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

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Running head: P3a and attention switching within working memory

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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 chunks within working memory realizes the access. This is reflected in object switching costs in response times when the item for the task processing should 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 is to demonstrate that switching of attention within working memory is a separable processing step. We apply a cued memory-updating task in which we instruct participants to update a memory list of four digits: In each trial, the presentation of a target symbol indicates the required mathematical operation and specifies the relevant memory item for updating. Prior to the instruction target, either neutral cues signalize that a mathematical sign will be presented next generally or valid cues announce in advance which memory item will be relevant. In the neutral cue condition, we expect prolonged updating times in switch compared to repeat trials. Additionally, we hypothesize that we observe an interaction effect on updating times between the cue-condition and the trial type (switch vs. repetition trials). We predict 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 and repeated-measurement analyses of variance will serve for hypothesis testing.

Keywords: Working memory; Focus of attention; Object switching; Memory updating; P3a; Cueing

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

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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 & 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, Braver, & Cohen, 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, Kane, & Tuholski, 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 & 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 & 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 & Nobre, 2012) and accompanied with time costs and specific cortical activation: Garavan (1998) was the first among other 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, Escera, Corral, & Perianez, 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, Rao, Lepsien, & Nobre, 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’s model (2003), such as orienting of attention in working memory (Leszczynski, Myers, Akyurek, & Schubö, 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, Lewandowsky, Oberauer, & Chee, 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 Figure 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 Figure 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 Figure 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 alia with a head start of retrieval.

The logic of this paradigm is based on Posner's cueing paradigm (Posner, 1980) but this time cues serve for the control of internal *(endogenous)* not perceptual (*exogenous*) attention (Doricchi, Macci, Silvetti, & Macaluso, 2010; Tamber-Rosenau, Esterman, Chiu, & Yantis, 2011). Both, endogenous and exogenous attention types, are part of a continuous general attention mechanism represented by the P3a component and it is impossible to extract one of them entirely. Nevertheless, drawing logical conclusions swings the balance of the core trigger mechanism eliciting the P3a component in favor of internal processes (in working memory) concerning this specific task. The P3a as an *exogenous* stimulus-driven orienting of attention is a function of infrequent and unexpected stimuli (Barcelo et al., 2006) which is not the case in the present study design (all stimuli appear with equal probability). Additionally, the task offers no novelty events out of some switching trials that are not of the same relevance for automatically *exogenous* attention because of habituation and experience with the task (Friedman, Cycowicz, & Gaeta, 2001); this contrasts *internal* switches where participants need to activate new contents and change their mental set every switching trial. When measuring many experimental blocks, it should be insignificant for the elicitation of the P3a component if the focus of *exogenous* attention shifts to a new or the former item in a following trial opposed to the *endogenous* activation and switching processes in working memory.

1.4 Hypotheses

The present study replicates and extends the working memory updating task reported in Berti (2016). Taken together, we predict the following pattern of results regarding the behavioral and physiological parameters: firstly, in the neutral cue condition, we reproduce the logic of the *processing condition* of the Berti (2016) study, resembling the working memory updating task (see Berti, 2008; Oberauer, 2002). Therefore, we expect prolonged updating times in object-switch trials compared to object-repetition trials in the neutral cue condition as a manipulation check (*hypothesis 1*).

Secondly, since object switching will presumably be executed in advance in the valid cue condition (i.e. in the cue-target interval), we expect participants to profit more from cueing events when a switch is required in comparison to trials where the same item is repeated concerning the updating times (*hypothesis 2*).

Lastly, in accordance with the expected pattern of results in the behavioral data, we hypothesize 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 (*hypothesis 3*).

