Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER

Cognitive Brain Research xx (2005) xxx – xxx

COGNITIVE BRAIN RESEARCH

www.elsevier.com/locate/cogbrainres

Research report

The control of memory retrieval: Insights from event-related potentials

Markus Werkle-Bergner[a], Axel Mecklinger[a,*], Jutta Kray[b], Patric Meyer[a,c], Emrah Düzel[c]

[a]Experimental Neuropsychology Unit, Department of Psychology, Saarland University, P.O. Box 15 11 50, D-66041 Saarbrücken, Germany
[b]Developmental Psychology Unit, Saarland University, Saarbrücken, Germany
[c]Department of Neurology II, Otto-von-Guericke-University, Magdeburg, Germany

Accepted 14 March 2005

Abstract

Effective performance on episodic retrieval tasks requires the ability to flexibly adapt to changing retrieval demands ('retrieval orientations'; [M.D. Rugg, E.L. Wilding, Retrieval processing and episodic memory, Trends Cogn. Sci. 4 (2000) 108–115]). We used event-related potentials (ERP) to examine whether maintaining a specific retrieval orientation and changing flexibly between different retrieval demands are mediated by the same brain systems or whether dissociable aspects of cognitive control are involved. Sixteen participants performed two recognition memory tasks. One required mere old/new decisions for words (general task), whereas the other task required the additional retrieval of each word's study font typeface (specific task). Furthermore, the participants either were asked to perform the same task continuously or to switch between the two tasks after every second test word. ERPs elicited by correctly rejected new (unstudied) words were analyzed. This enabled us to examine the ERP correlates of having adapted and maintained a task instruction as required during continuous blocks and of flexibly changing between retrieval demands during alternating blocks. The ERP analysis revealed more positive-going ERP slow waves for alternating blocks than for continuous blocks over bilateral frontal recording sites. This effect started around 250 ms after the test word and extended for several hundred milliseconds. As it was present for both trials requiring a switch to the other task or to stay on the same task between 500 and 750 ms and no differences between the latter two trial types were obtained, it can be assumed that it is more related to general coordination requirements in alternating blocks, rather than to the actual control required to switch the retrieval task set. In addition, contrasting ERPs for the two task types revealed more positive-going ERP slow waves in the specific task than in the general task in the continuous blocks at lateral frontal recording sites between 250 and 700 ms. Together, these findings suggest that there are electrophysiologically dissociable aspects of cognitive control, namely for adapting and maintaining a retrieval orientation and for flexibly changing between varying retrieval demands.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: Cognitive control; Episodic memory; Event-related potentials; Retrieval orientation; Slow waves; Task switching

1. Introduction

It is widely accepted in neuroscientific research that episodic memory retrieval is controlled by strategic processes such as the initiation of specific search operations, the adaptation of response thresholds, and the enabling of post retrieval evaluation of memory products [19,29,38, 50,331]. Neuropsychological studies [53,54] as well as functional brain imaging studies [5,41,42,51,52] suggest that the prefrontal cortex (PFC) plays an important role in the control of episodic memory retrieval. For example, patients with lesions restricted to the frontal lobes show a distinct pattern of memory deficits in the sense that they are less impaired in simple item recognition than in free recall or in source memory tasks [10,14,15,18,53]. These latter tasks require the ability to initiate strategic search operations

* Corresponding author. Fax: +49 681 302 6516.
E-mail address: mecklinger@mx.uni-saarland.de (A. Mecklinger).

0926-6410/$ - see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.cogbrainres.2005.03.011

and to evaluate retrieved information in order to determine the memory's source or to make appropriate judgments about the temporal order of past events [20,33]. This view is consistent with neurocognitive models of cognitive control that assume that the PFC exerts control by means of bias signals modulating information processing in more posterior association areas [7,30,47]. Furthermore, a number of fMRI results demonstrated that different aspects of episodic memory control are mediated by distinct areas within the PFC. The site of PFC activation depends on the type of processes (e.g., encoding or retrieval), the type of material (e.g., verbal, visual, or spatial) and the specific demands of the memory task (for reviews, see [8,9,34,35,38]).

Recently, Ranganath and colleagues [39–41] conducted a series of ERP and fMRI experiments that showed the importance of the left lateral PFC for the control of memory retrieval. In a modified recognition memory paradigm, the authors varied the amount of perceptual information of line drawings to be retrieved from episodic memory. During the study phase, the participants had to encode pictures of different objects. The test phase included size-changed versions of previously studied objects as well as old unchanged and new unstudied objects. In a "general" memory test, participants had to indicate whether each presented object was "old" or "new" irrespective of size changes. In a "specific test," the participants should respond "old" only to previously studied objects of unchanged size and "new" to all other objects. Comparing ERPs elicited by correct rejections of new items in blocks with the general and specific memory test, Ranganath and Paller found more positive going waveforms for specific test items than for general ones at left anterior–frontal recording sites starting around 300 ms after onset of the test stimuli [39], A topographically similar, though less left lateralized effect was obtained in a follow up study [40]. A subsequent fMRI study using an analogous experimental design confirmed these findings in showing a region within the left anterior–frontal PFC that was significantly more active in specific test trials than in general test trials [41]. The authors concluded that the (left) anterior PFC is important in allocating processing resources to retrieve perceptual detailed information and to maintain this information in working memory in order to evaluate a possible match with the results of memory retrieval.

According to a recently proposed taxonomy of control processes relevant for memory retrieval, such processes can be conceived as 'retrieval orientation' [45,56,57]. The term 'retrieval orientation' refers to the adaptation of a tonically maintained retrieval strategy that modulates the cognitive processes that are set in train in response to a retrieval cue. The initiation of such task-specific retrieval strategies enables successful memory performance as they allow that different aspects of memory representations are accessed upon presentation of one and the same cue and that different amounts of information are retrieved in pursuit of accurate memory judgments [45]. One way to examine these strategic memory processes is to examine ERPs to correctly rejected new items and varying which aspect of the encoded information is relevant to the retrieval task. In this framework, ERPs to correct rejections are assumed to reflect the consequences of having adapted a particular retrieval orientation, unconfounded by neural activity related to successful retrieval. The abovementioned findings by Ranganath and Paller suggest that neural activity in the anterior PFC is relevant for the adaptation and maintenance of retrieval orientations in the service of successful memory task performance.

In addition, there is increasing evidence for an anterior–posterior distinction within the PFC with respect to cognitive control processes [5,6,24,51]. On the basis of these findings, it has been suggested that posterior–frontal regions are involved in context-specific control processes required for the selection of representations according to external, contextual signals. Conversely, anterior regions within the PFC contribute to episodic control processes required for the selection of representations according to the temporal episode in which stimuli occur. These latter processes generalize across informational domains and adjust and integrate processing according to higher-order task goals [23,24,51].

A number of studies in recent years have demonstrated that the ability to switch between different task instructions is associated with switch costs in terms of longer reaction times and higher error rates compared to trials that demand for the repeated execution of the same task [1,17,26,31,43,49]. Switch costs were assumed to reflect cognitive control processes that initiate and configure the cognitive system in order to adopt to a new 'task set' [31,44] or to inhibit persisting activation of the previous 'task set' [1,59]. In this sense, a 'task set' can be "assumed to specify the configuration of perceptual, attentional, mnemonic and motor processes critical for a particular task goal" [[27], p.5]. Longer reaction times and higher error rates that result from shifting from one task to the other one can be thought of as the costs to establish flexibility on the level of cognitive control [1,4,26,27]. The observation that switch costs are reduced but still present even when tasks alternate in a completely predictable manner and/or task-specifying information is given prior to the task stimulus suggests that a task set cannot be activated in advance, i.e., at some point in the previous trial, but rather is initiated by task onset [44] Therefore, it is reasonable to assume that some of the mechanisms, associated with the affordance to reconfigure the task set at hand, take place in the post-stimulus epoch [1]. Experimental paradigms that compare the repeated performance of the same task with alternated execution of different tasks are therefore useful in measuring the effects of the need to adapt to changing task demands [25].

Ranganath and colleagues found electrophysiological and hemodynamic correlates of the ability to maintain retrieval orientations in bilateral PFC regions. Still an open issue, however, is whether the same control processes are involved in maintaining a specified retrieval orientation, as in situations that require the continuous performance of the same memory task, and in flexibly changing between different retrieval demands, as in task situations requiring to shift from one memory task to the other. Thus, the main goal of the present study is to examine whether the maintenance of retrieval orientations and flexibly changing between different retrieval demands are dissociable aspects of cognitive control during memory retrieval. We analyzed ERPs elicited by correct rejections of new items in episodic memory tasks to examine the consequences of having adapted and maintained a retrieval orientation and of flexibly changing between different retrieval orientations unconfounded by neural activity related to successful retrieval.

A second aim of this study is to examine whether the abovementioned findings of Ranganath and colleagues generalize to other types of stimulus materials. As in these only line drawings of everyday objects were used, it remains to be specified whether the lateral PFC regions are solely involved in the control of retrieval of perceptual details conveyed by pictorial materials or also by other types of perceptual details such as graphological information of written words.

