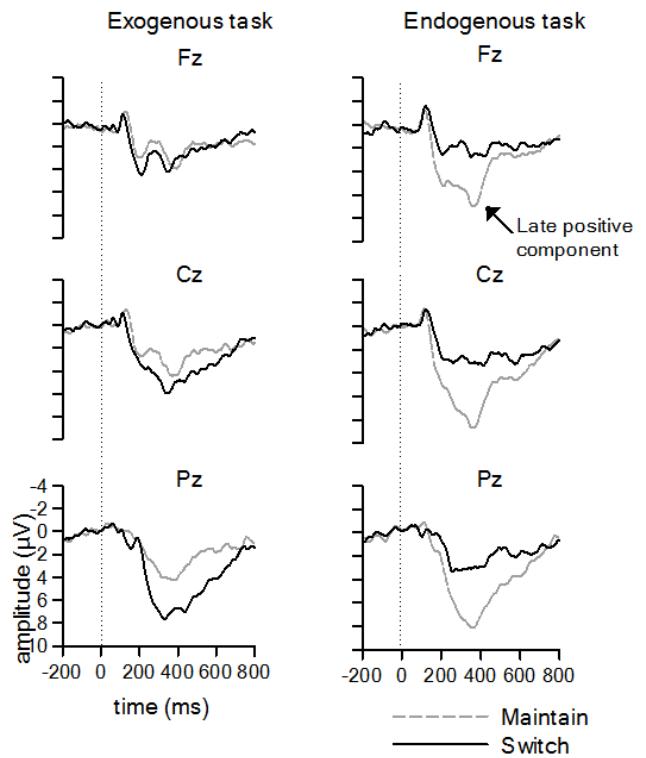


Fig. 4: Grand-averaged ERP waveforms in cue stimuli

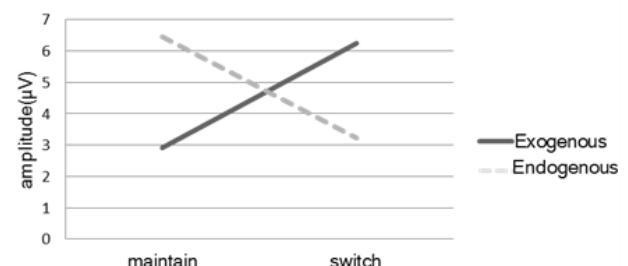


Fig. 5: Mean LPC amplitude in the cue stimuli at Pz

Figure 6 shows the grand-averaged ERP waveforms elicited by the target stimuli in our study. Figure 7 shows mean LPC amplitude by the target stimuli at Pz. For the late positive component (LPC) mean amplitude data, the ANOVA revealed significant main effect in electrode site factor,  $F(2, 11) = 14.90, p < .001$  and response rule switching factor  $F(2, 11) = 11.43, p < .006$ . In addition, there was a significant interaction between cue modality factor and switching factor  $F(1, 11) = 25.82, p < .001$ . In the target stimuli, LPC deflection in the endogenous task was larger in the maintain condition than in the switch condition but there was no significant difference in the exogenous task.