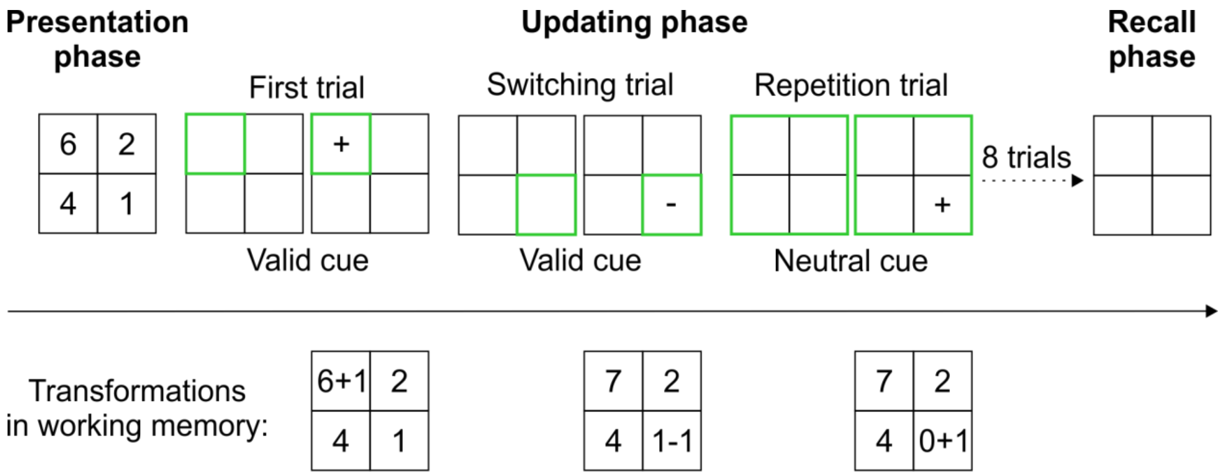

Figure 1 Example of a block sequence from the memory updating task with 11 trials. Each block starts with the presentation phase in which participants are instructed to memorize four digits at their specific location. In the following updating phase, one of these items has to be changed in each trial 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 as cues displaying the upcoming position of the operation symbol one second 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). 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.

2. Methods

2.1 Participants

The study will include a sample of university students with an age span between 18 and 40 years. They ought to be orthotic (or use corrective devices) and report a normal neurological health status. Therefore, the participants will complete a short survey about potential neurological, psychiatric, and other health issues (including the PHQ-4; Kroenke, Spitzer, Williams, & Löwe, 2009). Participants reporting neurological (i.e., a concussion within the last 12 months), psychiatric (e.g., attention disorders, depression, or general anxiety disorder), or other current health problems will be excluded from the study. Psychology students will receive course credits for their experiment participation. Before conducting the experiment, subjects shall declare written consent for their participation and we will inform them about the objective of the study in accord with the Declaration of Helsinki. The local ethics committee of the Institute for Psychology approved the procedure. Furthermore, participants will practice fixating the midpoint of the screen in training trials to exclude participants with difficulties in reducing the number of blinks and eye-movements (when presumably less than half of the trials could be analyzed).

We estimate the adequate sample size for this study (for an evaluation of the importance of sample size calculations, see Larson & Carbine, 2017) by applying a power analysis on the statistical method where we use the lowest estimated effect size of all above-mentioned hypotheses as reference. According to Berti (2016), analysis of variance (ANOVA) interaction effects on EEG data in this type of task have the lowest effect sizes (η_p^2 = .27 in an early P3 time window for a 2×2 ANOVA) compared to behavioral data analysis (η_p^2 = .30). Cohen (1977) considers these effect sizes as high which leads us to assume an estimate between low and medium of f = 0.18. Power analysis using G-Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) for a two-factor repeated measurement ANOVA (α = .05; $1 - \beta$ = .80) with a moderate estimate of correlation among measures (r = .5) and an adjusted f-value of 0.25 (necessary for G-Power for two within-factors, calculated according to Rasch, Friese, & Hofmann, 2014) reveals that at least datasets of 34 subjects (fulfilling the inclusion criteria, see section “Initial and behavioral analysis”) are needed to measure significant effects.

2.2 General procedure

The experiment is divided into two sessions: a *practice session* and a subsequent *experimental session*, conducted on two different days within one week. The practice session includes general information about the study, the declaration of consent, 10 training blocks of a memory updating task without measuring EEG, a reading span task for measuring working memory capacity (see Turner & Engle, 1989), and a short questionnaire, which covers the topics age, gender, neurological disorders, psychiatric diagnoses, visual acuity, and right- or left-handedness. The experimenter will be instructed to control the participants’ eye-movements via an on-screen webcam during the task training blocks and to give direct feedback about the eye-movements. We expect the first session to last about 60 minutes.

The experimental session comprises 32 blocks (plus two training blocks) of a memory updating task in two different conditions with EEG-measurement and a debriefing with questions about task solving strategies, general problems, and concentration problems. We schedule about two hours for this second session, mainly because of time-intensive EEG preparations. Subjects can decide individually when they want to take a break but will be encouraged to take a rest after a maximum of five blocks.

