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Exploring the switching of the focus of attention within working memory: A combined event-related potential and behavioral study

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ABSTRACT

Working memory enables humans to maintain selected information for cognitive processes and ensures instant access to the memorized contents. Theories suggest that switching the focus of attention between items within working memory realizes the access. This is reflected in object-switching costs in response times when the item for the task processing is to be changed. Another correlate of attentional allocation in working memory is the P3a-component of the human event-related potential. The aim of this study was to demonstrate that switching of attention within working memory is a separable processing step. Participants completed a cued memory-updating task in which they were instructed to update one memory item at a time out of a memory list of four digits by applying a mathematical operation indicated by a target sign. The hypotheses predicted (1) prolonged updating times in switch (different item compared to previous trial) versus repetition trials (same item), (2) an influence of cues (valid/neutral) presented before the mathematical target on switching costs, and (3) that the P3a-component is more pronounced in the cue-target interval in the valid cue condition and more pronounced in the post-target interval in the neutral cue condition. A student's *t*-test verified the first hypothesis, repeated-measurement analyses of variance demonstrated that hypotheses 2 and 3 should be rejected. Results suggest that switching of attention within working memory could not be separated from further processing steps and retro-cue benefits are not due to a head start of retrieval as well as that switch costs represent internal processes.

1. Introduction

When it comes to the performance of complex cognition tasks the *human working memory* ensures control, regulation, and active maintenance of relevant information (Miyake and Shah, 2003). It cannot be considered as a single unit (Berti, 2010; Cowan, 1988; Postle, 2006) but consists of a set of controlled processes, including dynamic interactions of multiple brain regions (O'Reilly et al., 2003). In general, working memory plays an active part in information processing: key functions—beside keeping information in an accessible state—are the selection of relevant information from sensory input or cognitive systems and the control of attention through a central executive (Cowan, 2003). The controlled attention view of working memory (Cowan, 2003; Engle et al., 2003) postulates that humans access maintained contents by switching the *focus of attention* within working memory between representation chunks; they are linked together to a higher order region of direct access according to the hierarchical organization of working memory (Kessler and Meiran, 2008; Oberauer, 2002). For example, if someone spells a word, working memory keeps it in the region of direct access and shifts the focus of attention from letter to letter. The capacity of temporary stored information is limited so that the content can rapidly get accessed and changed (Oberauer, 2002).

In sum, controlled attention within working memory allows local flexibility in the focus of attention and global stability in the region of direct access (Kessler and Meiran, 2008). There is, however, a lack of clarity calling for further investigation concerning the initial stages of flexible attention switching between chunks within working memory. Following the assumption that one initial stage of access in working memory is the allocation of the focus of attention (see for instance Cowan, 2003; Oberauer, 2002), one can postulate that a required switch of attention within working memory is separable from other subsequent working memory processes.

1.1. P3a as ERP-component for switching

Internal attention switching is a top-down cognitive function (Gazzaley and Nobre, 2012) and accompanied with time costs and specific cortical activation: Garavan (1998) was the first among other

Abbreviations: ERP, event-related potential; ANOVA, analysis of variance

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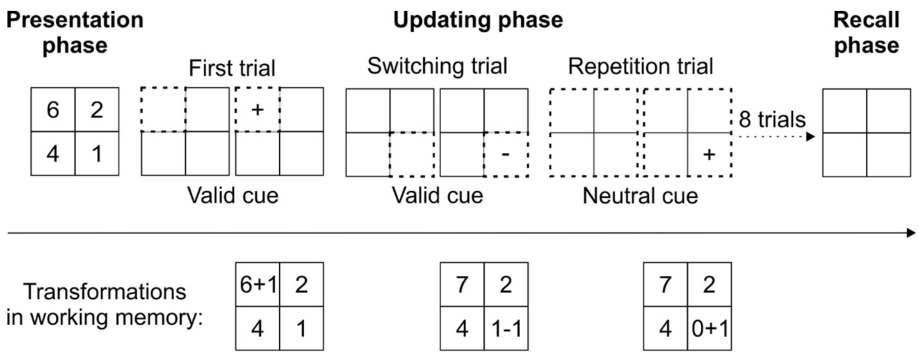

Fig. 1. Example of a block sequence from the memory updating task with 11 trials. Each block starts with the presentation phase in which participants are instructed to memorize four digits at their specific location. In the following updating phase, one of these items has to be changed in each trial according to the mathematical symbol by adding or subtracting the value of 1 from or to the relevant digit. The new generated number replaces the former memorized one; the other three digits stay the same. In switching trials, the position of the digit which has to be processed is different from the preceding trial; in repetition trials, the selected position of the digit does not change comparing to the former trial. Some trials contain small green squares (dashed lines) as cues displaying the upcoming position of the operation symbol 1 s in advance (valid cue condition); other trials do not give any information about the following symbol position by showing large green squares (neutral cue condition; dashed lines). The two conditions (valid cue/neutral cue) and trial types (switch/repetition) vary randomly from trial-to-trial with equal probability. After each block, subjects have to recall the final list of memory items.