Similarily to the Ranganath and Paller study [39,40], we used two versions of a recognition memory paradigm. One task required old/new decisions for words (general task; [G]), whereas the other task required the additional retrieval of each word's study font typeface (specific task; [S]). In addition, we applied a modified version of the "alternating runs paradigm" [44] so that we were able to compare the performance in blocks of repeated execution of the same task (continuous blocks; ...GGGGG... or ...SSSSS...) with blocks that demand for alternation between the two retrieval tasks in a fixed order (alternating blocks; ...GGSSGGSS...). A similar approach was recently used in an ERP study by Wilding and Nobre [57]. In their study, however, continuous and alternating task performance was manipulated across experiments and by this a direct comparison of continuous and alternating task performance was not possible. In the present study, we set out to examine the control processes set in train by test stimuli during continuous and alternating task performance in a within subject design. We predicted that the latter condition, relative to the first condition, on the behavioral level is associated with general switch costs [25,26] due to the requirement to maintain two retrieval orientations active and to coordinate these with information about the actual position in the task sequence. In addition, we separately examined switch (the first of two trials of one task) and nonswitch trials (the second of two trials of one task) within the alternating blocks [44]. This will allow us to examine whether the ERP correlates of flexibly adapting to changing retrieval demands in alternating blocks can be attributed to the actual control required to switch task sets or whether it reflects the contribution of more sustained control and coordination process that establish flexibility required in both switch and nonswitch trials. As the main interest of the present study was on processes that control memory retrieval independent from processes initiated by retrieval success, consistent with prior studies [41,42,56–58], all ERP analyses of the block effects were restricted to correct rejection trials, for which contributions of processes related to successful retrieval are negligible [45].

Moreover, the comparison of the two retrieval tasks should reveal processes involved in the adaptation and maintenance of a particular retrieval orientation in response to a test cue. On the basis of the findings by Ranganath and Paller, we hypothesized that, if the lateral PFC is involved in the maintenance of perceptual details of a test cue for the match with information retrieved from memory for various types of perceptual details, the requirement to retrieve each words font type should elicit topographically and temporarily similar frontal slow wave activity as reported by Ranganath and Paller [39,40]. The present study aimed at assessing the generality of the Ranganath and Paller findings. Another issue is whether the task-specific effect of retrieval orientation is only obtained when the two tasks are performed in separate blocks, as in the Ranganath and Paller studies, or can also be observed when participants have to alternate frequently between two retrieval tasks. To control for any impact of different response probabilities on ERP waveforms, the probability of old and new responses was identical (50%) in both task and sequence conditions. Consistent with the Ranganath and Paller studies, ERP responses to hits and correct rejections were included in this analysis.

2. Materials and methods

2.1. Participants

Twenty volunteers (10 female) from Saarland University community, who ranged in age from 20 to 28 years, participated in our experiment. All subjects were right-handed with normal or corrected-to-normal vision. They gave written informed consent and were paid for participating. All participants reported to be in good health with no history of neurological illness. Four subjects had to be excluded from further analysis due to excessive eye movement artefacts, technically unsatisfactory recordings, or low levels of task performance. Therefore, the final statistical analysis was based on a sample of 16 subjects (8 female, mean age = 24 years of age).

2.2. Stimuli

Stimulus materials were 320 concrete German nouns collected from the CELEX data base [2]. The words consisted of two or three syllables with a normed frequency of 1–7 per million within the CELEX-corpus. The words were presented in two visual highly distinguishable font typefaces (times new roman bold (tmsrb.fon 200) and helvetica bold (helvb.fon 200)). Each word was surrounded by a rectangle or an ellipse that served as cues to indicate the type of retrieval task (general or specific) that should be performed in the next trial. The assignment of cue type to retrieval task was balanced across subjects. The combination of the 320 nouns with the two font types was random, securing that half of the words within each study or test block consisted of one of the two font types. All visual stimuli and instructions were presented in central vision on a 17″ computer monitor using white color and a black background. Stimulus presentation and behavioral data collection were controlled by the ERTS software (BeriSoft Cooperation; [3]).

2.3. Procedure

Before starting the experimental session, each participant passed two practice sessions. One practice session comprised two continuous test blocks (one for each task) and one alternating test block. Words used for practice sessions were not used during experimental sessions.

During the experiment, each participant performed eight study test blocks, whereby continuous blocks were intermixed with alternating ones. Half of the four continuous test blocks consisted of general task instructions, the other half comprised of specific task instructions. Whether a participant started with a continuous test block in general or in specific task instruction or with an alternating block was balanced across subjects.

Each study block included 30 words that were presented sequentially for 1700 ms on a computer screen. The font type was distributed equally and randomly across words. Each study word was preceded by a central fixation-cross that was presented for 300 ms. For each word, during study, the participants had to indicate by a button press whether the word contained the letter 'A' or not. This procedure was used to constrain the variability of possible mnemonic strategies during study and to ensure an appropriate encoding for each word. After each study block, participants were shown an instruction for 5000 ms that indicated whether the following test block consisted of a continuous-general or a continuous-specific or an alternating test phase. This instruction was followed by a warning screen that remained for 2000 ms and indicated the start of the test phase 3000 ms later. Altogether, there were 10 s between the end of the study block and the beginning of the subsequent test block.

Test blocks consisted of 40 words mixed up of old words with the same font type as during study ('old-same'), old words with a different font type ('old-different'), and unstudied new words ('new'). The order of old-same, old-different, and new words within one test block was random and the proportion of each word type was adapted to sequence and task conditions in a way to ensure that an 'old' response was required for half of the presented words. This results in a total of 80 trials in each of the four combinations of the task and block factors. To equate the proportion of old and new responses in both tasks, there was a total of 40 old-same, 40 old-different, and 80 new trials in the general task and of 80 old-same, 40 old-different, and 40 new trials in the specific task, across all eight test blocks. Each test trial started with the appearance of a cue (rectangle or ellipse) indicating the type of task to be performed. After 300 ms, a test item was shown for 1700 ms within the cue. This was followed by a blank screen for 500 ms. Altogether, one test trial comprised of 2500 ms. The experimental procedure is illustrated in Fig. 1.

2.4. EEG recordings

EEG was continuously recorded from 64 silver/silver-chloride electrodes (Ag/AgCl) embedded in an elastic cap [Electro Cap International]. Recording locations were based on the extended international 10–20 system [16] including left and right mastoids. Data were acquired using initially a left mastoid reference and were re-referenced off-line to linked mastoids. The signals were band-pass filtered online from DC to 70 Hz and digitized at a rate of 500 Hz. A 50 Hz notch-filter was used to remove line frequencies. To assess electrooccular activity, vertical and horizontal EOG (EOGV/EOGH) were recorded bipolarly from two electrode pairs placed on the infra- and supraorbital ridges of the right eye and on the outer canthi of the two eyes. Electrode impedances were kept below 5 kΩ.

2.5. Data analysis

2.5.1. Behavioral data

Data analysis was based on mean reaction times (RT) for all correct responses, i.e., hits and correct rejections. Hits were defined as correct responses to old-same and old-different items in the general task and as correct responses for old-same items in the specific task. Correct rejections were defined as correct responses to new item in the general task and as correct responses to new and old-different items in the specific task. Recognition accuracy was estimated by means of P_r values [48]. P_r values are measures that estimate the degree of true memory judgments by subtracting the false alarm rate, as an estimate of guessing, from the hit rate. Therefore, a P_r value of 1 indicates perfect recognition performance, whereas a P_r value of 0 indicates chance performance. For reasons of consistency with the reaction time analyses and in order to keep performance measures comparable across task, in the specific task, false alarms were collapsed across old-same and new items, whereas in the general task, only false alarms to new items were taken into account for the estimate of the P_r values. To get an additional estimate of the source of false alarms in the specific task (new items, vs. old-different items), an additional P_r value (P_r-new), taking into account solely false alarms to new items, was computed.

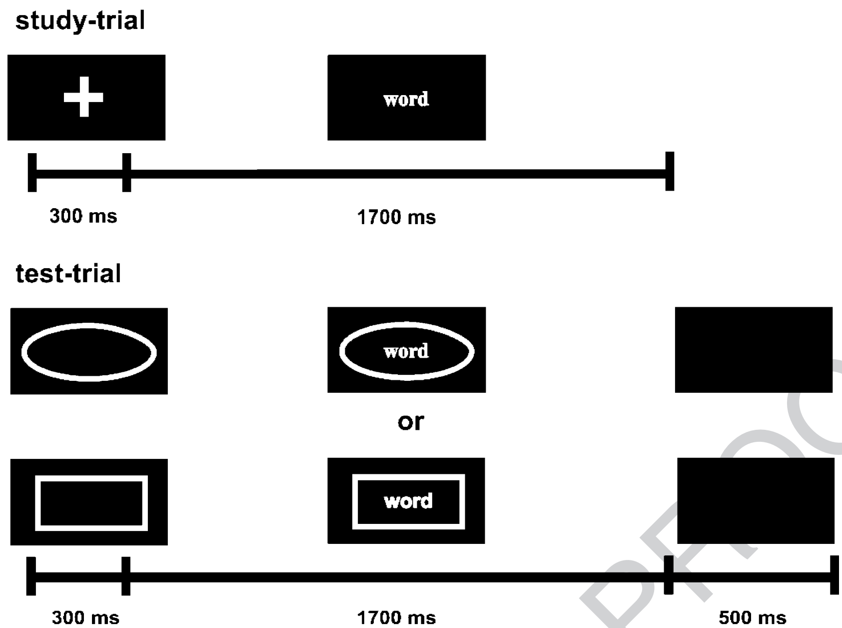

Fig. 1. Schematic illustration of timing and structure of study (top) and test trials (bottom) for all kinds of study and test blocks. During test trials, ellipse or rectangle indicated the type of retrieval task to be performed. To give an impression of the font types used in the experiment, the string 'word' within the ellipse is printed in tmsrb.fon, whereas the same string within the rectangle is printed in helvb.fon.

The modified version of the alternating-runs task-switching paradigm we used for this study furthermore allows for separation of two kinds of "switch costs": On the one hand, the contrast of performance measures between continuous and alternating blocks reveals "general switch costs" that were associated with the affordance to control the overall switch situation. On the other hand, a comparison of the performance for switch and nonswitch trials within alternating blocks reveals "specific switch costs," which index the costs for controlling the actual switch from one task to the other [4,25]. Therefore, we examined general and specific switch costs for all of the abovementioned performance measures.

