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Neural correlates of response-effector switching using event-related potentials

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ABSTRACT

The primary aim of the present study was to explore whether response-effector shifts can be considered as a cognitive component in models of task switching. The secondary aim was to provide some information regarding the issue of whether the two types of task shifts, stimulus-dimension shift and response-effector shift, share common and/or distinct switch-related ERP modulations. The tertiary aim was to illuminate the organization of task-set components by comparing the performance of a concurrent shift of both stimulus dimensions and response effectors to that of a single shift. Two experiments with two different types of judgment tasks (Experiment 1: a same-match-to-sample task; Experiment 2: a categorical-judgment task) were conducted. Intermittently cued task switching was employed. Each trial was composed of a series of stimulus displays following a transition-cue display, which indicated whether the current trial was identical to (repeat) or different from the previous trial (switch). There were stimulus-dimension (color and shape) and response-effector (hand and foot) variables that could be repeated or switched independently with an equal probability from the previous trial. Regarding the primary issue, the results of the two experiments reported in this study consistently showed significant RT switch costs as well as switch-related ERP modulations for a shift of response effectors. Yet, one of the switch-related ERPs, i.e., the cue-locked P3b, observed in this study was found to be reduced rather than increased in amplitudes. As to the secondary issue, the two experiments consistently showed that the two single shifts share some common switch-related ERPs. Finally, this study also provides ERP evidence for the integrated model of task-set organization.

1. Introduction

Daily scenarios often require people to switch between various tasks, such as reading a book, writing a paper, talking on the phone and so on. Hence, the ability to quickly adapt our behavioral repertoire to changing situations and to switch from one task to another is crucial in daily life. Furthermore, daily tasks often require people to modulate their perceptual-, cognitive-, and/or motor-level systems according to environmental demands and task goals to select and process various levels of mental task representations more effectively. Thus, switching between various tasks may differentially emphasize the need to pay attention to one or more of these levels of mental task representations. To examine the underlying mechanisms that enable people to flexibly switch among daily tasks, researchers have developed various forms of task-switching paradigms with different types of tasks that mimic real-world situations. Numerous researchers have consistently found that even shifting between two seemingly simple tasks (e.g., shifting between judging a digit to be greater or less than 5 and judging a digit to be odd or even) incurs significant behavioral switch costs, i.e., longer reaction times (RTs) and/or more error rates for switch-than repeat-trials (for a review, see Hsieh, 2012; Kiesel et al., 2010; Meiran, 2010; Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010).

However, most laboratory studies have centered on shifts involving the cognitive (non-motor) aspects of a task, such as a shift in stimulus dimensions (e.g., shifting between the color and shape of a stimulus; Hahn, Andersen, & Kramer, 2003; Hakun & Ravizza, 2012; Owen, Roberts, Polkey, Sahakian, & Robbins, 1991; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000; Rushworth, Passingham, & Nobre, 2005), response sets (e.g., shifting between different judgment-to-response mapping rules; Cools, Clark, & Robbins, 2004; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Hahn et al., 2003; Hakun & Ravizza, 2012; Hsieh & Yu,

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2003; Meiran, Chorev, & Sapir, 2000; Rubinstein, Meyer, & Evans, 2001; Rushworth, Passingham, & Nobre, 2002), or task-sets (a task-set includes stimulus sets, response sets, and the corresponding stimulus–response mappings; such as shifting between judging whether a digit is odd or even and whether a letter is a vowel or a consonant on a compound digit/letter stimulus (e.g., "6E"); e.g., Rogers & Monsell, 1995; Sohn & Anderson, 2001; Vandierendonck et al., 2008). Unlike real-life scenarios, relatively few laboratory studies have directly examined whether a shift in the motor aspects (on the level of motor execution) of a task, such as response modalities (effectors: vocal, finger, foot) generating similar switch costs as shifts in the non-motor aspects of a task. The issue is theoretically important because a response-effector shift involves a shift solely in the aspect of motor execution (i.e., in the level of response-action codes) while keeping the judgment (decision or task category)-to-response mapping rules the same in each trial, whereas a response-set shift involves a change of the judgment-to-response mapping rules. One behavioral study by Philipp and Koch (2011) directly explored the role of response modalities in task switching and demonstrated that modality-shift costs were not solely the outcome of motor-related mechanisms but rather emerged from a general switching process. These authors observed that a shift in response modality resulted in similar switch costs as did other forms of cognitive aspects of a task switch; thus, they concluded that response modality could be considered as a cognitive component in models of task switching (e.g., Philipp & Koch, 2005: vocal vs. finger vs. foot responses; also see Philipp & Koch, 2010, 2011). Their finding clearly shows that "task switching" also takes place in a response-effector shift even though the judgment-to-response mapping rules maintain the same in each trial (Philipp & Koch, 2011). Nevertheless, given the few studies directly examining a shift in the motor aspects of a task, the primary goal of the present study was to contribute more empirical data to the literature on this topic.