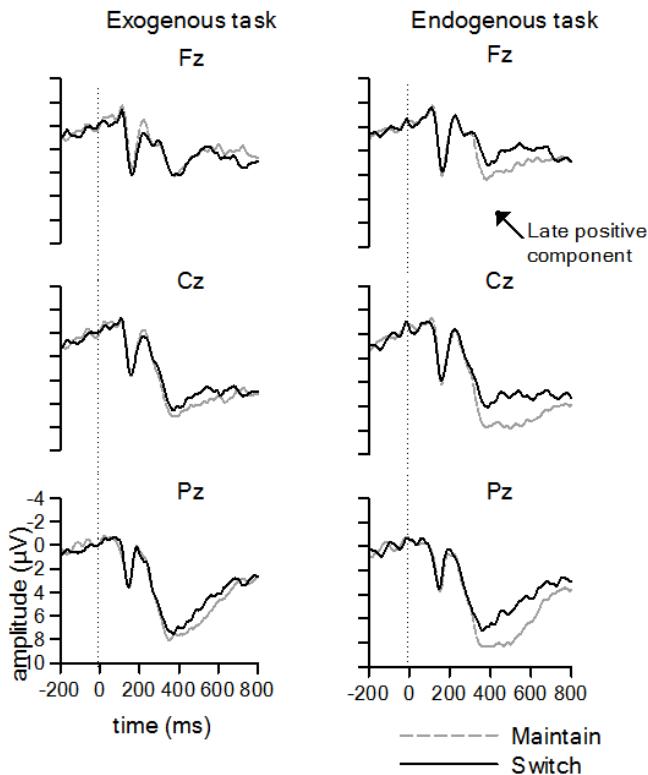


Fig. 6: Grand-averaged ERP waveforms in target stimuli

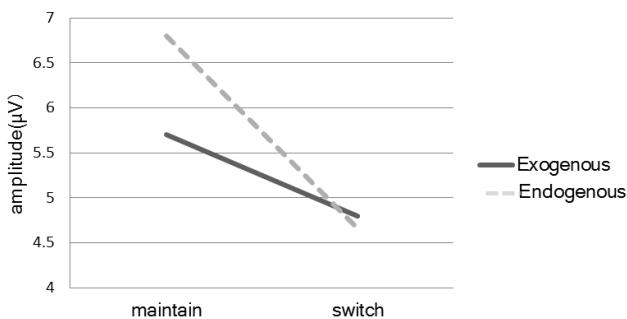


Fig. 7: Mean LPC amplitude in the target stimuli at Pz

## Discussion

The purpose of the present study is to explore the differences between ERP responses to exogenous and endogenous rule switching at cue stimulus onset. This study elucidated interesting ERP waveform changes elicited by the cue stimuli in various conditions. First we discuss the LPC amplitude at the cue stimuli. In the exogenous switching task, late positive component (LPC) amplitude was larger in the switching condition than in the maintaining condition, and thus, the ERP waveform pattern results ran parallel to the reaction time (RT) results. It is possible that changing the cue stimulus drives rule representation retrieval and working memory updates, and thus contributes to increases in positive deflection. Larger ERP deflection elicited by changing the cue stimulus is associated with the lengthening of RT upon presentation of the target stimulus. Surprisingly, the pattern of ERP deflection observed in endogenous task was reversed in the exogenous switching task. LPC amplitude was larger in the maintaining condition than in the switching condition when the switching criteria were endogenous, and this pattern contrasted with RT results.

This disparate pattern of ERP waveforms in the cue stimuli between the endogenous and exogenous tasks from the standpoints of reaction time (RT) measurements and task structure. We hypothesized that changing the cue stimulus in the endogenous switching task triggers voluntary top-down processing for response rule switching (such as memory retrieval and working memory updates) and therefore elicits a larger neural response, reflected by late positive component (LPC) amplitude. Contrary to our hypothesis, the results reflected a reduction of LPC amplitude in the response rule switching condition. Since the response rule was changed every two trials in the endogenous task, preparatory or anticipatory processes for rule switching might operate before the onset of the switching cue. In the present study's endogenous task, we occasionally presented instruction stimuli instead of cue stimuli, forcing participants to switch response rule at an unexpected time. Because of the inclusion of the instruction stimulus, participants could not switch the response rule thoughtlessly after two trials using the same response rule; participants still needed to identify the presentation of the switching cue stimulus carefully. We think that reduction of LPC amplitude in the switching condition indicates that the substance of the endogenous rule shifting process finishes before cue stimulus onset, and the cue stimulus is no more than a confirmation of the already-prepared new response rule. In addition, an increase in LPC amplitude during the ensuing maintaining trial might indicate the operation of proactive partial switching processes that anticipate the next trial. Since the maintaining condition is the last trial during which the participant uses an old response rule, the cue stimulus in maintain trials represents both the preservation of the current rule representation and its subsequent extinction. Because participants likely exercise considerable cognitive efficiency, processes of endogenous rule switching most likely take place at the earliest possible time. Therefore, the cue

stimulus in maintaining trials might cause the allocation of large attentional resources to subsequent rule switching and thus elicit large positive deflections in ERP. The switching cue stimulus presented during the following trial might only confirm an already-updated response rule and thus demand fewer resources, causing a smaller positive deflection. In the exogenous switching task, participants need to evaluate the content of the cue stimulus in every trial, and thus, preparatory or anticipatory rule shifting processes might not operate before the switch trials begin.