For completing the memory-updating task, participants will take a seat 70 cm in front of the screen in an electronically shielded and sound attenuated cabin. Participants will receive instructions about the updating task in a two-step procedure: in the *training session*, the task will be explained and demonstrated orally and on screen (pointing out accurate and fast task execution) with participants performing two short practice blocks accompanied by the invitation to ask questions when necessary. Before starting the other training blocks, the participants will be instructed to reduce eye movements while performing the task. In the *experimental session*, we will remind the subjects of the task procedure. In addition, the experimenter will again highlight the importance of accurate and fast task performance as well as of minimizing movements (including of the eyes) during the EEG recording. After each block, feedback will be provided informing about recall correctness to motivate participants and prohibit task misunderstanding.

2.3 Task procedure

Participants complete a working memory updating task in two different conditions varying trial-by-trial. Each block is separated in three phases: a presentation, an updating, and a recall phase (see Figure 1).

During the *presentation phase,* four squares appear simultaneously surrounding the midpoint of the screen, each filled with one digit between 1 and 9 (no numeric value selected more than once). The participants are instructed to memorize these digits at their specific location so that the squares can be used as a cue in the following updating phase. The digits disappear after this phase either when the subjects finish it by pressing a button or automatically after 10 s. The squares remain continuously on the screen during presentation and updating phase.

In the *updating phase*, one of the square frames or all the outer lines of the four squares together are colored in green at the beginning of each trial depending on the trial condition. After 1000 ms (see time course in Souza & Oberauer, 2016) either a plus or minus sign is presented within one of the four squares. The plus sign indicates to the participants the addition of the value one to the relevant memory item while a minus sign indicates the subtraction of the value one from the item.

Participants are instructed to keep the three other items in memory and to replace the former memorized item with the updated one. The instructions point out that the updating should be performed as fast and accurately as possible and that the participants should press a button (space bar) as quickly as possible after completing the updating, as the reaction time serves as a measure of task performance. The time for memory updating is restricted to 10 s. The next updating trial starts 500 ms after the participants' button press. Each block contains 11 trials including an initial first trial, which does not qualify for a classification of trial type depending on the preceding trial. Trials, in which a new item has to be activated, are called *switching trials*; trials requiring the updating of the same item as in the preceding trial are called *repetition trials*. The inter-trial interval lasts 1000 ms.

At the end of each block, participants recall aloud the final four memory digits (the *recall phase*). Participants receive feedback concerning the accuracy of their final answer.

The two conditions differ between the cue condition (Figure 1). In the *valid cue condition,* only the relevant square frame is colored in green to signalize to the participants the location of the upcoming mathematical operation symbol. The location is associated with the item in working memory selected for processing. In contrast, green colored outer lines of all four squares characterize the *neutral cue condition* without offering a hint about the location of the following symbol. Additionally, both cueing conditions include both trial types (switching and repetition). Conditions (valid cue/neutral cue) and task types (switching/repetition) vary trial-by-trial in randomized order. Each block has been randomized offline before the experiment with the following restrictions: (1) in the initial memory list, no digit is repeated. (2) Each intermediate, as well as the final results of the operations, consist of values between 0 and 9. (3) The probability for the two mathematical operations is equal. (4) The probability for the two trial types is equal with the exception that in the trial sequence no trial type recurs more than three times. Altogether, these constraints resulted in 82 repetition trials with neutral cues, 85 repetition trials with valid cues, 78 switching trials with neutral cues, and 75 switching trials with valid cues. Participants are informed that the digits as end and intermediate results can only reach values between 0 and 9. The randomized parameters (condition, trial type and values) are fixed on a list so that every participant will perform the same experiment process.

We measured the colorimetric values of the stimuli with a spectroradiometer (specbos 1201; Jeti, Jena, Germany) and report the results in terms of the CIE 1931 xyY system (ISO 11664-1:2008(E), 2006). Green frame squares represent the cue-stimuli (Y = 11.32 cd/m², x = .261, y = .516), the other stimuli are presented in black (Y = 0.92 cd/m², x = .324, y = .313) against a medium grey background (Y = 53.01 cd/m², x = .327, y = .336). All squares share the same visual angle of 3.0° and all digits the same visual angle of 0.7°.