2.6. ERP data

ERPs were computed separately for all electrodes, conditions, and subjects including a 300 ms baseline prior to stimulus presentation and a length of 1500 ms post-stimulus. Prior to averaging, excessive eye movements or muscle artefacts were rejected from further analysis using a pre-set criterion (threshold: standard deviation >40 μV; within a sliding window of 200 ms). Blink artefacts in the ERP signal were corrected using a modified linear regression technique [11] implemented in the EEProbe software package [A.N.T. Software BV] that was used for EEG analysis. The mean trial numbers used for ERP averaging were 22 (continuous trials) and 20 (alternating trials) in the general task and 20 and 18 for the respective trials in the specific task. For the analyses of switch and nonswitch trials, the mean trials numbers were 20 (switch) and 22 (nonswitch). All statistical analyses were conducted using a significance level of $\alpha = .05$. For all effects with two or more degrees of freedom in the numerator, we adjusted for violations of sphericity which are inherent in analyses of variances (ANOVAs) according to the formula by Greenhouse and Geisser [12] when appropriate.

3. Results

3.1. Behavioral results

3.1.1. Block comparison—general switch costs

Mean P_r values, mean RTs, and the percentage of correct rejections (% correct) for continuous and alternating blocks in both task conditions are summarized in Table 1. To examine recognition performance for both task types in alternating and continuous blocks, we conducted two-way repeated measures ANOVAs for mean P_r values and for % correct. The factors were block type (continuous, alternating) and task type (general, specific). For mean P_r values, we observed a main effect of block type ($F[1,15] = 7.80$, $P < .01$), reflecting the lower P_r values for alternating compared to continuous test blocks under both task instructions. Furthermore, a main effect of task type was obtained for P_r values ($F[1,15] = 61.39$; $P < .0001$), reflecting the fact that the specific task was more difficult than the general task, irrespective of block type. Similarly, the analysis of % correct for correct rejections revealed main effects of block type ($F[1,15] = 4.79$; $P < .04$) and task type ($F[1,15] = 98.61$; $P < .0001$). Neither P_r values ($F[1,15] = 1.33$; $P < .26$) nor % correct values ($F[1,15] = 2.15$; $P < .16$) revealed significant block type by task type interactions.

The analysis of P_r values revealed lower recognition accuracy in the specific than in the general task. To examine

Table 1
P_r values, mean reaction times (RT), and percent correct (% correct) for correct rejections as a function of block type and task type

Block type	Task type	P_r		RT				% correct	
		M	SE	*M* (hits)	SE (hits)	*M* (correct rejections)	SE (correct rejections)	*M*	SE
Continuous									
	General	.62	.04	1065.3	27.64	1077.3	32.25	87	.01
	Specific	.34	.02	1185.2	35.52	1168.8	41.35	67	.02
Alternating									
	General	.46	.05	1246.5	34.23	1201.3	41.14	83	.03
	Specific	.25	.04	1258.5	32.82	1279.4	46.22	60	.02

the source of this performance decrement in more detail, we computed additional P_r values on the basis of false alarm responses to new items. P_r-new was reliably higher in the continuous (.56) and in the alternating blocks (.47) as the corresponding initial P_r values (.34) and (.25), respectively (both P values < .0001). This indicates that the lower recognition performance in the specific task to a high extent results from false positive responses to old words presented in a different font type.

For the analysis of mean RTs, a three-way repeated measures ANOVA with factors block type (continuous, alternating), task type (general, specific), and response (correct rejections, hits) was used. This analysis revealed significant main effects for block type ($F[1,15]=101.39$, $P <$ .00001) and task type ($F[1,15]=32.55$; $P < .0002$) and significant block type × task type, $F(1,15)=6.92$, $P < .02$ and block type × task type × response interactions ($F[1,15]=29.11$; $P < .0001$). To further elucidate the three-way interaction, we conducted one-way repeated measures ANOVAs with factor task type. In the continuous blocks, reaction times for hits and correct rejections were faster in the general task than in the specific task (both P values < .001). In the alternating block, a task type effect was obtained for correct rejections only, $P < .001$, while the response times for hits did not differ as a function of task ($P = .62$).

3.1.2. *Trial comparison—specific switch costs*

The performance measures for nonswitch and switch trials in both task conditions, illustrating the specific switch costs, are summarized in Table 2. A two-way repeated measure ANOVA with factors trial type (switch trial, nonswitch trial) and task type (general, specific) for the P_r values revealed a main effect of trial type ($F[1,15] = 8.76$, $P < .01$), reflecting the lower P_r values for switch compared to nonswitch trials under both task instructions. In addition, there was a main effect of task type ($F[1,15] < 38.63$, $P >$ .0001), indicating lower task performance in the specific than in the general task. This suggests that the affordance to switch from one memory task to the other was associated with the same processing costs, irrespective of the task requirements.

In contrast, for % correct for correct rejections, there was no main effect of trial type ($F[1,15] = 0.19$; $P < .67$) but a significant task type effect ($F[1,15] = 102.85$; $P < .0001$) without an interaction of both factors (trial type × task type: $F[1,15] < 0.06$; $P > .80$).

The analysis of specific switch costs on mean RTs was accomplished by a three-way repeated measures ANOVA with factors trial type (switch trial, nonswitch trial), task type (general, specific), and response (correct rejections, hits). There were main effects of trial type ($F[1,15] = 68.94$; $P < .0001$) and task type ($F[1,15] = 6.20$; $P < .025$) and the interactions trial type × response ($F[1,15] = 6.87$, $P < .02$) and task type × response ($F[1,15] = 6.59$, $P < .02$.) Post hoc analyses revealed that, for nonswitch trials, reaction times for hits and correct rejections did not differ neither in the general nor in the specific task (both P values >.18.).

However, for switch trials, hit responses took longer than correct rejections in the general ask, $P < .03$, but not in the specific task, $P = .68$.

Taken together, the comparison of switch and nonswitch trials within the alternating blocks revealed that the actual switch from one memory task to the other is associated with higher specific switch costs (i.e., longer RTs and lower P_r values), irrespective of task instruction. Furthermore, it takes more time to respond correctly in the specific

Table 2
P_r values (P_r), mean reaction times (RT), and percent correct (% correct) for correct rejections as a function of trial type and task type

Trial type	Task type	P_r		RT				% correct	
		M	SE	*M* (hits)	SE (hits)	*M* (correct rejections)	SE (correct rejections)	*M*	SE
Nonswitch									
	General	.53	.06	1163.1	35.14	1137.2	33.81	83	.04
	Specific	.32	.06	1183.7	29.65	1208.2	42.28	59	.04
Switch									
	General	.40	.06	1361.9	41.67	1265.8	50.42	83	.03
	Specific	.19	.04	1357.8	44.29	1348.1	53.27	61	.03

compared to the general task. In the general task, when subjects have to switch to another task, hits take longer than correct rejections. In contrast to the general switch cost, no specific switch costs were obtained for % correct measures.

3.2. ERP results

3.2.1. ERP differences between continuous and alternating blocks

The ERP analysis of the block effects focused on correct rejection trials. This analysis should reveal the processes engaged in flexible adaptation of varying retrieval orientations and in the maintenance of a particular retrieval orientation, unconfounded by processes associated with successful memory retrieval [45].

In a first step, a five-way repeated measures ANOVA with factors block type (continuous vs. alternating), task type (general vs. specific), position (anterior–frontal [FP1, FPZ, FP2], frontal [F7, FZ, F8], central [T7, CZ, T8], and parietal [P7, PZ, P8]), lateral (left, middle, and right), and window (five successive time windows; 100–250 ms; 250–500 ms; 500–750 ms; 750–1000 ms; 1000–1250 ms) was conducted. In order to avoid reporting large amounts of statistical results not relevant for the issues under investigation (e.g., lateral × window interactions), for the EEG analysis, only main effects or interactions including the factors block type (block effect) or task type (task effect) will be reported.

Fig. 2 displays ERP waveforms for continuous and alternating test blocks. As the five-way ANOVA did not

