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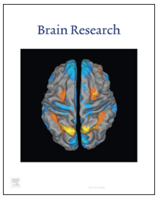

Research report

Electrophysiological correlates of the cognitive control processes underpinning mixing and switching costs

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ABSTRACT

Typically, in task-switching contexts individuals are slower and less accurate when repeating a task in mixed blocks compared to single-task blocks (mixing cost) and when switching to a new task compared to repeating a previous one (switch cost). Previous research has shown that distinct electrophysiological correlates underlie these two phenomena. However, this evidence is not a consistent result. The goal of this study was to better characterize differences between the control processes involved in mixing and switch costs. To this aim, we examined event-related potentials (ERPs) evoked during a cued task-switching experiment. In order to minimize the confounding effects of cognitive demands unrelated to task-switching, we asked participants to shift between two simple tasks (a letter identity task and a letter position task). The mixing cost was defined, in terms of ERPs, by contrasting repeat and single-task trials, whereas the ERP switch cost was obtained from the comparison of switch and repeat trials. Cue-locked ERPs showed that the mixing cost was mediated by two sustained components, an early posterior positivity and a late anterior negativity. On the other hand, the switch cost was associated with two early phasic positive components, one principally distributed over centro-parietal sites and the other located over left posterior sites. In target-locked ERPs the mixing cost was expressed by a frontal positivity, whereas the switch cost was expressed by a reduced parietal P3b. Overall, the results extend previous findings by providing elucidating ERP evidence on distinct proactive and reactive control processes involved in mixing and switch costs.

1. Introduction

In everyday life, we frequently and rapidly shift from one task to another. The cognitive ability underlying this operation is known as task-switching. A successful example of this ability within the verbal domain is represented by the capacity of bilinguals to switch language according to the interlocutor. A failure of this ability is evident in perseverative behaviors exhibited by patients with brain injuries (typically frontal), who keep repeating an action that has become inappropriate with respect to the context or the intention (Shallice et al., 2007). In experimental settings, researchers have investigated the mechanisms subtending task-switching abilities using paradigms that require an individual to promptly shift attention toward different features of stimuli and to respond to them according to new stimulus-response (S-R) rules ('attentional-shift' paradigms; Rushworth et al., 2002, 2005). These studies, which simulate real life situations, have unequivocally shown that such cognitive flexibility implicates costs in performance. Indeed, participants are slower and less accurate in performing a task which is different from the previously executed one (i.e., in switch trials) compared to performing the same task (i.e., in repeat trials). The required extra-time and the reduction of accuracy reflect the so-called 'switch cost' (see Kiesel et al., 2010 for a review; Meiran, 1996; Rogers and Monsell, 1995). Furthermore, participants are slower and less accurate on repeat trials, that is, when repeating a task in blocks that also include switch trials (mixed blocks), than on single-task blocks, that is, when performing a single task throughout the whole block. This effect is called the 'mixing cost' (Rubin and Meiran, 2005).[1]

To date, understanding the cognitive processes and neural mechanisms that underlie the behavioral switch and mixing costs remains an important issue (Karayanidis and Jamadar, 2014). One

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[1] Note that the cost referred to as the mixing cost in the comparison between mixed blocks (switch+repeat trials) and single-task blocks represents a more 'global' cost, whereas the cost referred as the switch cost in the comparison between switch trials and repeat trials represent a 'local' switch costs (Mayr, 2001).

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of the most robust process that supports the switch cost is *task-set reconfiguration* (Meiran et al., 2000; Rogers and Monsell, 1995; Rubinstein et al., 2001). This refers to an endogenous process that involves multiple sub-processes, such as shifting attention between stimulus attributes or features, retrieving task goals and rules, updating (or deleting) them in working memory, and enabling a different response set (Monsell, 2003). The task-set reconfiguration process plays a key role in task-switching operations by acting in anticipation of a stimulus. Indeed, it has been shown that in cued paradigms (where a cue signals the task that must be executed on the upcoming stimulus) longer preparation intervals (i.e., cue-to-target interval, CTI; Altmann, 2004; Koch, 2003; Li et al., 2012) and a greater amount of information carried by the cue (Czernochowski, 2014; Karayanidis et al., 2009; Nicholson et al., 2006b) produce a decrement in the switch cost. Interestingly, the same applies for the mixing cost, which has been found to diminish with increasing preparation intervals (Kray, 2006). These findings suggest that switch costs and mixing costs might in fact rely on common or partially-common preparatory mechanisms.