researchers (e.g. McElree, 2001; Oberauer, 2002) who revealed costs in processing times when task-performance requires switching between different objects in working memory. This type of switching was termed *object switching* (see Garavan, 1998; Oberauer, 2002), which allows a differentiation from task switching (see Monsell, 2003). Furthermore, previous studies applying event-related brain potentials (ERPs) demonstrated that the P3-components (pronounced positive deflections in the ERP observable from 300 ms after stimulus onset at the midline electrodes) mirror context updating and memory modification (Donchin, 1981) as well as cognitive control of attention (Barcelo et al., 2006). Polich (2007) suggests that some subcomponents of the P3 may also reflect inhibition of task-irrelevant brain activities. Other studies, however, examined other components in contexts of inhibitory and monitoring processes on sensory input levels (Kuo et al., 2009) and no inhibition on the level of representations in working memory (Oberauer, 2003).

The so-called P3a component of the ERP allows a detailed analysis of mechanisms of attentional control. The P3 consists of two subcomponents: a frontal subcomponent, the P3a, which has its maximal amplitude at frontal and central midline electrodes (i.e., Fz and Cz), and a parietal subcomponent, the classical P300 or P3b, peaking maximally at Pz (Polich, 2007). Classically, the P3a is assumed to reflect stimulus-driven and automatic, exogenous attention to novel and unexpected stimuli (Polich, 2007). Recently, this view was enhanced and extended by several studies proving that the P3a also relates to top-down control of attention: Holig and Berti (2010) demonstrated that the P3a is triggered by task-irrelevant as well as by task-relevant unexpected changes in the sensory stimulation. Importantly, the P3a was enhanced when a task-switch was required, suggesting that the P3a mirrors goal-oriented, top-down attention as well. A study by Barcelo et al. (2006) broadens this view showing that the P3a embodies changes in the mental set as "neural correlates of the internal reconfiguration or updating of goals" (Barcelo et al., 2006, p. 13). This relates to endogenous attention on internal processes as it is proposed in Cowan (2003), such as orienting of attention in working memory (Leszczynski et al., 2012, using the term visual short term memory). Consequently, Berti (2008, 2016) demonstrates that the P3a-component mirrors switching of attention between objects within working memory.

1.2. Retrieval processes in memory-updating tasks

Memory-updating tasks are well-established procedures to initiate and monitor these processes and components (Ecker et al., 2010; Oberauer, 2002). In the first of three phases, participants are instructed to memorize numbers presented on different locations on a screen. Concerning the following updating phase, participants must conduct a specific mathematical operation in each trial on one of the memorized numbers and to replace the former number with the new one. After a few trials, participants recall the numbers. It was proposed that this task is accompanied by a sequence of three independent processes (Ecker et al., 2010): the retrieval of the relevant item, the transformation by applying the mathematical operation, and the substitution of the former maintained item for the new generated number. Retrieval has been identified as a crucial factor in different working memory tasks because the accuracy of retrieval is strongly related to general working memory capacity; switching the focus of attention instantly entails the retrieval of an item due to activation of maintained information (Ecker et al., 2010). In this study, we implement two different trial types (see Fig. 1): the relevant item, which has to be processed, either stays the same (*repetition trial*) or is different from the preceding one (*switching trial*).

In these types of tasks, participants are presented with simple mathematical operations on different locations on the screen (i.e., in a four-quadrant matrix; see Fig. 1), in which the locations designate the relevant memory item. The presentation of the mathematical sign serves two purposes in this setting because it contains the information about the required mathematical operation as well as about which memory item is relevant. In other words, the mathematical operation sign also serves as a cue for the memory item so that the execution of the cognitive operations overlaps with the retrieval of the relevant item in working memory (esp. in switching trials). To unravel the mechanisms of retrieval, one must be able separate the cueing of the relevant memory item from cognitive task processing.

1.3. The paradigm of the present task

The present study focuses on switching of the focus of attention within working memory. As summarized above, this is considered as a central mechanism underlying working memory function (Cowan, 2003; Ecker et al., 2010; Engle et al., 2003; Oberauer, 2002). To support this theoretical assumption, we want to demonstrate that the allocation of attention as a retrieval process is separable from other following information processing steps such as transformation. In previous studies, the assignment of early measured components to specific processes is difficult because of a possible overlapping of processes resulting in P3a components of high amplitude (Berti, 2016). Because the P3a is a correlate of attention switching in general (see for instance, Polich, 2007), as well as within working memory (Berti, 2008, 2016), we aim at measuring the P3a component within different types of object switching trials. Therefore, we conduct an experiment containing two cue conditions (see Fig. 1): in the *valid cue condition,* participants receive a cue about which item has to be processed before exposure to the mathematical operation target. In the *neutral cue condition,* participants receive a cue without relevant information so that the activation of an item in the focus of attention in working memory happens after mathematic target presentation. Half of the trials are switching and the other half are repetition trials in both conditions. Souza and Oberauer (2016) have already reported so called *retro-cue benefits* concerning reaction times and accuracy arguing benefits may be connected inter