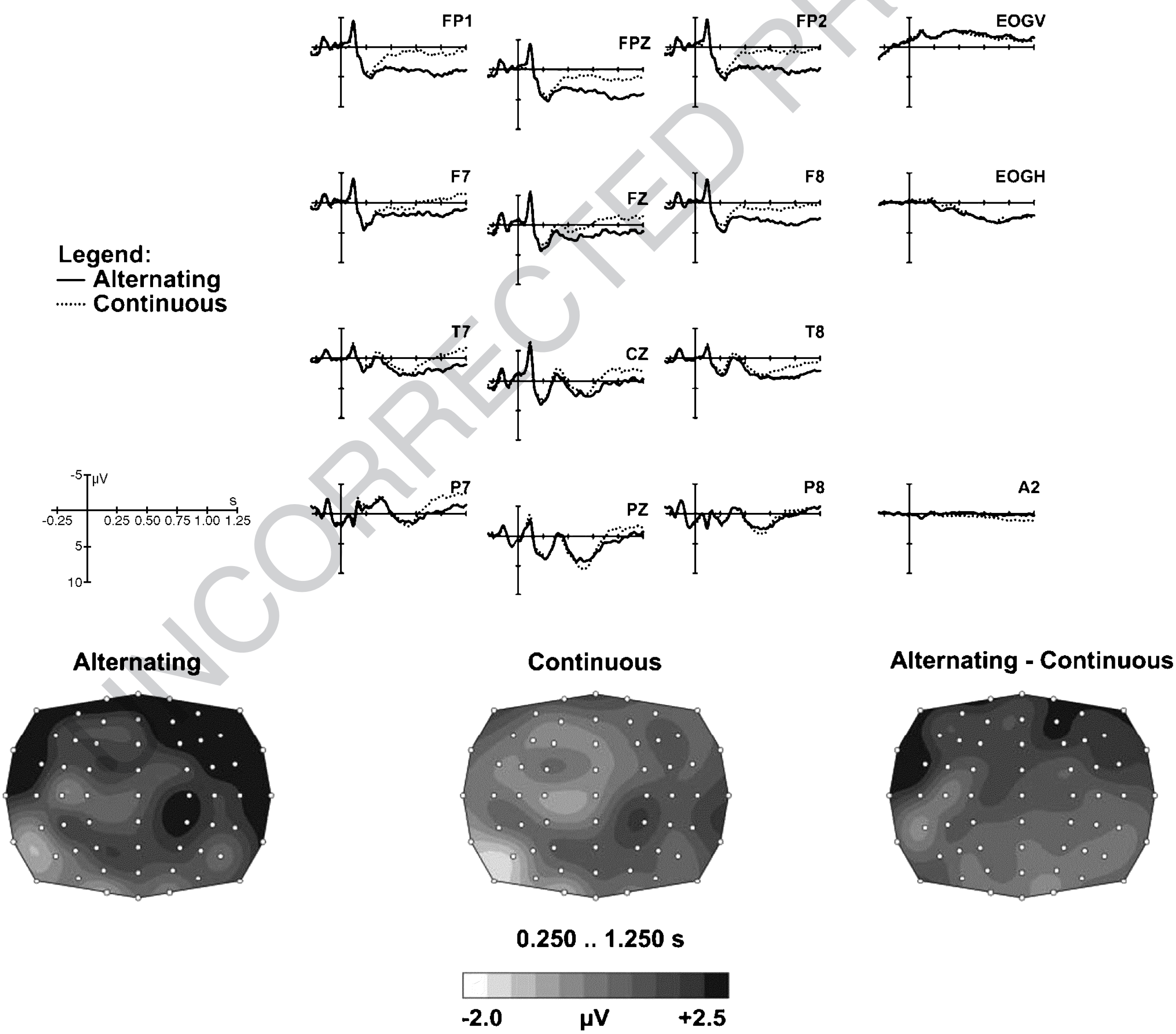

Fig. 2. [Top] ERP waves for correct rejections to new items within continuous (dotted line) and alternating (solid line) test blocks at the 12 electrode locations used for statistical analysis. [Bottom] Topographical maps for ERPs to correct rejections of new items within alternating (left) and continuous (middle) blocks as well as the differences between alternating and continuous blocks (right) from 250 ms to 1250 ms after stimulus onset. Note: as no interaction between the block type and the task type factor was obtained, the ERPs are collapsed for both types of task instructions.

reveal interactions involving both the block type and the task type factor (see below), the ERP waveforms in Fig. 2 were collapsed across the general and the specific task. As can be seen from this figure, test words in alternating blocks elicited more positive going ERPs than in continuous blocks. This difference started at around 250 ms and extended until 1250 ms and was most pronounced over bilateral anterior–frontal recording sites. These observations were confirmed by the statistical analyses.

The five-way repeated measures ANOVA revealed a main effect of block type ($F[1,15] = 7.21$; $P < .02$) and interactions of block type and position ($F[3,45] = 4.22$; $P < .04$) and block type × position × window: $F[12,180] = 4.84$; $P < .01$). Hence, differences between the two block conditions varied along the anterior–posterior dimension and across time windows. No significant main effect or interactions including the factor task type were obtained.

The differences between items in continuous and alternating blocks seem to attenuate along the anterior–posterior dimension. To further examine the block type × position × window interaction, we conducted three-way repeated measures ANOVAs for each level of the position and the window factor. As apparent from Table 3, differences between blocks that asked for maintaining a retrieval orientation and blocks that demanded for flexible adaptation of retrieval operations were most strongly reflected in ERP slow wave differences over anterior–frontal recording sites starting around 200 ms to 300 ms after onset of the test stimulus. Starting 250 ms post-stimulus at anterior–frontal recording sites, we found main effects of block type with increasing effect sizes as a function of time. At frontal recording sites, we also obtained long-lasting block type effects, but they did not reach the magnitude of the anterior–frontal effects and seemed to decrease in later time windows.

As the ERPs in alternating blocks were collapsed across switch and nonswitch trials, it is conceivable that these anterior–frontal slow wave differences reflect the contribution from switch trials only or are due to more sustained control processes present in both switch and nonswitch trials (cf. [4]). To examine this, we compared ERPs in continuous test blocks with ERPs for switch and nonswitch trials. To increase the signal-to-noise ratio in this analysis, all ERPs were collapsed across both task types. As illustrated in Fig. 3 at anterior–frontal recording sites, the waveforms are highly similar for switch and nonswitch trials, with both trial types eliciting more positive going slow waves than continuous trials. This effect (switch and nonswitch > continuous) was most pronounced in the 500 ms to 750 ms time window. In addition, at right frontal recordings, a switch > nonswitch and continuous pattern emerged. This latter effect started around 150 ms and extended until the end of the recording epoch. Notably, switch trials differed from the other two trial types also at posterior recording sites. As apparent from Fig. 3, there was a switch < nonswitch and continuous pattern at lateral and mid parietal sites.

For a statistical examination of these effects, a four-way repeated measures ANOVA with factors condition (continuous, nonswitch, switch), position, lateral, and window was performed. The latter three factors were identical with the initial ANOVA. This analysis revealed interactions between condition and lateral ($F[4,60] = 5.12$; $P < .0045$), condition and position ($F[6,90]= 4.58$; $P < .03$), condition and window ($F[8,120] = 3.34$; $P < .002$), and the three-way interactions condition × lateral × window ($F[16,240] = 2.28$; $P < .05$) and condition × position × window ($F[24,360] = 4.40$; $P < .008$). This suggests that condition-specific ERP differences vary along the topographical and the temporal dimensions. As the block effects of the initial analysis that reflect the contribution of both switch and nonswitch trials were most pronounced over anterior–frontal recording sites and virtually absent at posterior recordings (cf. Fig. 2), we refrained from further analyses of the condition effects at posterior recordings and restricted the analyses of the condition effects to anterior–frontal and frontal electrodes by using three-way ANOVAs (factors: condition, window, and lateral) for these sites. At anterior–frontal sites, there was a condition × window interaction ($F[8,120]=3.76$, $P < .02$). At frontal sites, lateral × condition ($F[4,60]=3.59$, $P < .02$) and condition × lateral × window interactions ($F[16,240]=2.56$, $P < .03$) were obtained. Based on these interactions in a next analyses step, condition effects were examined in each time window at anterior–frontal sites and in each time window for each of the levels of the lateral factor at the frontal recording sites. The results of these analyses are illustrated in Table 4. Consistent with Fig. 3 and Table 4, at anterior–frontal recordings sites, nonswitch and switch trials elicit more positive going ERP waveforms than continuous trials between 500 ms and 750 ms, with no differences between switch and nonswitch trials (P values >.10). In addition, there was a nonswitch > continuous pattern at mid-frontal recordings between 250 ms and 1000 ms. Finally, at right frontal recordings, switch trials elicited more positive ERP

Table 3
Block type effects at anterior–frontal and frontal recording sites in consecutive time windows

Position	Window	*df*	*F*	*P*	Ω^2
Anterior–frontal	100–250 ms	1,15	–	–	–
	250–500 ms	1,15	5.58	.03	.22
	500–750 ms	1,15	7.67	.01	.29
	750–1000 ms	1,15	8.16	.01	.31
	1000–1250 ms	1,15	8.78	.01	.33
Frontal	100–250 ms	1,15	–	–	–
	250–500 ms	1,15	4.39	.05	.17
	500–750 ms	1,15	4.92	.04	.20
	750–1000 ms	1,15	4.68	.05	.19
	1000–1250 ms	1,15	4.68	.05	.19

The respective effect size measures (Ω^2) are given in the last column. For details of the analysis, see text.