2.4 Initial analysis and reliability estimates

The first part of data analysis examines the subjects' performance within the memory task. We will only analyze blocks with correct recall because we aim at measuring successful switching within working memory. The first trial of each block will be excluded because the assignment of trials to the switching or repetition type depends on the preceding trial. Data sets of participants with EEG epochs below a threshold (e.g. due to artifacts or too low performance) will be excluded from data analysis as well. Precisely, we will identify the acceptable trial count minimum per subject after data collection in the reliability analysis (see section below). Prospectively, fewer than 40 epochs in at least one condition or trial type will not provide a sufficient signal-to-noise ratio in this kind of task (see Berti, 2016). Information gathered from debriefing after the experiment cannot lead to exclusion and will only serve for interpreting the results later.

We will report the ERP score reliability using the ERA-Toolbox (Clayson & Miller, 2017a) based on generalizability theory with the Φ-coefficient (value is comparable to the internal consistency coefficient r) as dependability estimate. The threshold for an acceptable reliability of EEG studies is commonly above $\Phi = .70$ (Clayson & Miller, 2017b). This is in line with a previous study on P300 component including other task types (Hall et al., 2006); some other studies, however, estimated reliability coefficients between $r = .60$ and .70 for measurements on P3/P3a components (Cassidy, Robertson, & O'Connell, 2012; Segalowitz & Barnes, 1993; Walhovd & Fjell, 2002). Therefore, we will define $\Phi = .65$ as the minimum acceptable reliability and adjust the trial count minimum to the reliability estimation.

2.5 Behavioral analysis

The time interval between presentation of the mathematical operation target (plus or minus sign) and the point of time when the subject presses the button after completing the update task represents the *updating time* as behavioral measurement. It is limited to a maximum of 10 sec and updating times shorter than 300 ms will be excluded from analysis. It is impossible to conduct an adequate processing in such a short period (updating time means > 1400 ms in Berti, 2016) and may be due to unintentional button press. Means of updating times will be computed separately for *conditions* (cue/neutral-cue) and *trial types* (switch/repetition).

2.6 Analysis of EEG-recordings

The electroencephalogram (EEG) will record participants' cortical brain activity during task performance using a BrainAmp DC (Brain Products, Gilching, Germany) in the electronically shielded and sound attenuated cabin from 35 scalp sites (Fp1, Fp2, F3, F4, F7, F8, F9, F10, Fz, FC5, FC6, C3, C4, CP1, CP2, CP5, CP6, P3, P4, P7, P8, Pz, TP9, TP10, T7, T8, PO3, PO4, PO7, PO8, PO9, PO10, O1, O2, Oz) with cap-mounted Ag/AgCl-electrodes (Easy-Cap, FMS, Munich, Germany) of the enhanced 10–20 system (Towle et al., 1993). Abrasion prepares the skin of the participants for better recordings. The impedance will be kept below 10 kΩ and the experimenter is going to measure electrode impedance at the beginning and at the end of each experimental session. The reference electrode will be placed at AFz and the ground electrode at FCz. Additionally, the horizontal (electrodes besides the eyes) and vertical (electrodes above and below the right eye) electrooculography (EOG) will control for eye-movements from four electrodes. We will sample all signals at 500 Hz with an online DC-70 Hz low pass filter. The EEG will be band-pass filtered offline with an 2nd order IIR Butterworth 0.01-30 Hz filter (roll-off 24 dB/octave, 3 dB half-power) on continuous data. The recorded time window covers the interval between -200 and 600 ms relative to the onset of the stimulus of interest. The 200 ms pre-stimulus interval serves as a baseline for correction.

We will only include trials of blocks with correct recall of the final memory list and without artifacts for averaging. Artifacts can originate from recordings, e.g. amplifier saturation, line noise or bad electrodes, and from non-cerebral participant artifacts such as blinks, eye-movements, muscle activity, and skin potentials. The authors apply a two-step procedure for artifact detection: in the first step, we will spot trials with EOG activity greater than 75 µV within a 200 ms moving time window and reject them due to blinks and eye movements. In the second step, we will eliminate all other types of artifacts by excluding all trials containing excessive EEG activity (i.e., whenever the peak-to-peak amplitude exceeds 200 µV within a 1000 ms moving window at one or more of the 35 channels). We will compare the data before and after data rejection concerning the amount of trials and updating times to detect possible systematic differences between experimental conditions resulting from data rejection.