1.1. Electrophysiological correlates of task switching

Over the past decade, electrophysiological studies of task switching have emerged because of the advantage of studying event-related potentials (ERPs), which measure processing (in milliseconds) between a stimulus and a response and allow researchers to infer the processes that precede a response before the stimulus onset. In task-switching paradigms, two time epochs of an ERP are often analyzed: the time locked to cue onset (cue-locked ERP) and the time locked to stimulus onset (stimulus-locked ERP). Using this method, researchers have identified several switch-related ERP components for both cue- and stimulus-locked epochs.

Regarding cue-locked switch-related ERP components, many studies have identified an enlarged positivity at a posterior centroparietal site on the scalp for task-switch trials compared to repeat trials. This centroparietal positive shift (known as P3b-like centroparietal positivity) occurs approximately 400 ms after cue onset, which has often been interpreted as an anticipatory preparation for the upcoming task (e.g., Goffaux, Phillips, Sinai, & Pushkar, 2006; Karayanidis, Coltheart, Michie, & Murphy, 2003; Kieffaber & Hetrick, 2005; Lavric, Mizon, & Monsell, 2008; Miniussi, Marzi, & Nobre, 2005; Nicholson, Karayanidis, Poboka, Heathcote, & Michie, 2005; Rushworth et al., 2002; Swainson et al., 2003). In addition, a long-lasting late frontal negativity (LFN) that starts at 300 ms after cue presentation has also been reported in previous studies, and this LFN might reflect the preparation for an upcoming response conflict (Astle, Jackson, & Swainson, 2006; Astle, Jackson, & Swainson, 2008a.b; Mueller, Swainson, & Jackson, 2007). Please note, although these two switch-related cue-locked ERP components have been commonly observed, there are a few exceptions which will be elaborated in the general discussion section.

Regarding stimulus-locked switch-related ERP components, most studies in this field have identified a smaller positivity (a P3b-like component), which peaks approximately 400–800 ms after the stimulus onset for task switches relative to repeat trials at centroparietal sites (e.g., Barceló, Periáñez, & Knight, 2002; Gehring, Bryck, Jonides, Albin, & Badre, 2003; Goffaux et al., 2006; Hsieh & Chen, 2006; Hsieh & Liu, 2008, 2009; Karayanidis et al., 2003; Kieffaber & Hetrick, 2005; Poulsen, Luu, Davey, & Tucker, 2005; Swainson et al., 2003; Wylie, Javitt, & Foxe, 2003). This ERP effect has been hypothesized to reflect the difference in the difficulty in implementing the task rule and/or resolving interference at the response selection/execution level (Ikeda & Hasegawa, 2012; Jamadar, Michie, & Karayanidis, 2010; Swainson, Jackson, & Jackson, 2006), yet some other researchers have related this switch-related ERP effect to working memory processes (Barceló et al., 2002; Gehring et al., 2003). In addition to the stimulus-locked P3b, P2 and N2 amplitudes were also found to be modulated in switch trials compared to the repeat trials (Tieges, Snel, Kok, Plat, & Ridderinkhof, 2007), which were hypothesized to reflect the "associative strengthening" (P2; Kieffaber & Hetrick, 2005; Tieges et al., 2007) and the strength of stimulus-response associations (N2; Rushworth et al., 2002), respectively.

1.2. Neural correlates of attention (rule) vs. effector switch

The above review of switch-related ERP components was mainly obtained from shifts in stimulus dimensions, response sets, or task sets. Similar to the behavioral studies, few ERP studies have targeted motor-related shifts, such as response-effector shifts. In addition, there have been relatively more behavioral and neuroimaging studies (including ERP and functional magnetic resonance imaging (fMRI) studies) in the current literature addressing the distinction between the stimulus-dimension and response-set shifts (see behavioral study: Hahn et al., 2003; fMRI study: Hakun & Ravizza, 2012; ERP study: Hsieh & Wu, 2011; Karayanidis et al., 2003; Kieffaber & Hetrick, 2005; Kieffaber et al., 2006; Moulden et al., 1998; Rushworth et al., 2002). As mentioned before, a response-effector shift differs from a response-set shift in terms of keeping the judgment-to-response mapping rules the same while shifting, hence, while the previous studies have investigated common and/or distinct neural correlates (ERP, fMRI) of task switching, particularly regarding anticipatory preparation between the stimulus-dimension and response-set shifts, it is still unclear if a response-effector shift shares common or distinct preparatory and/or implement processes with a stimulus-dimension or stimulus-categorization shift.

To our knowledge, only two ERP studies (Tieges et al., 2007; West, Bailey, & Langley, 2009) and one fMRI study (Philipp, Weidner, Koch, & Fink, 2013) directly contrasted task-rule and effector shifts. However, although these two ERP studies consistently showed that the response-effector shift, similar to other forms of cognitive-task shifts, also incurred cue-locked and stimulus-locked switch-related ERP components, yet they did not reach consensus on whether common or distinct underlying mechanisms of preparation control processes (reflected on cue-locked ERPs) were associated with task-rule vs. effector shifts. As for the fMRI study by Philipp et al. (2013), two distinct brain areas, the left inferior frontal gyrus and parietal cortex, have been shown to be specifically involved in the shift of stimulus dimensions and the shift of response effectors respectively. They claimed that their findings were in accordance with the other ERP study by Brass, Ullsperger, Knoesche, von Cramon, and Phillips (2005) who suggested that activation of the prefrontal cortex is related to the