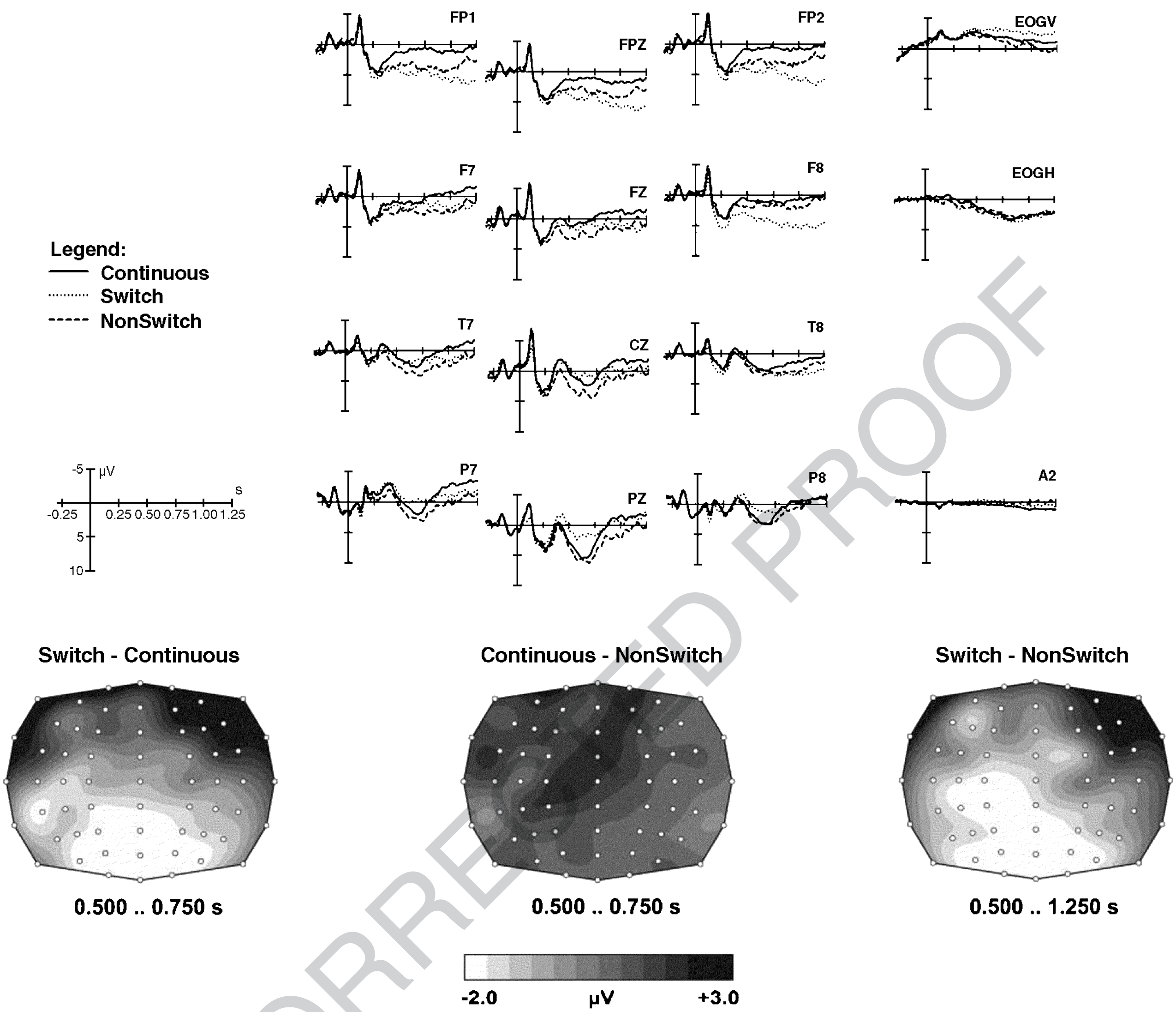

Fig. 3. [Top] ERP waveforms for correct rejections of new items within continuous blocks (solid line) and for switch trials (dotted line) and nonswitch trials (broken line) within alternating blocks at the 12 electrode sites used for statistical analysis. [bottom] Topographical maps for ERP difference waves for correct rejections of new items: switch trials within alternating blocks minus continuous (left) and nonswitch trials within alternating blocks minus continuous (middle) from 500 ms to 750 ms post-stimulus, switch minus nonswitch trials within alternating blocks (right) from 500 ms to 1250 ms.

waveforms than both other trial types (P values < .05), with this switch > nonswitch and continuous pattern being present between 100 and 1250 ms.

To summarize, alternating blocks relative to continuous test blocks are characterized by a bilateral anterior–frontal positive slow wave in the time interval between 250 and 1250 ms. Further analyses indicate that both switch and nonswitch trials did not differ at anterior–frontal recordings and contribute to a similar extent to this anterior–frontal slow wave pattern between 500 and 750 ms. In addition, a sustained positive slow wave was observed, being more pronounced for switch than nonswitch and continuous trials. This switch > nonswitch and continuous pattern started as early as 100 ms and was focused at right frontal recording sites.

3.2.2. *Topographical profile analysis*

The ERP differences between continuous and alternating test blocks are most pronounced over bilateral anterior–frontal recording sites and extended over a prolonged time window, i.e., 250 to 1250 ms. This topographical dissociation may suggest that different neuronal sources contribute to the maintenance of a retrieval orientation and to flexible alternations between retrieval demands. However, any inferences on intracranial sources, drawn from differential scalp topographies of ERPs in different conditions, presuppose that the topographical differences between conditions are not confounded with differences in absolute amplitude between the contrasted conditions [28]. We therefore performed a topographical profile analysis by scaling the data by the root mean square (RMS) method [28]

Table 4
Significant results (α < .05) of pairwise comparisons of continuous, nonswitch, and switch ERPs to correct rejections of new items for each time window at anterior–frontal electrodes and each level of the lateral factor and each time window at frontal recording sites

Position	Lateral	Window	Factor	*df*	Continuous vs. nonswitch		Continuous vs. switch		Nonswitch vs. switch	
					F	*P*	*F*	*P*	*F*	*P*
Anterior–frontal		100–250 ms			–	–	–	–	–	–
		250–500 ms			–	–	–	–	–	–
		500–750 ms	Condition	1,15	8.97	.009	4.96	.04	–	–
		750–1000 ms			–	–	–	–	–	–
		1000–1250 ms	Condition	1,15	–	–	6.41	.02	–	–
Frontal	Left	100–250 ms			–	–	–	–	–	–
		250–500 ms			–	–	–	–	–	–
		500–750 ms			–	–	–	–	–	–
		750–1000 ms			–	–	–	–	–	–
		1000–1250 ms			–	–	–	–	–	–
	Middle	100–250 ms			–	–	–	–		
		250–500 ms	Condition	1,15	7.63	.01	–	–	–	–
		500–750 ms	Condition	1,15	11.88	.004	–	–	4.39	.05
		750–1000 ms	Condition	1,15	7.86	.01	–	–	–	–
		1000–1250 ms			–	–	–	–	–	–
	Right	100–250 ms	Condition	1,15	–	–	5.77	.03	10.45	.006
		250–500 ms	Condition	1,15	–	–	8.59	.01	3.18	.09
		500–750 ms	Condition	1,15	–	–	11.92	.004	6.14	.03
		750–1000 ms	Condition	1,15	–	–	9.80	.007	6.30	.02
		1000–1250 ms	Condition	1,15	–	–	11.21	.004	6.22	.02

so that the scaled amplitudes for continuous and alternating blocks across both task conditions in their respective time windows were the same. A three-way repeated measures ANOVA with factors condition (alternating vs. continuous), lateral (left, middle, right), and position (anterior–frontal, frontal, central parietal) on RMS-scaled amplitude measures revealed a significant condition × position interaction ($F[3,45] = 4.16$; $P < .03$). Because any difference in the magnitude of both ERP waveforms is removed after RMS scaling, this condition by position interaction can unambiguously be taken to reflect qualitatively different neuronal generators along the anterior–posterior axis subserving maintenance and flexible alternation between retrieval orientations.

3.2.3. ERP differences between general and specific task

The initial statistical analysis of block effects did neither reveal a main effect of task type nor any interaction involving this factor. On the basis of our a priori hypothesis of larger positive slow wave activity at electrodes located over the PFC when a retrieval orientation that supports the retrieval of specific perceptual details from a study phase is activated, we restricted the task-specific analysis to the frontal and anterior–frontal recording sites. Consistent with the aforementioned studies by Ranganath and Paller in addition to correct rejections, also hit responses were entered in this analysis. A six-way repeated-measures ANOVA with factors block type (continuous vs. alternating), task type (general vs. specific), response (correct rejection vs. hit), window (five time windows as in the block analysis), and position (two levels: anterior–frontal [FP1, FPZ, FP2] and frontal [F7, Fz, F8] and lateral (left, middle, right)) was conducted. There were main effects of block type ($F[1,15] = 5.51$; $P < .03$) and response ($F[1,15] = 9.51$; $P < .007$) and a block type × task type interaction ($F[1,15] = 4.29$; $P < .05$), The interaction suggests that the differences between the general and the specific task are modulated by the block type factor.

In support of this view, the five-way ANOVA for alternating blocks did not reveal any effects involving the task type factor. The corresponding ANOVA for continuous blocks revealed a main effect of response ($F[,15] = 6.52$, $P <$ .02) and the interactions task type × response × position ($F[1,15] = 4.39$, $P < .05$) and task type × response × window × position × lateral ($F[8,120] = 2.60$, $P < .05$). Notably, no effects involving the lateral factor were obtained neither in the ANOVAs for continuous and alternating blocks nor in any subsidiary analyses. Further ANOVAs performed for both levels of the position factor revealed main effects of task type ($F[1,15] = 5.67$, $P < .03$) and response ($F[1,15] = 7.92$, $P < .01$) and a marginally significant task type × windows interaction ($F[4, 60] = 3.28$, $P < .06$) at frontal recordings. No effects involving the task type factor were obtained in the corresponding analysis at anterior–frontal sites. As apparent from Fig. 4, showing the ERP waveforms elicited by hits and correct rejections in the general and specific task at left and right frontal recording sites, the response effect at frontal recordings reflects the generally more positive going ERP waveforms for hits than for correct rejections, whereas the task type effect took the form of more positive going waveforms in the specific than the general task at the left and right frontal recordings.

