



## Neural correlates of reconfiguration failure reveal the time course of task-set reconfiguration



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### ABSTRACT

The ability to actively prepare for new tasks is crucial for achieving goal-directed behavior. The task-switching paradigm is frequently used to investigate this task-set reconfiguration. In the present study, we adopted a novel approach to identify a neural signature of reconfiguration in event-related potentials. Our method was to isolate neural correlates of reconfiguration failure and to use these correlates to reveal the time course of reconfiguration in task switches and task repetitions. We employed a task-switching paradigm in which two types of errors could be distinguished: task errors (the incorrect task was applied) and response errors (an incorrect response for the correct task was provided). Because differential activity between both error types distinguishes successful and failed reconfiguration, this activity could be used as a neural signature of the reconfiguration process. We found that, whereas reconfiguration takes place on task repetitions and task switches, it occurred earlier in the former than in the latter. Single-trial analysis revealed that the same activity predicted the amplitude of error-related brain activity, providing further support that this preparatory activity reflects reconfiguration. Our results implicate that reconfiguration is not switch-specific but that task switches and task repetitions differ with respect to the time course of reconfiguration. Furthermore, this study demonstrates that considering neural correlates of failure is a promising approach to link cognitive mechanisms to specific neural processes.

### 1. Introduction

Theories on cognitive control assume that goal-directed behavior is achieved by reconfiguring the task set, that is, by adjusting perceptual, cognitive and motor processes according to current goals and intentions (Kiesel et al., 2010). Mechanisms underlying task-set reconfiguration have frequently been investigated using the cued task switching paradigm. In this paradigm, participants have to perform two tasks in random order and a cue indicates the relevant task on each trial. Response times (RTs) and error rates are typically higher on task switches than on task repetitions. This so-called switch cost has initially been viewed as a marker of task-set reconfiguration (Meiran, 1996). Despite 20 years of research, however, the role of task-set reconfiguration in cued task switching and the interpretation of switch costs is still under debate. Whereas some theories assume that reconfiguration occurs on switch trials only (Monsell and Mizon, 2006), other accounts proposed that reconfiguration occurs on all trials but is more efficient on task repetitions (Altmann and Gray, 2008). And finally, some even denied that reconfiguration is involved at all in cued task switching (Schneider and Logan, 2005).

In recent years, numerous studies considered preparatory activity in event-related potentials (ERP) to investigate task-set reconfiguration in cued task switching. These studies have identified several ERP components related to reconfiguration processes but these components vary strongly across paradigms and tasks (Karayanidis et al., 2010). A rather consistently found component is the posterior positivity (Astle et al., 2008; Goffaux et al., 2006; Jost et al., 2008; Karayanidis et al., 2009, 2003, 2011; Kieffaber and Hetrick, 2005; Lavric et al., 2008; Miniussi et al., 2005; Nicholson et al., 2006a, b; Poljac and Yeung, 2014; Ruge et al., 2006; Steinhauser et al., 2009; Travers and West, 2008; Wang et al., 2015; West et al., 2010; Wylie et al., 2009), which has a P300-like parietal spatial distribution, and which starts between 300 and 500 ms after cue onset and lasts for several hundreds of milliseconds. The posterior positivity is not only larger on task switches than on task repetitions, it is also larger in blocks with task switching than in blocks with a constant task (Goffaux et al., 2006; Jost et al., 2008; Ruge et al., 2006; Wylie et al., 2009). Moreover, the amplitude of the posterior positivity predicts RT (Karayanidis et al., 2011; Lavric et al., 2008; Wang et al., 2015). These findings have been taken as evidence that the posterior positivity reflects task-set reconfiguration (Karayanidis et al.,

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2010).

Despite this large body of evidence, one could ask whether these methods are specific enough to discriminate between neural correlates of reconfiguration and other preparatory activity. First, the mentioned results could reflect preparatory activity related to the optimization of the already established task set. For instance, task switches are assumed to be associated with a more conservative response criterion (Schmitz and Voss, 2012). Switch-specific neural activity could thus reflect an update of the response criterion whereas activity reflecting task-set reconfiguration could be similar for task switches and task repetitions. Second, it has recently been proposed that differences between task switches and task repetitions in fMRI data are due to neural adaptation (De Baene et al., 2011). Similarly, the increased posterior positivity on task switches could actually reflect adapted, and hence, reduced activity on task repetitions rather than task-set reconfiguration. These considerations demonstrate that a more specific test is needed before we can definitely conclude that the posterior positivity reflects task-set reconfiguration. More specifically, we have to show that the posterior positivity is directly related to the successful establishment of a task set.

In the present study, we adopted a novel approach to identify preparatory activity related to task-set reconfiguration. Our method was to isolate a neural correlate of reconfiguration failure and to use this correlate as a marker of reconfiguration. We employed a task-switching paradigm in which two types of errors could be distinguished (Steinhauser and Gade, 2015): *task errors* (in which the response associated with the alternative task was executed) and *response errors* (in which a response associated with none of the tasks was executed). Because reconfiguration failure is more likely to be involved in task errors than in response errors, the difference in preparatory activity between both error types reflects the difference between successful and failed reconfiguration. This difference can therefore be used as a neural marker of the reconfiguration process itself. By considering this neural marker, we asked whether task switches and task repetitions differ with respect to the existence and the time course of reconfiguration.