Secondly we discuss the LPC amplitude at the target stimuli. In the endogenous switching task, the late positive component (LPC) amplitude was larger in the maintain condition than in the switching condition, and this pattern contrasted with reaction time (RT). However in the exogenous switching task, there was no significant difference between the switching condition and maintaining condition (Fig.7). This result indicated discrepant pattern similar to ERPs of cue stimulus. It is likely that additional cognitive processes operates at target stimulus in maintain condition in endogenous task. In maintain condition, RT was smaller than in switch condition and thus additional process reflected by larger LPC might not be associated with reaction processes to target stimulus. We thought that this process is similar to results of cue triggered ERPs in endogenous task and associated with operation of proactive partial switching processes that anticipate the next trial.

Contrary to ERP results, switch cost, which is the difference in reaction time (RT) between switching and maintaining conditions, showed no significant differences between exogenous and endogenous switching tasks. A previous study conducted by Rogers and Monsell indicated that switch cost varies according to the response-stimulus interval (Rogers & Monsell, 1995), which corresponds to the cue-target interval in the present study. Although variation of switch cost is thought to be associated with processes of task-set reconfiguration (Karayanidis, et al., 2003), this is inconsistent with ERP results in present study. In endogenous task late positive component deflection elicited by switching cue stimulus was reduced but RT was larger than in maintain trial. Some previous studies indicate that switch cost reflects not only task-set reconfiguration before target response but also certain proactive interference (e.g., Karayanidis, et al., 2003). In present study the representation of the new response rule determined by the cue stimulus in both tasks might not be fixed perfectly in the participant's mind at the time of target stimulus onset. In addition participants' lack of experience in applying a new response rule just after applying an old response rule might contribute to this lengthening of RT.

## Conclusion

The ERP results suggest that participants' rule switching strategies vary implicitly according to task structure. To the best of our knowledge, no study has compared bottom-up and top-down task switching processes directly. We used a novel cued switching task to find differences between

neurophysiological responses during exogenous and endogenous rule shifting processes. We can say that exogenous rule switching is explicit stimulus-driven processes whereas endogenous rule switching is implicitly parallel processes independent of external stimulus.

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## References

Adam C. Savine, T. S. B. (2010). Motivated Cognitive Control: Reward Incentives Modulate Preparatory Neural Activity during Task-Switching. *Neuroscience*, 30(31), 10294-10305.

Anderson, S., Damasio, H., Jones, R. D., & Tranel, D. (1991). Wisconsin Card Sorting Test performance as a measure of frontal lobe damage. *J Clin Exp Neuropsychol*, 13, 909-922.

Gold, J., Carpenter, C., Randolph, C., Goldberg, T., & Weinberger, D. (1997). Auditory working memory and Wisconsin cars sorting performance in schizophrenia. *Arch Gen Psychiatry* 54, 159-165.

Goldberg, T. E., & Weinberger, D. R. (1994). The effects of clozapine on neurocognition: an overview. [Comparative Study Review]. *The Journal of clinical psychiatry*, 55 Suppl B, 88-90.

Jersild. (1927). *Mental set and shift* (Vol. Whole No.89).

Johnston, K., Levin, H. M., Koval, M. J., & Everling, S. (2007). Top-down control-signal dynamics in anterior cingulate and prefrontal cortex neurons following task switching. [Research Support, Non-U.S. Gov't]. *Neuron*, 53(3), 453-462. doi: 10.1016/j.neuron.2006.12.023

Kamigaki, T., Fukushima, T., & Miyashita, Y. (2009). Cognitive set reconfiguration signaled by macaque posterior parietal neurons. [Research Support, Non-U.S. Gov't]. *Neuron*, 61(6), 941-951. doi: 10.1016/j.neuron.2009.01.028

Karayanidis, F., Coltheart, M., Michie, P. T., & Murphy, K. (2003). Electrophysiological correlates of anticipatory and poststimulus components of task switching. *Psychophysiology*, 40(3), 329-348.

Lezak, M. D. (1995). *Neuropsychological Assessment*. New York: Oxford University Press.

Milner, B. (1963). Effects of different brain lesions on card sorting: the role of the frontal lobes. . *Archives of Neurology* 9, 90-100.

Rogers, R., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *J Exp Psychol Gen* 124, 207-231.

Rowe J, H. L., Eckstein D, Owen AM (2008). Rule-selection and action-selection have a shared neuroanatomical basis in the human prefrontal and parietal cortex. *Cereb Cortex*, 18, 2275-2285.

Ruge, B. (2007). Neural mechanisms of cognitive control in task switching: rules, representations, and preparation. In W. J. Bunge SA, eds (Ed.), *The neuroscience of rule-guided behavior* (pp. 255-283). New York: Oxford UP.