To further elucidate the temporal characteristics of the task type effect in the continuous blocks, three-way

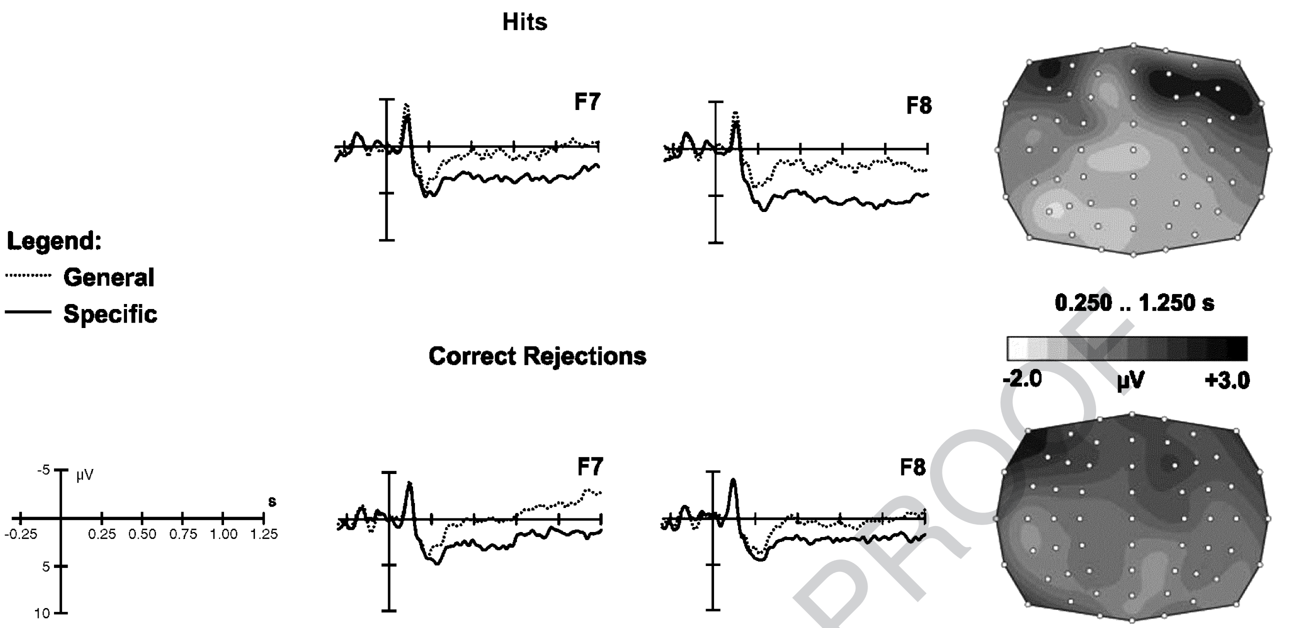

Fig. 4. [Left] ERP waves for hits to old-same items (top) and correct rejections to new items (bottom) within continuous test blocks under either general (dotted line) or specific (solid line) task instructions at left (F7) and right (F8) frontal electrode positions. [Right] Topographical maps for ERP difference waves (specific minus general) for hits (top) and correct rejections to new items (bottom) within continuous blocks from 250 ms to 1250 ms after stimulus onset.

ANOVAs with factors response, task type, and lateral for each of the five time windows were conducted. There were main effects of the task type factor for the time windows from 250 to 1000 ms (all $F[1,15] > 5.59$; all $P < .04$) and marginally significant in the 1000 to 1250 ms window ($P <$ .06) These results confirm the visual impression that the ERP differences between the two task types start quite early (e.g., around 250 ms), are not modulated by the response factor, and extend for several hundred milliseconds at left and right recording sites.

3.2.4. ERP old/new effects

The fact that the effects of retrieval orientation in the continuous blocks started quite early raises the question of how these processes are temporarily related to the retrieval process proper. To examine this, we computed the old/new effects for both task types in the continuous blocks at parietal locations in a time window from 250 to 700 ms, as old/new effects with these spatio-temporal characteristics are usually taken as an electrophysiological correlate of memory retrieval [29,45]. As illustrated in Fig. 5, hits elicit more positive going ERP waveforms than correct rejection in both tasks. This old/new effects started around 250 ms and extended for several hundred milliseconds in both tasks. A three-way ANOVA with factors response (hit vs. correct rejection), task type (general vs. specific), and lateral (left, middle, right) for the mean amplitude measures between 250 and 750 ms at the three parietal electrode sites (P7, PZ

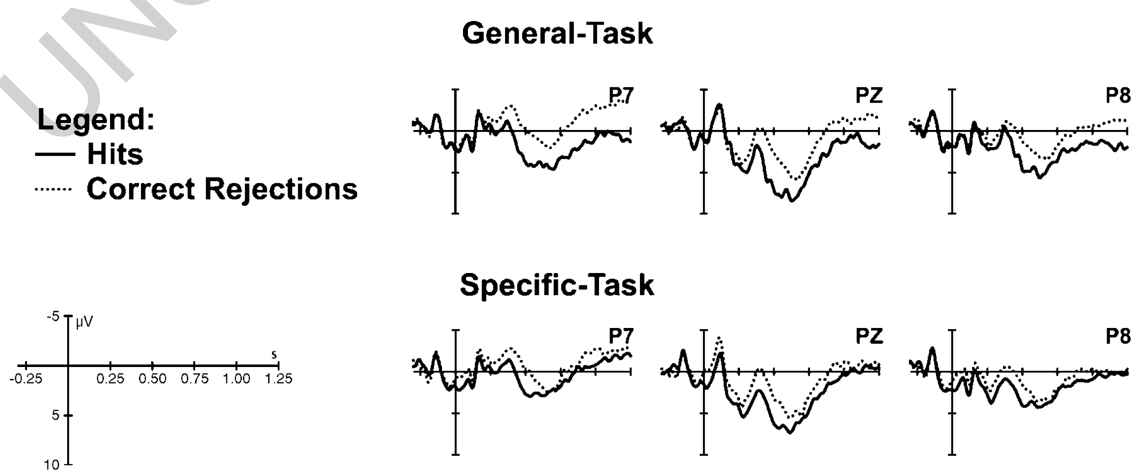

Fig. 5. ERP waveforms for hits to old-same items (solid line) and correct rejections to new items (dotted line) for continuous test blocks under either general (top row) or specific (bottom row) task instruction at selected parietal recording locations.

and P8) revealed a main effect of factor response ($F[1,15] = 11.50$; $P < .004$) without any significant interaction (all $F < 1.85$; all $P > .18$). This additional analysis supports the view that the processes reflected in the task effect at frontal recordings operate in parallel to memory retrieval.

4. Discussion

In this study, we aimed to clarify whether maintaining a retrieval orientation and flexible alternation between different retrieval orientations are mediated by different brain processes. We approached this issue by recording ERPs in two recognition memory tasks combined with a modified version of an "alternating runs" task-switching paradigm [25,44]. Comparing ERPs elicited by retrieval cues in continuous and alternating blocks enabled us to separate processes set in train during recognition memory judgments that allow to either adapt and maintain a retrieval strategy or to flexibly change between retrieval demands. In addition, this procedure also allows to examine electrophysiological correlates of having adapted a particular retrieval orientation, i.e., an orientation that enables the retrieval of perceptual detailed information of words previously encoded in a study phases. Only a few studies so far combined classical recognition memory paradigms with procedures used in the study of cognitive control processes [32,57].

Measures of performance (RT, P_r) indicate that we were indeed able to induce different levels of cognitive control during memory retrieval. Despite the fact that the specific task was overall more difficult than the general one, we found robust general switch costs, as reflected by lower P_r values, increased RT, and decreased % correct in alternating relative to continuous blocks, irrespective of task [1,43,57].

In addition, our analyses also revealed specific switch costs that are associated with the initiation of new task sets for mean P_r values as well as for mean RTs to hits and correct rejections. These specific switch costs were independent of the retrieval task to be performed. These results show that the affordance to switch between varying (retrieval) task sets on a trial by trial basis indeed asks for additional control processes that allow to reconfigure the cognitive systems for performance on the upcoming task. The fact that we found no specific switch effect for % correct for correct rejections, while the % correct measures revealed reliable general switch effects provides support of the notion that different control processes may be engaged on the block and on the trial level [3,25]. Whereas the block analysis may tap into processes used for the sustained regulation of processing resources to provide flexibility in situations where rapid adaptation is needed, the trial analysis indexes the actual costs to perform the proper reconfiguration of the cognitive system towards the upcoming task.

These observations could be extended by the ERP results. We obtained more positive going ERP slow waves for correct rejections in alternating relative to continuous test blocks. Those differences were most pronounced over anterior–frontal recording sites, started around 250 ms, and lasted for several hundred milliseconds. As two types of trials contributed to the ERP pattern in the alternating blocks, those in which a new retrieval orientation had to be activated (switch trials) and those in which the retrieval orientation was the same as in the preceding trial (nonswitch trials), additional analyses were conducted in which we examined whether switch and nonswitch trials similarly contribute to this ERP slow wave effect. Interestingly, between 500 and 750 ms after onset of the test stimuli, the positive anterior–frontal slow wave was highly similar for switch and nonswitch trials, whereas at the right frontal recording sites, a switch > nonswitch and continuous pattern emerged that may suggest a selective involvement of the right PFC for trials in which a new retrieval orientation had to be activated. In the following, both effects will be discussed in detail.

One account for the pronounced positive slow wave in the alternating block at anterior–frontal recording sites for switch and nonswitch trials in the present study can be derived from recent fMRI studies [22,23,36,37]. Pollmann and colleagues conducted visual search experiments that demanded either to switch between object features within the same dimension (e.g., color) or across different dimensions (e.g., color or motion) [36,37]. They found frontopolar cortex activity associated with the deployment of attentional resources away from currently attended visual dimensions to new dimensions (between dimension switches; e.g., from color dimension to motion). They suggested that the frontopolar cortex is involved in the monitoring of events that demand for reallocation of attention or in the actual initiation of attentional switches. In this framework, it is conceivable that the anterior prefrontal positive slow wave observed in the alternating blocks reflected frontopolar cortex activation related to the initiation of attentional switches from one retrieval orientation to the other. This interpretation, however, is weakened by the fact that the anterior–frontal slow wave pattern was also obtained for nonswitch trials in which the retrieval orientation had not to be changed.

An alternative account can be derived from recent fMRI findings in dual task paradigms. Koechlin and colleagues [22–24] found anterior–frontal activity when a secondary task has to be performed while holding a primary task in working memory (i.e., branching). The authors assume that frontopolar regions subserve processes underlying the online integration of intermediate secondary tasks within an ongoing primary task [23]. Interestingly, this frontopolar activity was more lateral for random task sequences and more medial for predictive sequences of primary and secondary task. On the basis of these findings, it is tempting to speculate that, in the present study, the flexible adaptation of varying retrieval tasks within a fixed and predictable sequence may have imposed a branching situation: participants had to perform the actual memory retrieval task while keeping both retrieval tasks active in working memory and monitoring the actual position within the task sequence. These processing requirements were relevant in both switch and nonswitch trials. Hence, it is conceivable that "branching processes" were also required for successful performance within alternating blocks for both trial types and that the anterior–frontal slow wave pattern reflects the recruitment of frontopolar brain regions by these more sustained control processes (see also [51] for related findings). The observation that switch and nonswitch trials contribute in a similar manner to the anterior–frontal slow wave pattern and were not different from each at anterior–frontal sites is consistent with this interpretation.