In a further step, we used single-trial analysis to investigate whether this neural marker of reconfiguration predicts the Ne/ERN (error-related negativity; Falkenstein et al., 1990; Gehring et al., 1993), a negative deflection following errors that reflects an early correlate of error processing (Holroyd and Coles, 2002; Yeung et al., 2004). A successfully established task set is not only crucial for preventing errors, it is also an important precondition for detecting these errors. Current models of performance monitoring assume that detecting an error relies on the ability to determine the correct response (Holroyd et al., 2005; Steinhauser et al., 2008; Yeung et al., 2004). Therefore, a failure of task-set reconfiguration should substantially impair error detection. Evidence for this comes from recent studies demonstrating impaired conscious error detection for task errors relative to response errors (Steinhauser and Gade, 2015), and smaller Ne/ERN amplitudes for task switches than for task repetitions (Ikeda and Hasegawa, 2011). Accordingly, if task errors in the present study were due to a failure of reconfiguration, neural activity related to error detection should also be reduced in these errors. Such a correlation between preparatory activity and the Ne/ERN would further validate the link between this preparatory activity and (failed) reconfiguration.

## 2. Material and methods

### 2.1. Participants

Fourteen participants (11 female) between 19 and 25 years of age (mean 20.8) with normal or corrected-to-normal vision participated in three experimental sessions of about one hour each. Participants were paid 7 Euro per hour. The study was conducted in accordance with the Declaration of Helsinki and informed consent was acquired from all participants.

### 2.2. Task and procedure

#### 2.2.1. Tasks

We employed a paradigm that was previously used for distinguishing task errors and response errors (Steinhauser and Gade, 2015). Participants worked on two tasks - a character task and a picture task - in random order. Each trial started with a cue that indicated the relevant task (see Fig. 1A). After a cue-stimulus interval (CSI), a stimulus appeared that consisted of a character and a picture. Each task required to categorize one of the two stimulus elements by pressing one of three response keys, whereas the same three response keys were used for each of the tasks (see Fig. 1B). For the character task, the character in the stimulus had to be classified as 'letter', 'numeral', or 'symbol'. For the picture task, the picture in the stimulus had to be classified as 'animal', 'fruit' or 'vehicle'. Responses were given with the right hand by pressing the 'arrow left' key with the index finger for the categories 'letter' and 'animal', the 'arrow down' key with the middle finger for the categories 'numeral' and 'fruit', or the 'arrow right' key with the ring finger for the categories 'symbol' and 'vehicle'.

#### 2.2.2. Stimuli

Each stimulus consisted of a character and a picture presented horizontally arranged. The set of characters consisted of four letters (A, B, C, D), four numerals (1, 2, 3, 4), and four symbols (\$, %, &, ?), taken from the Arial font. The set of pictures consisted of four animals (bird, cat, dog, mouse), four fruits (apple, banana, cherry, pear), and four vehicles (aircraft, bike, car, sailboat), taken from the Snodgrass-Vanderwart Set of Standardized Pictures (Snodgrass and Vanderwart, 1980). Only characters and pictures were combined that were associated with different responses (i.e., incongruent stimuli). These combinations were realized in each possible order (left/right). Altogether, this resulted in 384 possible stimuli. The stimuli subtended a visual angle of about 5.6° width and 2.8° height at a viewing distance of 60 cm. A circle and a square, both 2.8° in diameter, were used as cues. Cues and stimuli were presented in white color on a black background. In half of the participants, the circle indicated the character task and the square indicated the picture task. In the other half, the cue-task mapping was reversed.

#### 2.2.3. Procedure

The exact timing of trials is provided in Fig. 1A. Each trial started with the presentation of the cue for 300 ms followed by a blank screen for 900 ms (resulting in a CSI of 1200 ms). Then, the stimulus appeared for 150 ms followed by another blank screen. A new trial started after a response-cue interval (RCI) of 1200 ms. If a second response (e.g., an error correction) occurred during the RCI, a new interval of 1200 ms was started. No feedback on the accuracy of the response was provided. The experiment consisted of one practice session and two test sessions. In each session, participants worked through eight blocks with 96 trials each. Within each block, the order of cues and stimuli was randomized. In the first four practice blocks, participants performed the tasks without time pressure while the task rules were depicted on a sheet of paper. In the remaining practice and test blocks, participants were instructed to respond as fast as possible. At the end of each block, participants were encouraged to respond more quickly when the error rate dropped below 15%.

### 2.3. Data acquisition

The electroencephalogram (EEG) was recorded during the test sessions using a BIOSEMI Active-Two system (BioSemi, Amsterdam, The Netherlands) with 64 Ag-AgCl electrodes from channels Fp1, AF7, AF3, F1, F3, F5, F7, FT7, FC5, FC3, FC1, C1, C3, C5, T7, TP7, CP5, CP3, CP1, P1, P3, P5, P7, P9, PO7, PO3, O1, Iz, Oz, POz, Pz, CPz, Fpz, Fp2, AF8, AF4, AFz, Fz, F2, F4, F6, F8, FT8, FC6, FC4, FC2, FCz, Cz, C2, C4, C6, T8, TP8, CP6, CP4, CP2, P2, P4, P6, P8, P10, PO8, PO4, O2 as well as

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