Regarding effects on the P3a (*hypothesis 3*), variations of the P3a amplitude should be confined to the Fz electrode because the P3a is defined as the frontal P3-subcomponent. The P3a is expected to be maximally at fronto-central electrodes and diminishes at more posterior recordings sites. Therefore, we will compute the mean amplitude (defined as the area under the curve) within the respective time window at each of the midline electrodes Fz, Cz, and Pz separately for the two conditions and the two stimulus types across all participants to evaluate the spatial distribution of the P3a further by depicting scalp distributions of the ERP in the respective time window. With regard to the previous study (Berti, 2016), the authors expect the switching-related P3a at Fz in the time window to be between 230 and 330 ms after stimulus presentation.

2.7 Statistical analysis and hypothesis testing

To test whether updating times in switching trials are prolonged compared to repetition trials (*hypothesis 1*), we will conduct a Student's *t*-test for paired samples and report Cohen's *d* (Cohen, 1977) to evaluate the corresponding effect size. We assume at least a medium effect size of Cohen's $d > 0.5$ (calculated from the original data in Berti, 2016). In contrast, if no significant difference between switching and repetition trials in the neutral cue condition exists in the data, the results of the study cannot be interpreted regarding the present research question.

We argue that cueing events reduce updating times more in switching than in repetition trials (*hypothesis 2*) and, therefore, hypothesize an interaction effect between the factors *condition* and *trial type* in a repeated-measurement ANOVA. We will use partial eta-squared (η_p^2) and the Pearson correlation coefficient for a measure of effect size as well as the Mauchly test to identify violations of sphericity and, if necessary, implement the Greenhouse-Geisser adjustment (Greenhouse & Geisser, 1959) for correction. As hypothesis 2 represents a central assumption, we expect at least a medium effect size (η_p^2 = .06) for interpretable results. If we observe a null result, the cueing paradigm failed to work or participants cannot access chunks in working memory in advance by switching and hypothesis 3 will be obsolete. If the null result can be interpreted to the absence of cueing paradigm effects, the general main effect of the factor *condition* in the same ANOVA should neither be significant.

Following *hypothesis 3*, 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. On a statistical level, we predict an interaction effect in the repeated-measurement ANOVA on ERP data between the *condition* factor (valid cue/neutral cue) and the *interval* factor (cue-target/post-target) on the P3a positive mean amplitude difference waves (meeting the problem of multiple explicit comparisons, see Luck & Gaspelin, 2017) between switching and repetition trials in the relevant time window (see section "Analysis of EEG-recordings"). We will add the factor *electrode* (Fz/Cz/Pz) to the ANOVA to evaluate the spatial distribution of the component. We will report partial eta-squared (η_p^2) and the Pearson correlation coefficient as a measure of effect size, the Greenhouse-Geisser correction factor epsilon (i.e., whenever the degrees of freedom are greater than one), corrected degrees of freedom, and the corrected *p*-values. As proposed in the power analysis, only effect sizes between low and medium or higher (f > .18) will be informative. A null result indicates that either endogenous switching within working memory does not exist or that the experimental paradigm does not work in the expected way. We are going to conduct all behavioral analyses in SPSS (v23) and all EEG-analysis in ERPLAB (Lopez-Calderon & Luck, 2014) with $\alpha = .05$.

2.8 Additional measure

Beside the above-mentioned exclusion criteria, we implement working memory capacity (WMC) as a control of sample homogeneity. The individual WMC will be determined by means of the commonly used Reading Span Task (Turner & Engle, 1989) in a computerized version (Conway et al., 2005). In this task, participants are instructed to memorize a series of letters, which are presented one by one. Between two letters, participants need to decide if a displayed sentence makes sense or not. Finally, subjects type the memorized letters into the computer. The task consists of 3 training trials and 15 test trials. The number of letters in the test phase varies between 3 and 7 (2 in the training phase). The sum of all perfectly recalled sets represents the measure of the individual WMC. The individual WMC will be used for an exploratory analysis of WMC on correlational basis to unravel possible inter-individual differences in updating times and ERP-data.

2.9 Timeline

The experiment is ready to start and we are currently acquiring participants. We are going to conduct the experiment from May to June if pre-registration review is successful. The following weeks are scheduled for data analysis and writing the manuscript. Resubmission of the whole paper is expected to be no later than September.

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