A similar role for the anterior prefrontal cortex has recently been proposed by Ramnani and Owen [43]. They argue that "relational integration, the general requirement to coordinate and combine the outputs of multiple cognitive operations is the main function of the anterior prefrontal cortex". In support of this latter view, a recent fMRI study in which subjects had to perform two semantic classification tasks in alternating and single task blocks found increased (right) anterior prefrontal activation for alternating relative to single task blocks [4]. The authors argue that these brain regions are activated when task performance involved a subgoal component and/or under conditions in which memory task-relevant representations have to be maintained for long periods of time. Our data are consistent with both of these views.

Wilding and Nobre [57], similar to the present study, also examined ERP correlates of memory retrieval under condition that required to alternate frequently between two retrieval tasks or to maintain a particular retrieval mode over a sustained period of time. In their study, however, two retrieval conditions (i.e., image-based and phonological) were either separated into two test blocks (Experiment 1) or randomly cued within the same test (Experiment 2). By this, a direct within-experiment comparison of ERPs elicited by words in alternating and in continuous test blocks as in the present study was not possible. In showing that the control processes required for frequently alternating between two retrieval tasks are associated with anterior–frontal ERP slow wave activity and that switch and nonswitch trials contribute to a similar extent to this effect, the present findings extend the ones reported by Wilding and Nobre.

In addition to this anterior–frontal effect reflecting the high dual task coordination requirements for switch and nonswitch trials in alternating blocks, an additional and temporally overlapping positive slow wave pattern was obtained at right frontal recording sites for switch trials only. ERP slow wave activity at right frontal recording sites has been reported in recognition memory task under conditions of low confidence recognition decisions. Rugg, Allan, and Birch [46] found larger right frontal old/new effects for words studied in a shallow than in a deep encoding condition starting at around the time the subjects responded. Consistent with these findings, functional imaging studies revealed larger right prefrontal cortex activation during low confidence decisions in recognition memory tasks [13,60]. On the basis of such findings, it has been proposed that the right PFC might be involved in retrieval monitoring under conditions in which the retrieved information is of impoverished nature and items are close to response criterion. Given this, a tentative interpretation of the present slow wave pattern could be that, in switch trials that are characterized by high dual task requirements and the additional need to reactivate a new retrieval orientation, less resources are available for memory retrieval and decision, leading to higher decision uncertainty and increased monitoring demands, as reflected in the right frontal slow wave pattern. This account extends previous accounts of the right frontal old/new effect by showing that it does not presuppose recollection but may be related to aspects of the decision process.

The second ERP effect we reported was set in train while participants made memory judgments that required the retrieval of perceptual details from the study episode and the matching of this memory output with the features of the retrieval cue. We found more positive going ERP waveforms at bilateral frontal recordings for words to be retrieved under this specific as compared to the general task instruction for both hits and correct rejections. This effect was only obtained when both tasks were performed continuously in separate blocks but not in alternating blocks in which a frequent alternation between both tasks was required. Consistent with previous findings [39,40], the slow wave pattern started at around 250 ms and extended over several hundred milliseconds. In contrast to [39] reporting a left lateralized topography of this effect, it showed a bilateral topography in the present study and in [40]. Even though the exact contribution of the left and right PFC to this effect remains to be specified, the combined results suggest that left and right prefrontal regions are relevant for implementing this form of control. In accordance with Ranganath and Paller [39], we assume that the task effect may be a reflection of the availability of perceptually detailed attributes of memory in the pursuit of successful task performance.

Interestingly, the onset of these processes at around 250 ms suggests that they operate in parallel to the parietal old/new effects that were present in around the same time interval. This suggests that frontal control of memory retrieval is not restricted to a postretrieval phase in which the products of retrieval are evaluated but rather operates prior to or at least in parallel to the retrieval process. The increased demands on cognitive control in the specific task may reflect enhanced demands on working memory, i.e., the need to maintain more perceptual details of the test cue available for the match with the information retrieved from memory.

The present findings extend those by Ranganath and Paller in several ways: in contrast to their studies, we controlled for response probability as an additional factor that could influence ERP measures. In their study, two-thirds of the items within the general task, but only one-third within the specific task, required "old" responses. For the present study, we assured equal probabilities for "old" and "new" responses for all task and sequence conditions. In addition, we used verbal materials that require the retrieval of detailed differences in letter fonts rather than line drawings as in their studies and obtained ERP slow waves, whose topographical and timing characteristics were highly similar to the ones reported in one of their studies [40]. Given this, we feel safe to conclude that the ERP differences indeed reflect control processes set in train by the requirement to retrieve specific perceptual attributes of memory representations irrespective of stimulus formats.

The observation that the frontal effect of retrieval orientation is not obtained when participants have to alternate frequently between the two retrieval tasks is consistent with the findings of Wilding and Nobre [57]. The authors found reliable effects of having adapted a retrieval task only when the tasks were completed in separate blocks. On the basis of this finding, they assume that the requirement to alternating between retrieval orientations within one block may have hindered the participants from engaging in task-specific retrieval processes. The absence of reliable ERP indices of task-specific retrieval in the alternating blocks is consistent with this view and also suggests that adapting a task-specific retrieval orientation requires the completion of several successive retrieval trials.

An alternative interpretation for the frontal retrieval orientation effect has been proposed by Rugg, Allan, and Birch [46]. The authors examined ERPs to new words in two different test blocks, preceded by either a shallow or a deep study task. The ERPs in the test blocks following the shallow task revealed a left frontal ERP effects that resembles the frontal effect in the present study quite closely. As the response criterion in the test blocks following the shallow task was more conservative, the authors propose that rather than being tied to the adaptation of a particular retrieval orientation, their left frontal effect could also reflect the setting and maintenance of a more conservative response criterion in the more difficult to perform (shallow) task. To examine whether this interpretation also holds for the present results, we conducted measures of response bias (Br) [48] for both the general and the specific retrieval tasks in the continuous condition in which the frontal effect was obtained. As in the initial analyses of recognition performance in the specific task, both types of false alarms (old-different words and new words) were taken into account. The Br values were .39 in the general task and .50 in the specific task and by this statistically different, $P < .005$. This indicates that subjects adopted a more liberal response criterion in the more difficult (specific) task for which the left frontal effect was obtained. This argues against the view that the left frontal effect is a reflection of the maintenance of a more stringent response criteria in the harder to perform retrieval task.

Another objection against the retrieval orientation interpretation of the task effect can be derived from the fact that error rates were higher and response times longer in the specific than in the general task. Thus, rather than reflecting the consequences of having adapted different retrieval orientations, the positive slow wave difference between the specific and the general task could be a reflection of the differential mobilization of processing resources in both tasks. This aspect of retrieval processing has been labeled retrieval effort [45]. We assumed that, if the frontal effect is indeed a mere reflection of different levels of retrieval effort required in the two tasks, it should have been also revealed by contrasting two other conditions differing in task difficulty to a similar extent. Examination of the frontal slow waves elicited by switch and nonswitch trials shows that this is not the case. Even though both conditions show differences on the behavioral level with the switch trials being harder to perform than the nonswitch trials, the corresponding slow wave differences are largest at right frontal recordings and virtually absent at the left frontal recordings (cf. Fig. 3). This observation makes the interpretation of the frontal effect being a mere reflection of retrieval effort in the more demanding task condition rather unlikely.

Taken together, the combined results related to the task effect suggest that left and right prefrontal regions exert control over retrieval processes in the service of providing and maintaining appropriate information about the test cue against which the output of memory retrieval can be matched in particular when working memory demands are high, as in the present specific-test condition. The processes that allow the controlled retrieval of episodic information are set in train by engagement in a retrieval attempt and deploy their influence by adapting retrieval thresholds and initiating detailed search operations [19,20,33,45].

4.1. Conclusion

With the present study, we could identify ERP correlates of different control processes set in train during recognition memory judgment in pursuit of successful task performance. Bilateral anterior–frontal activity can be linked to more general control requirements that allow the coordination of various memory retrieval demands with other task demands. As the topographical analyses revealed different topographical distributions in the alternating as compared to the continuous condition along the anterior–posterior axis, we feel safe to conclude that maintaining a retrieval orientation on the one side and flexibly changing between different retrieval demands on the other side are mediated by dissociable brain systems within PFC. Right frontal slow wave activity is associated with higher needs for retrieval monitoring in situation characterized by high dual task coordination requirements and presumably lower decision confidence. Finally, bilateral frontal activity can be linked to processes that control the retrieval of highly detailed episodes, irrespective of stimulus formats.

5. Uncited references

[21]
[55]

Acknowledgments

We wish to thank Sandra Schappert for her assistance in data collection, Bertram Opitz for support during data analysis, and Christian Doeller and Mikael Johansson as well as three anonymous reviewers for valuable comments on an earlier version of the manuscript.