Importantly, the benefits afforded by the duration of the preparation interval and by the information provided by the cue do not completely eliminate the switch cost. With long CTI durations and with high levels of cue informativeness a ‘residual cost’ is still observed (De Jong, 2000; Meiran, 1996; Rogers and Monsell, 1995). These findings reveal that (i) the task-set reconfiguration process is likely not completed in the preparation phase but is still ongoing during the implementation phase and (ii) additional preparation processes are entailed during the CTI. Among these, *inhibitory* processes have to be mentioned, which aim at resolving the conflict and overcoming the interference produced by the previous task-set, a phenomenon called ‘task-set inertia’ (Allport et al., 1994) or ‘backward inhibition’ (Mayr and Keele, 2000). Indeed, even though long preparation intervals minimize the proactive interference of a previous task-set, the target stimulus triggers the activation of the competing S-R association. This evidence suggests that inhibitory processes intervene at both the preparation and implementation phases. Notably, the persistence of the competing S-R association causes conflict even in repeat trials (Los, 1996; Rubin and Meiran, 2005). Therefore, inhibitory processes seem to contribute to the mixing cost as well. Moreover, both switch and mixing costs have been shown to reflect the greater *memory* demands needed for retrieving the relevant task rules from long term memory and updating and maintaining more than one task-set active (Mayr and Keele, 2000).

In order to disentangle the contribution of specific processes related to the switch and mixing costs previous research has combined cued task-switching paradigms with the simultaneous recording of electroencephalography (EEG). The excellent temporal resolution of EEG enables us to distinguish between cue-related task preparation processes (i.e., proactive control) and target-related task execution/implementation processes (i.e., reactive control) (Braver, 2012). Thus far, multiple topographically and temporally distinct event-related potentials (ERPs) have been reported, which are thought to reflect different cognitive processes. Below, we briefly overview the main cue-locked and target-locked ERP components associated with the proactive and reactive control processes, respectively.

1.1. *Cue-locked ERPs*

A positive posterior ERP component, sometimes labeled ‘switch-positivity’, has been consistently observed after cues signaling a switch as compared to cues indicating a task repetition (for reviews see De Baene and Brass, 2014; Karayanidis and Jamadar, 2014; Karayanidis et al., 2010). Typically, this component reaches maximum amplitude over centro-parietal scalp sites and, in some cases, shows a left-lateralized distribution (Elchlepp et al., 2012). The fact that a larger switch-positivity has been found to be associated with smaller behavioral switch costs suggested that it likely represents an index of proactive task-set reconfiguration processes (Capizzi et al., 2016; Karayanidis et al., 2011a; Lavric et al., 2008). Furthermore, the amplitude, duration, and onset of the switch-positivity have been found to be modulated by the CTI duration and the amount of information about the upcoming task provided by the cue (Karayanidis et al., 2009; Nicholson et al., 2006a). According to some studies, this component could also reflect the ‘reloading’ of the new S-R mapping (Periáñez and Barceló, 2009).

A posterior cue-related potential has been documented not only in switch trials as compared to repeat trials, but also in repeat trials as compared to single-task trials (Czernochowski, 2011; Eppinger et al., 2007; Jost et al., 2008; Karayanidis et al., 2011a, 2011b; Kray et al., 2005; Manzi et al., 2011; Wylie et al., 2009). This component has been referred to as the ‘mixing-positivity’ (Karayanidis and Jamadar, 2014). The topographic and temporal dynamics of the mixing-positivity as well as its functional role in relation to the switch-positivity have not yet been clearly characterized. At least in part, it may represent the decoding of the cue (Karayanidis et al., 2009), which implies rule retrieval and goal activation processes (Jost et al., 2008).

A further cue-related component, occurring in the late portion of the CTI in both switch and repeat trials is a slow fronto-central negativity, sometimes labeled ‘pre-target negativity’ (Astle et al., 2006, 2008; Hsieh and Cheng, 2006; Karayanidis et al., 2011a; Mueller et al., 2007; Nicholson et al., 2005; Poulsen et al., 2005; Rushworth et al., 2002). This component has been predominantly associated with the contingent negative variation (CNV) and given a general anticipatory attention and/or task preparation function (Brunia and van Boxtel, 2001). Interestingly, this component was not been observed when covert responses were required (Astle et al., 2008a, 2008b) and it has been found to be reduced or absent in univalent conditions compared to bivalent conditions and when the tasks are mapped onto separate response keys compared to when they are mapped onto the same response keys (Astle et al., 2008a, 2008b; Mueller et al., 2007, respectively). These findings support the view that this negativity may reflect inhibition of the competing S-R mapping. However, the modulation of this component by trial type (i.e., switch or repeat) is not consistent across studies. Some studies report larger negativities on switch trials (Astle et al., 2006, 2008; Mueller et al., 2007; Poulsen et al., 2005), while others report larger frontal negativities on repeat trials (Goffaux et al., 2006; Hsieh and Cheng, 2006; Nicholson et al., 2005; Rushworth et al., 2002). Therefore, its precise functional role is still debated.

A less consistently observed ERP component linked to switch trials is a positivity emerging over frontal sites, at around 150–200 ms after cue onset (P2; Astle et al., 2008a, 2008b; Capizzi et al., 2015; Finke et al., 2012; Lavric et al., 2008; Periáñez and Barceló, 2009). Since this component has an early latency and reaches higher amplitude in switch compared to repeat trials, it has been theorized to reflect cue change detection, i.e. rapid context updating processes (De Baene and Brass, 2014). Interestingly, the P2 amplitude was found to be more pronounced for informative switch cues compared to uninformative switch and repeat cues (Finke et al., 2012), suggesting that this component is not a mere index of cue sensory changes but an index of goal-directed context updating, which induces endogenous preparatory processes.