References

[1] A. Allport, E.A. Styles, S. Hsieh, Shifting intentional set: exploring the dynamic control of tasks, in: C. Umilta, M. Moscovitch (Eds.), Attention and performance XV, MIT Press, Cambridge, 1994, pp. 421–452.
[2] R.H. Baayen, R. Piepenbrock, H. vanRijn, The CELEX Lexical Data Base on CDROM, Linguistic Data Consortium, Philadelphia, 1993.
[3] J. Beringer, Computerunterstützte Testverfahren, in: J. Oldings-Kerber, J. Leonard (Eds.), Psychopharmakologie. Experimentelle und klinische Aspekte, Gustav Fischer Verlag, Stuttgart, 1992, pp. 134–149.
[4] T.S. Braver, J.R. Reynolds, D.I. Donaldson, Neural mechanisms of transient and sustained cognitive control during task switching, Neuron 39 (2003) 713–726.
[5] R.L. Buckner, Functional–anatomic correlates of control processes in memory, J. Neurosci. 23 (2003) 3999–4004.
[6] K. Christoff, J.D.E. Gabrieli, The frontopolar cortex and human cognition: evidence for a rostrocaudal hierarchical organization within the human prefrontal cortex, Psychobiology 28 (2000) 168–186.
[7] R. Desimone, J. Duncan, Neural mechanisms of selective visual attention, Annu. Rev. Neurosci. 18 (1995) 193–222.
[8] J. Duncan, A.M. Owen, Common regions of the human frontal lobe recruited by diverse cognitive demands, Trends Neurosci. 23 (2000) 475–483.
[9] P.C. Fletcher, R.N.A. Henson, Frontal lobes and human memory: insights from functional neuroimaging, Brain 124 (2001) 849–881.
[10] F.B. Gershberg, A.P. Shimamura, Impaired use of organizational strategies in free recall following frontal lobe damage, Neuropsychologia 33 (1995) 1305–1333.
[11] G. Gratton, M.G.H. Coles, E. Donchin, A new method for off-line removal of ocular artefacts, Electroencephalogr. Clin. Neurophysiol. 55 (1983) 468–484.
[12] S. Greenhouse, S. Geisser, On methods in the analysis of profile data, Psychometrika 24 (1959) 95–112.
[13] R.N. Henson, M.D. Rugg, T. Shallice, O. Josephs, R.J. Dolan, Recollection and familiarity in recognition memory: an event-related functional magnetic resonance imaging study, J. Neurosci. 12 (1999) 3962–3972.
[14] J.S. Janowsky, A.P. Shimamura, L.L. Squire, Source memory impairment in patients with frontal lobe lesions, Neuropsychologia 27 (1989) 1043–1056.
[15] J.S. Janowsky, A.P. Shimamura, M. Kritchevsky, L.L. Squire, Cognitive impairment after frontal lobe damage and its relevance to human amnesia, Behav. Neurosci. 103 (1989) 548–560.
[16] H.A. Jasper, The ten–twenty system of the international federation, Electroencephalogr. Clin. Neurophysiol. 10 (1958) 371–375.
[17] A.T. Jersild, Mental set and mental shift, Arch. Psychol. 89 (1927).
[18] W. Jetter, U. Poser, R.B. Freeman, H.J. Markowitsch, A verbal long-term memory deficit in frontal lobe damaged patients, Cortex 22 (1986) 229–242.
[19] M.K. Johnson, MEM: mechanisms of recollection, J. Cogn. Neurosci. 4 (1992) 268–280.
[20] M.K. Johnson, S. Hashtroudi, D.S. Lindsay, Source monitoring, Psychol. Bull. 114 (1996) 3–28.
[21] D. Keppel, Design and analysis, Prentice-Hall, Englewood Cliffs, 1991.
[22] E. Koechlin, G. Basso, P. Pietrini, J. Grafman, The role of anterior prefrontal cortex in human cognition, Nature 399 (1999) 148–151.
[23] E. Koechlin, G. Corrado, P. Pietrini, J. Grafman, Dissociating the role of the medial and lateral anterior prefrontal cortex in human planning, Proc. Natl. Acad. Sci. 97 (2000) 7651–7656.
[24] E. Koechlin, Chr. Ody, F. Kouneiher, The architecture of cognitive control in the human prefrontal cortex, Science 302 (2003) 1181–1185.
[25] J. Kray, U. Lindenberger, Adult age differences in task switching, Psychol. Aging 15 (2000) 1–22.
[26] S.A. Los, On the origin of mixing costs: exploring information processing in pure and mixed blocks of trials, Acta Psychol. 94 (1996) 145–188.
[27] U. Mayr, S.W. Keele, Changing internal constraints on action: the role of backward inhibition, J. Exp. Psychol. 129 (2000) 4–26.
[28] G. McCarthy, C.C. Wood, Scalp distribution of event-related potentials: an ambiguity associated with analysis of variance models, Electroencephalogr. Clin. Neurophysiol. 62 (1985) 203–208.
[29] A. Mecklinger, Interfacing mind and brain: a neurocognitive model of recognition memory, Psychophysiology 37 (2000) 565–582.
[30] E.K. Miller, J.D. Cohen, An integrative theory of prefrontal cortex function, Annu. Rev. Neurosci. 24 (2001) 167–202.
[31] S. Monsell, Task switching, Trends Cogn. Sci. 7 (2003) 134–140.
[32] A.M. Morcom, M.D. Rugg, Getting ready to remember: the neural correlates of task set during recognition memory, NeuroReport 13 (2002) 149–152.
[33] M. Moscovitch, Memory and working-with-memory: a component process model based on modules and central systems, J. Cogn. Neurosci. 4 (1992) 257–267.
[34] S.F. Nolde, M.K. Johnson, M. D'Esposito, Left prefrontal activation during episodic remembering: an event-related fMRI study, NeuroReport 9 (1998) 3509–3514.
[35] S.F. Nolde, M.K. Johnson, C.L. Raye, The role of prefrontal regions during tests of episodic memory, Trends Cogn. Sci. 2 (1998) 399–406.
[36] S. Pollmann, Switching between dimensions, locations and responses: the role of the frontopolar cortex, NeuroImage 14 (2001) 118–124.
[37] S. Pollmann, R. Weidner, H.J. Müller, D.Y. vonCramon, A fronto-posterior network involved in visual dimension changes, J. Cogn. Neurosci. 12 (2000) 480–494.
[38] C. Ranganath, R.T. Knight, Prefrontal cortex and episodic memory: integrating findings from neuropsychology and functional brain imaging, in: E.L. Wilding, A. Parker, T. Bussey (Eds.), Memory encoding and retrieval: a cognitive neuroscience perspective, Psychology Press, New York, 2003.
[39] C. Ranganath, K. Paller, Frontal brain potentials during recognition are modulated by requirements to retrieve perceptual detail, Neuron 22 (1999) 605–613.
[40] C. Ranganath, K. Paller, Neural correlates of memory retrieval and evaluation, Cogn. Brain Res. 9 (2000) 209–222.
[41] C. Ranganath, M.K. Johnson, M. D'Esposito, Left anterior prefrontal activation increases with demands to recall specific perceptual information, J. Neurosci. 20 (RC108) (2000) 1–5.

[42] C. Ranganath, M.K. Johnson, M. D'Esposito, Prefrontal activity associated with working memory and episodic long-term memory, Neuropsychologia 41 (2003) 378–389.

[43] N. Ramnani, M. Owen, Anterior prefrontal cortex: insights into function from anatomy and neuroimaging, Nat. Rev., Neurosci. 5 (2004) 184–194.

[44] R. Rogers, S. Monsell, Costs of predictable switch between simple cognitive tasks, J. Exp. Psychol. 124 (1995) 207–231.

[45] M.D. Rugg, E.L. Wilding, Retrieval processing and episodic memory, Trends Cogn. Sci. 4 (2000) 108–115.

[46] M.D. Rugg, K. Allan, C.S. Birch, Electrophysiological evidence for the modulation of retrieval orientation by depth of study processing, J. Cogn. Neurosci. 12 (2000) 664–678.

[47] A.P. Shimamura, The role of prefrontal cortex in dynamic filtering, Psychobiology 28 (2000) 207–218.

[48] J.G. Snodgrass, J. Corwin, Pragmatics of measuring recognition memory: applications to dementia and amnesia, J. Exp. Psychol. 117 (1988) 34–50.

[49] A. Spector, I. Biedermann, Mental set and mental shift revisited, Am. J. Psychol. 89 (1972) 669–679.

[50] E. Tulving, Elements of episodic memory, Oxford University Press, Oxford, 1983.

[51] K. Velanova, L.L. Jacoby, M.E. Wheeler, M.P. McAvoy, S.E. Petersen, R.L. Buckner, Functional–anatomic correlates of sustained and transient processing components engaged during retrieval, J. Neurosci. 23 (2003) 8460–8470.

[52] M.E. Wheeler, R.L. Buckner, Functional dissociation among components of remembering: control, perceived oldness and content, J. Neurosci. 23 (2003) 3869–3880.

[53] M.E. Wheeler, D.T. Stuss, E. Tulving, Frontal lobe damage produces episodic memory impairment, J. Int. Neuropsychol. Soc. 1 (1995) 525–536.

[54] M.E. Wheeler, D.T. Stuss, E. Tulving, Toward a theory of episodic memory: the frontal lobes and autonoetic consciousness, Psychol. Bull. 121 (1997) 331–354.

[55] R. Weidner, S. Pollmann, H.J. Müller, D.Y. vonCramon, Top-down controlled visual dimension weighting: an event-related fMRI study, Cereb. Cortex 12 (2002) 318–328.

[56] E.L. Wilding, Separating retrieval strategies from retrieval success: an event-related potential study of source memory, Neuropsychologia 37 (1999) 441–454.

[57] E.L. Wilding, A.C. Nobre, Task-switching and memory retrieval processing: electrophysiological evidence, NeuroReport 12 (2001) 1–5.

[58] E.L. Wilding, M.D. Rugg, An event-related potential study of recognition memory with and without retrieval of source, Brain 119 (1996) 889–905.

[59] G.R. Wylie, D.A. Allport, Task switching and the measurement of 'switch costs', Psychol. Res. 63 (2000) 212–233.

[60] G.C. von Zerssen, A. Mecklinger, B. Opitz, D.Y. von Cramon, Conscious recollection and illusory recognition: an event-related fMRI study, Eur. J. Neurosci. 13 (2001) 2148–2156.